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Abstract. A precise measurement of the radio-purity levels of the $CaWO_4$ crystals used for both the CRESST and the NUCLEUS experiment, is fundamental for a better background understanding. The sensitivity of HPGe detectors is not sufficient to the excellent radio-purity levels of the $CaWO_4$ crystals produced in-house at the Technische Universität München (TUM). We report on a cryogenic α-screening facility which will provide a method to determine the radio-purity of this crystals by measuring the alpha-decays with a high precision, taking advantage of the unique experimental environment of the shallow underground laboratory (UGL) of the TUM.

1. Physics motivation

CRESST [1] (Cryogenic Rare Event Search with Superconductive Thermometers) aims at the direct detection of dark matter using cryogenic detectors. The detectors consist of a 24 g $CaWO_4$ crystal equipped with a Transition Edge Sensor (TES) to precisely account for the amount of energy deposited in the detector after a particle interaction. The detectors are cooled to temperatures around $\sim$10 mK in a He^3-He^4 dilution refrigerator. Similarly, the NUCLEUS [2] experiment, aiming at the detection of coherent elastic neutrino nucleus scattering (CEνNS), takes advantage of the high sensitivity and energy resolution accessible when using cryogenic particle detectors. In this case, the detector is a 1 g $CaWO_4$ crystal cube also equipped with a TES. Therefore, a comprehensive study on the intrinsic radio-purity of the crystals used for both experiments is crucial for a better background understanding.

The shallow underground laboratory (UGL)[3] at the Technische Universität München (TUM) provides an excellent environment to realize these studies. It consists of a large experimental area of 160 m^2 with an overburden of $\sim$15 m.w.e. hosting an ISO-7 clean room for detector production and assembly, HPGe detectors for material screening and a He^3-He^4 dilution refrigerator (cryostat). The μ-rate is reduced by a factor of three compared to the above ground rate. Currently experiments are on-going to determine the neutron background in the UGL.

An α-screening facility will be installed at the UGL cryostat. It will allow to determine the radio-purity of the $CaWO_4$ crystals for both the CRESST and Nucleus experiment.

2. $CaWO_4$ crystal growth at TUM

For many years, $CaWO_4$ crystals have successfully been produced and characterized at TUM. In order to ensure a high $CaWO_4$ crystal quality, the whole production process of the detector crystals, including powder production, crystal growth and post-growth treatments like cutting and polishing are performed at TUM. The state of the art process is as follows: In a first step, the $CaWO_4$ powder is produced via a solid-state reaction from the raw materials WO_3 and $CaCO_3$, hereby taking great care to select only the cleanest available raw materials. Afterwards, the $CaWO_4$ crystal is grown from this powder using the Czochralski method, see figure 1 *left*. Thereafter, the crystal is cut and polished in the TUM crystal laboratory [4].

Looking at the low energy events recorded during CRESST-II phase 2 (shown in figure 1 *right*), the crystal TUM40 (black line) showed an exceptional performance and a much higher radio-purity compared to commercially purchased crystals Daisy (dashed red line) and VK31 (dashed black line) [5]. Another technique which allows to measure the activity of single isotopes is based on the identification of characteristic α-lines. The high statistics of the TUM40 data obtained in the CRESST run together with Monte-Carlo simulations provided an excellent understanding of the backgrounds originating from intrinsic impurities thereby giving input for further optimization of the radio-purity of the $CaWO_4$ crystals.

Recently, an extensive chemical purification of the raw materials $CaCO_3$ and WO_3, a novel production method of $CaWO_4$ via a precipitation reaction and a washing procedure of the synthesized $CaWO_4$ powder have been developed at TUM with the goal to increase the radio-purity of the crystals further by a factor of 100. First measurements of the powder using HPGe-detectors show promising results concerning the radio-purity of the powder. However, HPGe-measurements are not anymore sensitive enough for the current purity level. In August 2019, the first crystal was grown from the purified material [6].

