Status of the CRESST-II Experiment for Direct Dark Matter Search

Andrea Münster for the CRESST collaboration

Physik-Department and Excellence Cluster Universe, Technische Universität München,
Garching, Germany

DOI: http://dx.doi.org/10.3204/DESY-PROC-2015-02/muenster_andrea

The CRESST-II (Cryogenic Rare Event Search with Superconducting Thermometers) experiment aims for the direct detection of dark matter in form of WIMPs. Scintillating $CaWO_4$ single crystals are used as target material. We present the results of a low-threshold analysis of one single detector module employing a crystal (m $\sim$ 250 g) grown at the Technische Universität München with an improved radiopurity and excellent properties of the phonon detector. With an exposure of 29 kg days new parameter space could be explored for WIMP masses below 3 GeV/c^2. In addition, the high potential of CRESST in the low WIMP-mass regime will be shown in a projection employing detectors that are further improved in performance and radiopurity.

1 Introduction

CRESST-II (Cryogenic Rare Event Search with Superconducting Thermometers) is an experiment for the direct search of dark matter in form of Weakly Interacting Massive Particles (WIMPs). A particle interaction in one of the scintillating $CaWO_4$ single crystals used as target produces heat (phonon signal) and scintillation light (light signal). Both signals are recorded simultaneously by two separate detectors (forming a detector module) operated at mK temperatures. The phonon signal consisting of the main part of the energy deposited enables a precise energy measurement. The light signal depends on the kind of interacting particle. The parameter *light yield* defined as the fraction of light energy to phonon energy is, therefore, used for particle discrimination on an event-by-event basis: electron recoils are normalized to a light yield of 1 (at 122 keV). α-particles and nuclear recoils, due to light quenching, are found at lower light yields of ~ 0.22 and ~ 0.02–0.11 (depending on the nucleus), respectively [1]. For WIMPs, nuclear recoils at energies smaller than 40 keV are expected.

2 CRESST-II Phase 2

CRESST-II Phase 2 collected two years of data between summer 2013 and summer 2015. The main goal was to clarify the origin of an excess signal observed in CRESST-II Phase 1 [2]. In the present work we concentrate on the results of only one $CaWO_4$ crystal (TUM40) equipped with an upgraded crystal holding scheme. By holding the block-shaped crystal (m $\sim$ 250 g) with scintillating $CaWO_4$ sticks, background events related to the decays of ^{210}Po nuclei on non-

