Latest results of CRESST-III's search for sub-GeV/c^2 dark matter

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Abstract. The CRESST-III experiment searches for direct interactions of dark matter with ordinary matter. The main event signature would be a nuclear recoil inside one of the scintillating $CaWO_4$ crystals. Operating the crystals as cryogenic calorimeters provides a phonon signal as measure of the deposited energy. The simultaneous readout of both signals is used to actively discriminate backgrounds. CRESST-III focuses on the sub-GeV/c^2 mass region where the sensitivity is driven by the threshold. In the first data taking campaign of CRESST-III from 2016-2018 an unprecedented low threshold of 30.1 eV for nuclear recoils was obtained. In this contribution, we will report the status of the experiment and the latest results.

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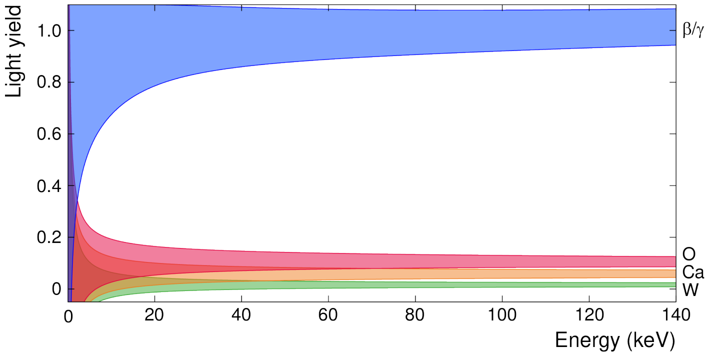


Figure 1: Schematic illustration of light yield versus total deposited energy. Visible are the populations of β/γ events (*blue band*) and recoils on O (*red band*), Ca (*orange band*) and W (*green band*) nuclei.

1. Introduction

Dark Matter (DM) is one of the strongest indications for the existence of physics beyond the Standard Model (SM) of particle physics. However, no particle candidate was unambiguously discovered yet. Beside the classic WIMP scenario [1] also candidates with masses below $1\,\mathrm{GeV/c^2}$, e.g. SIMP [2], are viable.

A consequence of lighter DM particles is a lower energy deposition for a hypothetical DM-SM interaction in a direct detection experiment. Hence, a low detection threshold is crucial to maintain sensitivity. With detection thresholds of $< 100\,\mathrm{eV}$, the CRESST experiment at the *Laboratori Nazionali del Gran Sasso* (LNGS) in Italy has a unique sensitivity to light DM.

After a short introduction of the detection principle of CRESST in section 2, we will discuss the detector evolution in (section 3) and report the latest results on *spin-independent* (SI) and *spin-dependent* (SD) scattering (section 4), before we finally close with a summary in section 5.

2. Detection principle

The main signature for a potential DM event in a CRESST detector is a nuclear recoil, whereas radioactive background mainly causes β/γ scatterings. CRESST operates $CaWO_4$ target crystals as cryogenic bolometers at $\mathcal{O}(10\,\mathrm{mK})$ temperatures. Two signals are recorded simultaneously: phonon signal and light signal.

The phonon signal is generated by excitations of the crystal lattice and the thermalized phonons are finally recorded via *transition edge sensors* (TES) evaporated on the target crystals. This signal gives a measure for the total deposited energy. The scintillation light is collected via a reflective housing around the target crystal and detected by a dedicated cryogenic light detector inside the housing, which itself is read-out via a second TES.

Because the scintillation *light yield* (LY), i.e. the ratio of light signal over phonon signal, depends on the type of scattering particle it enables a straightforward particle identification: If the LY of β/γ events is normalized to one, then recoils on O-, Ca-, W-nuclei form populations at quenched LY values below $\approx 20\,\%$, see fig. 1. Therefore, a simple cut on the LY rejects most of the radioactive backgrounds. However, for low energy depositions that are typical for light DM, the β/γ events start to leak into the nuclear recoil bands and the rejection power degrades.