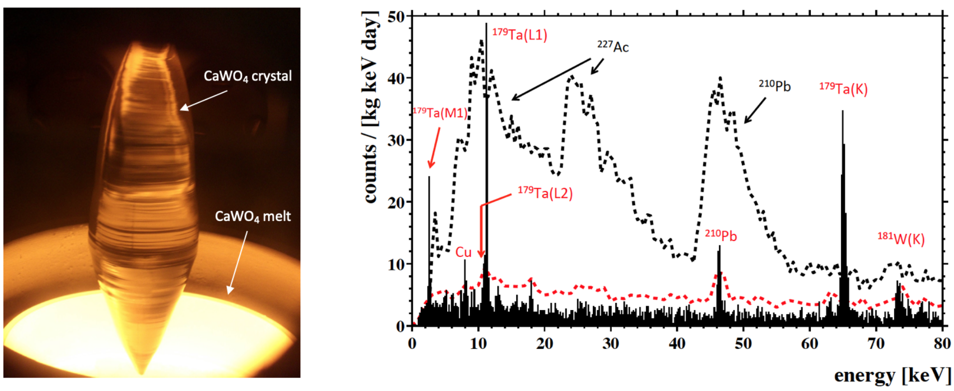

Figure 1. *Left:* $CaWO_4$ crystal in the Czochralski oven at TUM just after the growth. *Right*: Histogram of the low-energy events of the detector TUM40 (black bars) recorded during CRESST-II Phase 2. The most prominent peaks are labelled. In comparison the two commercially bought crystals Daisy (dashed red line) and VK31 (dashed black line). Figure from [5].

3. Cryogenic α-Screening facility in the shallow underground laboratory

Due to the new strategy of CRESST to reduce the crystal mass and aim for a lower threshold of the modules, the exposure of the crystals is reduced significantly, leading to less statistics concerning α-decays. Additionally, the TUM group aims at a screening station providing fast feedback on the crystal growth, thereby allowing a characterization of the crystals prior to mounting them into CRESST. The working principle of the new detector module is shown in figure 2. It is based on the i-stick design used in CRESST-III [1]. The $CaWO_4$ crystal is standing on an instrumented silicon-stick, which has a TES attached to it. When an event is happening within the $CaWO_4$ crystal, a fraction of the created phonons are transmitted to the i-stick and are read out by the TES. The emitted scintillation light is collected by a CRESST-type Silicon-on-Sapphire light detector [1]. The $CaWO_4$ crystal itself has no TES attached. As α-decays have a much higher energy than the usual electromagnetic background, only these high-energy events transmit enough energy to the i-stick to produce a signal. Hence, the module can be operated in a moderate-high background environment like the UGL. It was constructed in a way that it can easily be adapted to different crystal sizes. As the measurement does not rely on a readout of a TES on the $CaWO_4$ the crystals do not have to be treated in advance to allow for such measurements.

In conclusion, the α-screening module offers an unique possibility to measure kilogram-scale crystals in a timescale of one month in a shallow underground laboratory with a potential sensitivity down to 5 µBq/kg.

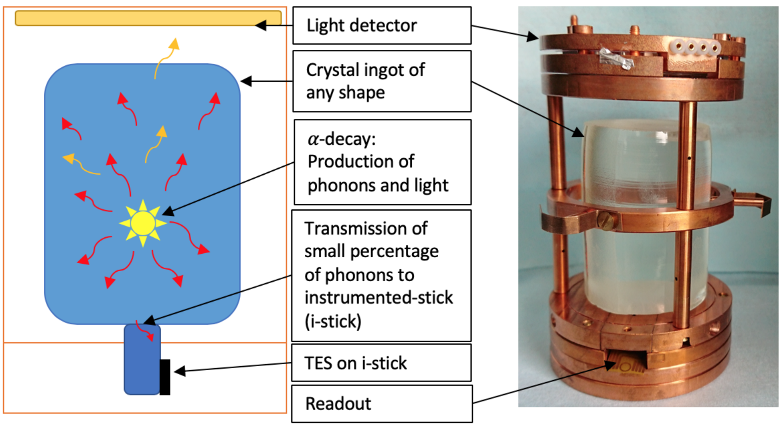

Figure 2. *Left:* Working principle of the cryogenic α-screening module: $CaWO_4$ crystal (blue) standing on an instrumented silicon-stick (dark blue) with TES attached to it. When an event is happening within the $CaWO_4$ crystal, some percent of the created phonons are transmitted to the i-stick and are read out by the TES. The emitted scintillation light is collected by a light detector. The $CaWO_4$ crystal itself has no TES attached. *Right:* First assembly of the α-screening module at TUM.

References

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