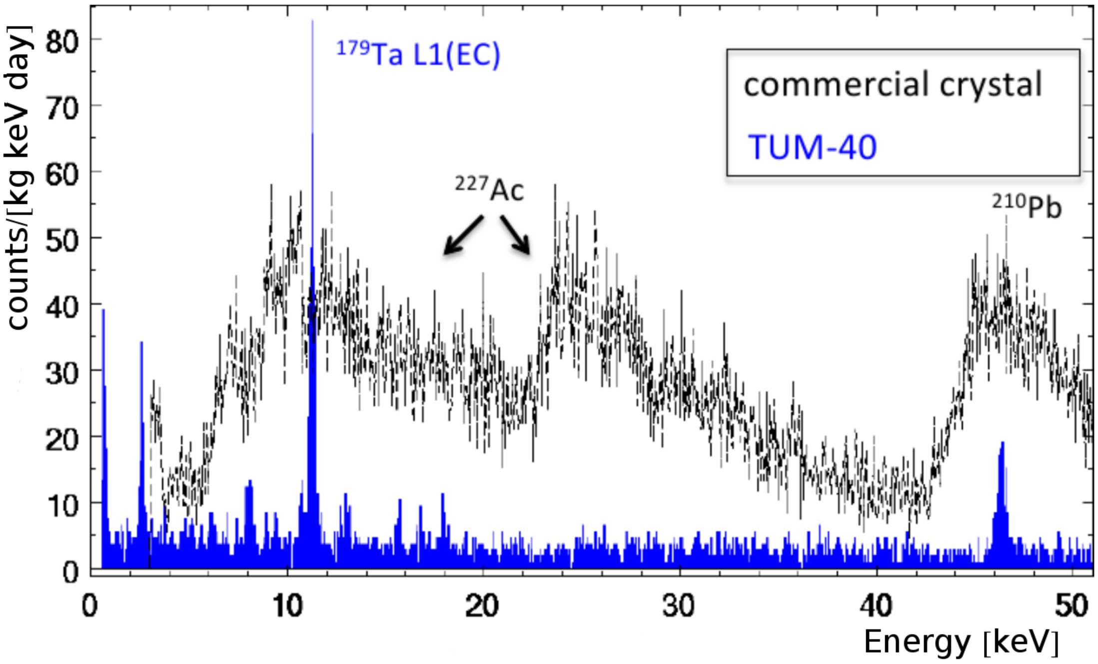

Figure 1: Low-energy spectrum of TUM40 (blue) compared to a typical commercial crystal (black). The commercial crystal is dominated by the decays of ^{227}Ac and ^{210}Pb from the natural decay chains. Due to the improved radiopurity of TUM40, lines originating from cosmogenic activation of ^{182}W become visible in its spectrum.

scintillating clamps, as observed in CRESST-II Phase 1 [2], are efficiently vetoed. The single crystal mounted in this stick-design module was directly grown at the Technische Universität München (TUM) via the Czochralski method.

It is crucial for CRESST detectors to have a radiopurity as good as possible. The radiopurity of TUM40 in comparison to $CaWO_4$ crystals obtained from commercial suppliers was quantified in [3, 4] by determining total α-activities between 1.5 MeV and 7 MeV. The total α-activity of TUM40 was found to be 3.07 ± 0.11 mBq/kg which is comparable to the radiopurest commercial crystals with activities ranging between $\sim$ 3 mBq/kg and 107 mBq/kg [3]. As can be seen in Figure 1, this result is confirmed by the investigation of background events at low energies: in the energy range (1–40) keV, 3.51 counts/(kg keV day) were detected for TUM40, whereas commercial crystals are worse by a factor of 2–10 (6–30 counts/(kg keV day)) [4]. The γ-lines visible in the spectrum of TUM40 in Figure 1 mainly originate from the cosmogenic activation reaction ^{182}W(p, α)^{179}Ta.

In addition to this significant improvement in radiopurity, TUM40 shows an excellent performance of the phonon detector, in particular, a low trigger threshold of 603 eV and an outstanding baseline resolution of $\sim$ 90 eV [5]. A non-blind low-threshold analysis applied to the first 29 kg days of data results in the exclusion limit (solid red line) shown in Figure 2 [6]. Part of the signal region seen in CRESST-II Phase 1 can already be excluded by this analysis. Additionally, new parameter space could be explored for WIMP masses below 3 GeV/c^2. A

