Current Status of the Dark Matter Search Experiment CRESST

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2014-04/240

CRESST is a cryogenic direct Dark Matter search experiment based on phonon-light technique. It is aiming for the detection of *weakly interacting massive particles* (WIMPs) via their scattering off nuclei in $CaWO_4$ target crystals. Significant improvements have been achieved with respect to previous measurement campaigns in terms of intrinsic radiopurity of $CaWO_4$ crystals and rejection of nuclear recoil events from alpha decays near surfaces. In this contribution, the related changes in the detector design will be discussed. Based on the first ~ 30 kg-live-days of data acquired by a single $CaWO_4$ detector module with a new design, we present limits for the spin-independent WIMP-nucleon cross section, which exclude new parameter space below $3\,\mathrm{GeV}/c^2$.

1 Introduction

Various observations point to the existence of particle-like Dark Matter [1]. However, the actual particle candidate, which may be a *weakly interacting massive particle* (WIMP), has not yet been discovered undoubtedly: Some experiments, e.g. LUX [2] and SuperCDMS [3], obtained null results, whereas other experiments, e.g. DAMA/LIBRA [4] and previously also CRESST [5], observed a potential signal.

CRESST recently published the result of a new search for WIMP-nucleon scattering based on a single upgraded detector module, *TUM40* [6]. After a short introduction of the CRESST experiment in sec. 2, we will present the improvements of this upgraded module (sec. 3) and the obtained result (sec. 4) before we conclude in sec. 5.

2 The CRESST experiment

The cryogenic Dark Matter search CRESST is looking for nuclear recoils induced by the elastic scattering of WIMPs off the nuclei in $CaWO_4$ targets. The energy deposited by a potential WIMP-nucleon scattering is only in the order of a few 10 keV, therefore a sufficient background suppression is crucial [5]. To discriminate e^-/γ background events, CRESST simultaneously reads out signals from two channels: the scintillation light emitted by the $CaWO_4$ crystal (*light signal*) and the non-thermal phonon excitation of the crystal lattice (*phonon signal*). The rejection of *near-surface α events* will be outlined in sec. 3. A detailed description of the experimental set-up, the data acquisition, and analysis can be found in earlier publications [7, 8].

The phonon signal, which is independent of the interacting particle type, is used to measure the deposited energy E. Contrary, for the same E, the light signal of nuclear recoils is suppressed with respect to the light signal of e^-'s/γ's, and decreases with the mass of the nucleus.

This *quenching effect* is evident in the plane of *light yield* (LY), i.e. the ratio of light signal over phonon signal, versus E as schematically shown in fig. 1: The e^-/γ-band is normalized to $LY = 1$ at 122 keV via calibration with a ^{57}Co source. At decreasing values of LY, bands for α recoils and recoils of the O, Ca, and W nuclei are located [9].

Due to the overlapping of the bands at low energies, see fig. 1, a low background activity and a low experimental threshold are necessary for dedicated low-mass WIMP searches. CRESST made progress in both aspects with an upgraded detector module, resulting in a WIMP sensitivity down to $\sim 1\,\mathrm{GeV}/c^2$ [6].

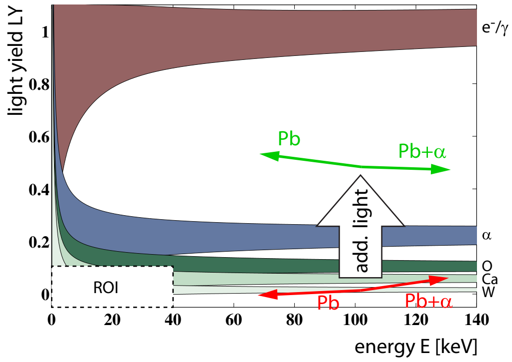

Figure 1: Illustration of the various bands in the light yield−energy-plane for a $CaWO_4$ detector and the region of interest (ROI) for the WIMP search with the TUM40 detector module. Additional scintillation light shifts near-surface α and Pb events out of the vicinity of the nuclear recoil bands [12], for details see text.

3 The upgraded detector module TUM40

CRESST runs with 18 detector modules of various designs and a total target mass of roughly 5 kg [6] in its current data taking period (CRESST-II Phase 2). Here, we will focus on 29.35 kg d recorded with only one module, *TUM40*, based on a $CaWO_4$ crystal with a mass of $\sim$ 250 g [6]. This module shows three improvements: a decreased intrinsic e^-/γ background, a fully efficient rejection of near-surface α background, and a high phonon resolution allowing to set a low trigger threshold.

The intrinsic e^-/γ background is reduced by growing the crystal in a dedicated furnace at the TU Munich [10]. Figure 2 compares the background spectrum of TUM40 (*filled blue histogram*) with the one of a commercial $CaWO_4$ crystal (*open black histogram*). Whereas the spectrum of the com-

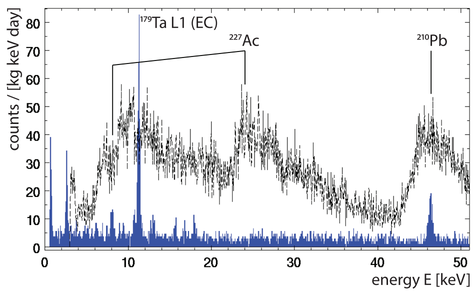

Figure 2: Background spectra for a commercial $CaWO_4$ crystal (*open black histogram*) and TUM40 (*filled blue histogram*). Prominent features are the beta decays of ^{227}Ac and ^{210}Pb, and the electron capture of cosmogenic ^{179}Ta [6, 11].

mercial crystal is dominated by beta decays of internal ^{227}Ac and ^{210}Pb contaminations, these are strongly reduced in the TUM40 spectrum: The background rate of TUM40 is with ~ 3.5 counts/kg/d/keV up to 10 times lower than the one of a comparable commercial crystal. A detailed discussion of the remaining background of TUM40 can be found in [11].