3. Detector evolution

The current iteration of the experiment, CRESST-III phase 1, was designed based on the experience we gained in CRESST-II phase 2.

With the detector module "TUM40", CRESST-II phase 2 reached in 2014 for the first time the $1\,\mathrm{GeV/c^2}$ regime of DM mass [3]. Furthermore, with this detector we start an in-house production of radiopure $CaWO_4$ crystals with contamination levels up to ≈ 30 times lower than in commercial crystals. A novel way to hold the targets with $CaWO_4$ sticks provides an effective way to reject events originating from α decays near the surfaces. Based on the data collected

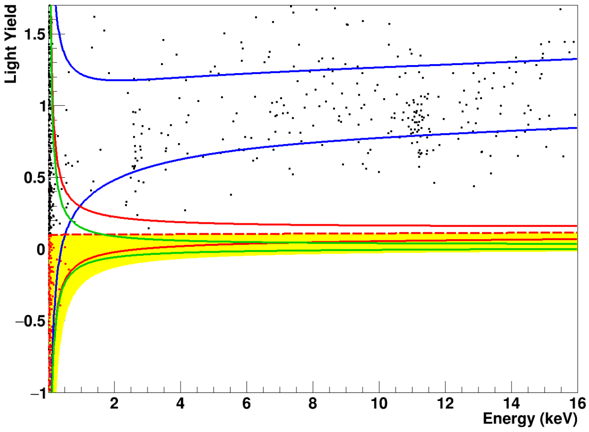


Figure 2: Light yield versus energy of events in Detector A after selection. Shown are the electromagnetic (*blue*), the O- (*red*) and W-recoil (*green*) bands. Events in the *yellow* acceptance area for a potential DM signal are shown in *red*. At energies 11.3 keV and 2.6 keV the decay of cosmogenically produced ^{179}Ta to ^{179}Hf is visible via EC from the L- and M-shell respectively. Taken from [6].

with TUM40 we developed a Geant4 model of electromagnetic backgrounds in CRESST [4]. CRESST-II crossed into the sub-GeV/c^2 regime with the detector module “Lise”, featuring a detection threshold of (307.3 ± 3.6) eV [5]. Reaching a sensitivity down to 500 MeV/c^2 (*red dashed line* in fig. 3a) the importance of a low detection threshold for the search for light DM was confirmed.

CRESST-III continues both approaches: reducing the background and lowering the detection threshold. By reducing the target mass of a CRESST-III module to a tenth, i.e. ≈ 24 g, detection thresholds as low as ≈ 30 eV can be reached. The use of in-house produced CaWO$_4$ is continued and an improved crystal holding scheme called “instrumented sticks” is applied.

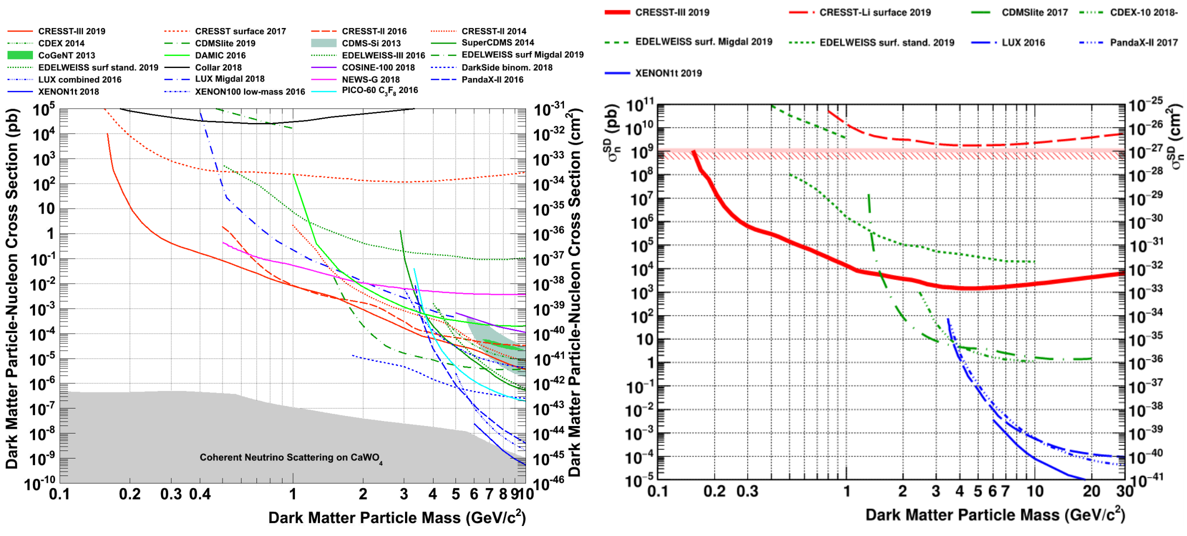
A new continuous data acquisition allows the application of the Gatti-Manfredi optimum filter to increase the signal-to-noise ratio in an offline data processing. After filtering, an optimal threshold is determined by requiring that noise triggered events must not exceed a rate of $1\,\mathrm{kg}^{-1}\mathrm{d}^{-1}$, see [6] for details.