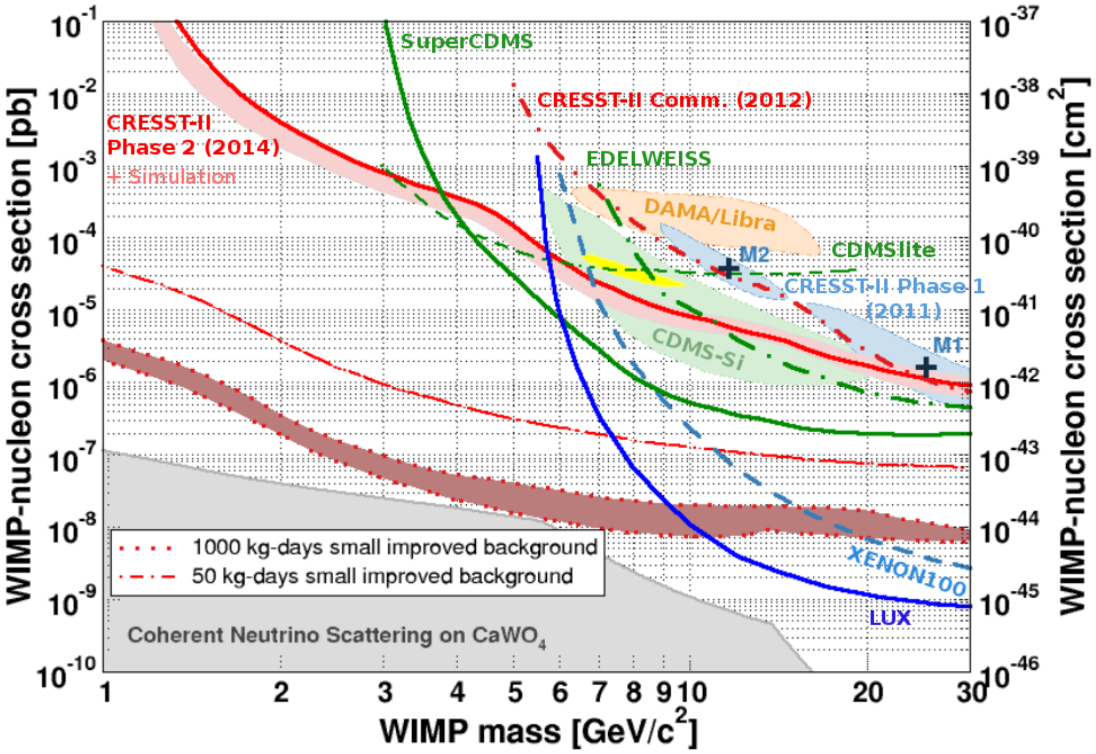

Figure 2: Spin-independent WIMP-nucleon cross section plotted against the WIMP mass including the results of selected direct dark matter search experiments [2, 7, 8, 9, 10, 11, 12, 13, 14, 15]. The solid red line shows the exclusion limit obtained from a low-threshold analysis of the CRESST-II Phase 2 detector TUM40 (29 kg days) [6]. A simulation of the expected sensitivity based on an empirical e^-/γ-background-only model is included (light red band). In addition, the sensitivity (1σ C.L.) expected for the operation of small (24 g) $CaWO_4$ crystals with a radiopurity improved by a factor of 100 is plotted for two different exposures [16].

simulation of the sensitivity expected from an empirical e^-/γ-background-only model is included (1σ borders as light-red shaded area in Figure 2) and shows no hint for any additional background not considered.

3 CRESST-III

In the upcoming CRESST-III the low WIMP-mass region will be further investigated which requires more improvements in the performance of the detectors. Smaller crystals with a mass of only 24 g are expected to lower the threshold of the phonon detector to less than 100 eV. Furthermore, the smaller size allows more light to escape the crystal resulting in a higher amount of light detected. For the second phase of CRESST-III we aim to improve the radiopurity of the $CaWO_4$ crystals by a factor of 100 to $\sim 10^{-2}$ counts/(kg keV day). This improvement is feasible as all the crystal production steps take place at the TUM (see Figure 3): starting

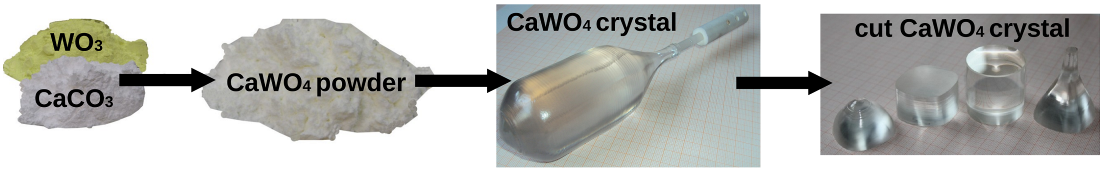

Figure 3: Production of $CaWO_4$ detector crystals starting from the two raw materials $CaCO_3$ and WO_3. As all production steps including the powder processing, the crystal growth, the aftergrowth treatment and further processing of the crystals take place at the TUM [17], further improvements in radiopurity can be achieved.

from the high-purity raw materials $CaCO_3$ and WO_3, $CaWO_4$ powder can be synthesized via a solid-state reaction. This $CaWO_4$ powder is the base material for the growth of $CaWO_4$ single crystals via the Czochralski method [17]. The grown crystals are then further processed to CRESST detectors. There are, in particular, two ways to achieve the required improvement in radiopurity: a) In a chemical purification, contaminations can be extracted from the raw materials, b) recrystallization of an already grown crystal uses the fact that crystal growth itself is a cleaning process.
Figure 2 shows the sensitivity (1σ C.L.) expected for the operation of 24 g crystals with this improved radiopurity for an exposure of 50 kg days (dash-dotted red line) as well as for an exposure of 1000 kg days (dotted red line) [16].