Near-surface α decays are mostly $^{210}\mathrm{Po} \rightarrow {}^{206}\mathrm{Pb} + \alpha$ decays near surrounding surfaces and contribute to the background in two ways: If the resulting α particle hits the crystal after having already lost most of its energy, it can leak as *degraded* α into the nuclear recoil bands. In case the resulting ^{206}Pb nucleus hits the crystal, such an event can leak from its band closely below the W band to the ROI. To actively veto this α (Pb) background, already previously each crystal was encapsulated by a scintillating and reflecting foil which is hit by the remaining α particle. The additional scintillation light of the foil shifts the event to a higher LY value as illustrated in fig. 1. However, previously not the complete surrounding of the crystals was scintillating due to the bronze clamps that hold the crystal. This results in an unexpected high rate of non-vetoed near-surface α decays in the previous data taking period (CRESST-II Phase 1) [5]. The TUM40 module holds the target crystal by sticks made of scintillating $CaWO_4$, therefore it is nearly fully surrounded by scintillating surfaces, which strongly increase the veto efficiency against near-surface α events. So far, TUM40 found no near-surface α events which are not vetoed. A detailed evaluation of the *$CaWO_4$-stick-design* will be given in [12].

The TUM40 module features also an excellent trigger threshold: Measured with electronic calibration pulses, the trigger efficiency reaches 50 % already at ~ 600 eV. Furthermore, a very good energy resolution of ~ 100 eV has been achieved. This is validated by the widths of the γ lines in fig. 2 [6]. The good energy resolution together with the very low threshold predestines the TUM40 module for a low-mass WIMP search.

4 Results of a dedicated low-mass WIMP search

The TUM40 module alone collected an exposure of 29.35 kg d, before all cuts and corrections for detection efficiencies in 2013 [6]. The *region of interest* (ROI) for WIMPs on the $LY-E$-plane includes all events with a LY lower than the central LY of the O recoil band and within an energy interval starting at the trigger threshold of 600 eV and ending at 40 keV [6], see fig. 1.

Applying Yellin's optimum interval method [13] on the events in the ROI results in an exclusion limit at 90 % CL for elastic spin-independent WIMP-nucleon scattering as shown in fig. 3 (*red line*) [6]. We emphasize three features of this limit:

First, it is a leading limit and excludes new parameter space for $m_\chi \leq 3\,\mathrm{GeV}/c^2$. Second, compared to other

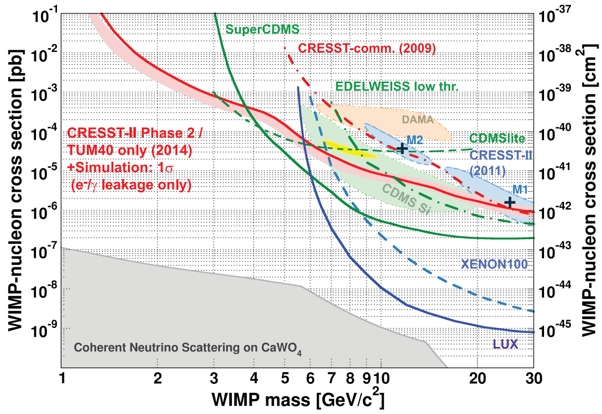

Figure 3: Limit on elastic spin-independent WIMP-nucleon scattering reported in [6] (red solid line) compared to selected results of current Dark Matter searches, see [6] for the references.

limits, this limit is relatively flat: Due to the multi-element target $CaWO_4$, CRESST is sensitive to the scattering of WIMPs at low and high masses via O ($A = 15.999\,\mathrm{u}$), and W ($A = 183.84\,\mathrm{u}$). Therefore, this limit is also relevant at higher WIMP masses. For instance, the TUM40 results exclude the low-mass maximum M2 and constrain the higher mass maximum M1 where CRESST-II Phase 1 previously reported an event excess over expected background [5]. Third, the experimental limit agrees with the expected 1σ limit due to the assumed leakage of e^-/γ background in the ROI (fig. 3, *light red region*). Therefore, no additional background component is necessary to explain the observed events [6].

5 Conclusion and outlook

With $\sim 30\,\mathrm{kg\,d}$ of data, CRESST could show the improved performance of the upgraded TUM40 detector module: a decreased intrinsic e^-/γ background by a factor of up to 10, an improved rejection power against near-surface α events, and a low trigger threshold of $\sim 600\,\mathrm{eV}$. Combined, these improvements result in a leading limit on elastic spin-independent WIMP-nucleon scattering below $3\,\mathrm{GeV}/c^2$ and in the exclusion of the M2 maximum of CRESST-II Phase 1.

It is planned to continue data taking with CRESST-II Phase 2 until reaching an exposure sufficient to clarify the nature of M1, probably mid of 2015. As all of the recent progress is well understood, projections based on reasonable further improvements indicate the possibility to reach $\sim 10^{-6}\,\mathrm{pb}$ at $\sim 3\,\mathrm{GeV}/c^2$. Therefore, CRESST is especially predestined to test new parameter space at low WIMP masses.

Acknowledgments

This work was supported by funds of the German Federal Ministry of Science and Education (BMBF), the Munich Cluster of Excellence (Origin and Structure of the Universe), the Maier-Leibnitz-Laboratorium (Garching), the Science and Technology Facilities Council (STFC) UK, and the Helmholtz Alliance for Astroparticle Physics. We gratefully acknowledge the work of Michael Stanger from the crystal laboratory of the TU Munich. We are grateful to LNGS for their generous support of CRESST, in particular to Marco Guetti for his constant assistance.

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