4. Latest results

From July 2016 to February 2018, CRESST operated ten CRESST-III modules in its setup at LNGS. One of these modules, “Detector A”, reached an unprecedented low threshold for nuclear recoils of 30.1 eV [6]. With a target mass of 23.6 g a gross exposure of $5.6\,\mathrm{kg} \cdot \mathrm{d}$ was recorded [6], nearly twice the exposure of the first analysis [7]. See [6] for a detailed description of the complete analysis including applied selection criteria and cuts. The surviving events are shown in fig. 2. Starting at the detection threshold and reaching up to ≈ 200 eV an event population of yet unknown origin is visible which leaks into the acceptance region. The shape of this population varies for other detector modules. This argues strongly against a common origin and favours a detector specific background [6]. In a conservative approach, we treat all 441 accepted events as potentially dark matter induced to extract a 90 % CL exclusion limit using Yellin’s optimal interval method, the standard halo model and an energy dependent signal survival probability.

In case of SI interactions (*solid red line* in fig. 3a) [6], it improves the previous CRESST-II phase 2 limit based on Lise [5] by one order of magnitude at 500 MeV/c^2. Furthermore, the range of sensitivity is extended down to 160 MeV/c^2. Hence, CRESST explores a region of the parameter space which was previously regarded as the exclusive domain of experiments using DM-electron scattering as their signature [8]. In the sub-GeV/c^2 regime, the lowered detection threshold by nearly one order of magnitude with respect to Lise drives the improved sensitivity despite the near-threshold background which prevents an improvement at higher masses.

Analysing the same data set under the premise of pure SD DM-neutron interaction on ^{17}O results in the limit shown in fig. 3b as *red solid line* [6]. Also in this case the low detection threshold allows the mapping of new parameter space down to 160 MeV/c^2. Besides the



(a) (b)

Figure 3: Limits obtained with Detector A of CRESST-III phase 1 (*red solid lines*) for spin-independent (a) and spin-dependent (b) interactions. Taken from [6], for references see there.

limitation by the near-threshold background, this SD analysis is also limited by the tiny natural abundance of ≈ 0.04 % for ^{17}O [6]. As shown in a separate surface measurement, the CRESST detector technology is not restricted to $CaWO_4$ as target material, but can be also applied to e.g. Li_2MoO_4 (*red dashed line* in fig. 3b), which is sensitive to SD interactions via ^{7}Li but with a higher natural abundance of ≈ 90 % [9].

5. Summary

Detector A of CRESST-III phase 1 featured an unprecedented low detection threshold of 30.1 eV for nuclear recoils. The analysis of its complete data set allowed the exploration of previously inaccessible parameter space down to 160 MeV/c^2.

However, we also encounter a yet unknown, detector specific background at the detection threshold. Currently, the CRESST collaboration is in a dedicated R&D phase to investigate and reduce this background by systematic tests of modified detector designs. In parallel the development of improved analysis schemes and background models is ongoing.

Acknowledgments

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