4 Conclusion and outlook

In this work we present the results of a low-threshold analysis of the CRESST-II Phase 2 detector TUM40. New parameter space could be explored for WIMP masses below 3 GeV/c^2. A further improvement of the limit in the low WIMP-mass region could be achieved with the detector module Lise [18]. Additionally, the combined exposure of several detectors operated will clarify the origin of the signal observed in CRESST-II Phase 1.

It was shown, that a suitable technology for the development of an experiment with a high target mass is available. However, the highest potential of CRESST lies in the investigation of the low WIMP-mass region. In two phases, CRESST-III will be able to explore new parameter space with a changed detector design using small $CaWO_4$ crystals. Additionally, in the second phase it is aimed for an increased exposure and a radiopurity improved by a factor of 100. It is demonstrated in a projection that the resulting sensitivity will be close to the region where coherent neutrino nucleus scattering becomes an irreducible background for dark matter search with $CaWO_4$ crystals [19].

Acknowledgments

This research was supported by the DFG cluster of excellence: Origin and Structure of the Universe, the Helmholtz Alliance for Astroparticle Physics, the Maier-Leibnitz-Laboratorium (Garching), the Science & Technology Facilities Council (UK) and by the BMBF: Project 05A11WOC EURECA-XENON. We are grateful to Michael Stanger from the crystal laboratory (TUM) and to LNGS, in particular to Marco Guetti, for the constant support of CRESST.

References

[1] R. Strauss *et al.*, EPJ C **74**, 7 (2014), [arXiv:1401.3332 [astro-ph.IM]].

[2] G. Angloher *et al.*, EPJ C **72**, 4 (2012), [arXiv:1109.0702 [astro-ph.CO]].

[3] A. Münster *et al.*, JCAP **2014 05**, 018 (2014), [arXiv:1403.5114 [astro-ph.IM]].

[4] R. Strauss *et al.*, JCAP **2015 06**, 030 (2015), [arXiv:1410.4188 [physics.ins-det]].

[5] R. Strauss *et al.*, EPJ C **75**, 8 (2015), [arXiv:1410.1753 [physics.ins-det]].

[6] G. Angloher *et al.*, EPJ C **74**, 12 (2014), [arXiv:1407.3146 [astro-ph.CO]].

[7] A. Brown *et al.*, Phys. Rev. D **85**, 021301 (2012), [arXiv:1109.2589 [astro-ph.CO]].

[8] R. Agnese *et al.*, Phys. Rev. Lett. **112**, 241302 (2014), [arXiv:1402.7137 [hep-ex]].

[9] R. Agnese *et al.*, Phys. Rev. Lett. **112**, 041302 (2014), [arXiv:1309.3259 [physics.ins-det]].

[10] R. Agnese *et al.*, Phys. Rev. Lett. **111**, 251301 (2013), [arXiv:1304.4279 [hep-ex]].

[11] E. Aprile *et al.*, Phys. Rev. Lett. **109**, 181301 (2012), [arXiv:1207.5988 [astro-ph.CO]].

[12] D. S. Akerib *et al.*, Phys. Rev. Lett. **112**, 091303 (2014), [arXiv:1310.8214 [astro-ph.CO]].

[13] C. Savage *et al.*, JCAP **2009 04**, 010 (2009), [arXiv:0808.3607 [astro-ph]].

[14] E. Armengaud *et al.*, Phys. Rev. D **86**, 051701 (2012), [arXiv:1207.1815 [astro-ph.CO]].

[15] C. E. Aalseth *et al.*, Phys. Rev. D **88**, 012002 (2013), [arXiv:1208.5737 [astro-ph.CO]].

[16] G. Angloher *et al.*, arXiv:1503.08065 [astro-ph.IM].

[17] A. Erb and J.-C. Lanfranchi, CrystEngComm **15**, 2301-2304 (2013).

[18] G. Angloher *et al.*, to be published (2015)

[19] A. Gütlein *et al.*, Astroparticle Physics **69**, 44 - 49 (2015), [arXiv:1408.2357 [hep-ph]].