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Production of low-background $CuSn_6$-bronze for the CRESST dark-matter-search experiment

B. Majorovits [a,*], H. Kader [b], H. Kraus [a], A. Lossin [b], E. Pantic [c], F. Petricca [c], F. Proebst [c], W. Seidel [c]

[a] Department of Physics, University of Oxford, Keble Road OX1 3RH, UK
[b] Norddeutsche Affinerie, Hovestr. 50, 20539 Hamburg, Germany
[c] MPI für Physik, Föhringer Ring 6, 80805 Munich, Germany

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ABSTRACT

One of the most intriguing open questions in modern particle physics is the nature of the dark matter in our universe. As hypothetical weakly interacting massive particles (WIMPs) do interact with ordinary matter extremely rarely, their observation requires a very low-background detector environment regarding radioactivity as well as an advanced detector technique that allows for active discrimination of the still present radioactive contaminations. The CRESST experiment uses detectors operating at milli-Kelvin temperature. Energy deposition in the detectors is recorded via the simultaneous measurement of a phonon-mediated signal and scintillation emitted by the $CaWO_4$ crystal targets. The entire setup is made of carefully selected materials.

In this note we report on the development of ultra-pure bronze ($CuSn_6$) wire in small quantities for springs and clamps that are currently being used in the CRESST II setup.

1. The CRESST dark-matter-search experiment

The cryogenic rare event search with superconducting thermometers—CRESST—is an experiment dedicated to the search for hypothetical WIMP particles as the solution for the dark-matter problem (Goodman and Witten, 1985). The CRESST experiment is placed at the underground site of the Laboratori Nazionali del Gran Sasso (LNGS). It is using scintillating $CaWO_4$ calorimeters that are read out using superconducting tungsten phase-transition thermometers (Meunier et al., 1999). A small rise in temperature creates an appreciable increase of the resistance of the tungsten film. This is measured using SQUIDs (Henry et al., 2007). Additionally, and in coincidence, a scintillation signal is measured using specially developed light detectors (Petricca, 2005). The amount of scintillation light produced inside the crystal depends on the energy deposited and on the interaction type, i.e. nuclear recoil or electron recoil. Recorded in coincidence, these two signals permit discrimination of background events that are being produced by radioactivity, largely depositing the energy of emitted radiation or particles via interaction with the electron system of the $CaWO_4$ crystal.

A nuclear recoil, through which energy is transferred to a nucleus, produces considerably less light output for the same energy deposited. This is due to the different ionization densities of the two processes.

In the second phase of the CRESST experiment a total of 33 $CaWO_4$ crystals with a total mass of up to approximately 10 kg will be used for the search for dark-matter particles (Angloher et al., 2004).

In order to house such an amount of crystals in the experimental setup a completely new design had to be developed. The new holder system is shown in Fig. 1. The bulk of the material is low-heat leak NOSV copper[1] from the Norddeutsche Affinerie. It is the same material that had been used for the earlier detector holders of the first phase of the CRESST experiment (Bravin et al., 1999). Since the holders, carrying the crystals, have to be protected from external mechanical vibrations, the whole system rests on up to six compression springs (see Fig. 1).

2. Selection of material for the springs

There exist severe constraints regarding the materials that can be used for production of the holder system. The springs are not

* Corresponding author. Present address: MPI für Physik, Föhringer Ring 6, 80805 München. Tel.: +49 89 32354262; fax: +49 89 32354528.
E-mail address: bela@mppmu.mpg.de (B. Majorovits).

[1] NOSV is the trade name of Norddeutsche Affinerie for their highest conductivity copper with residual resistivity ratio of $\geqslant$400.

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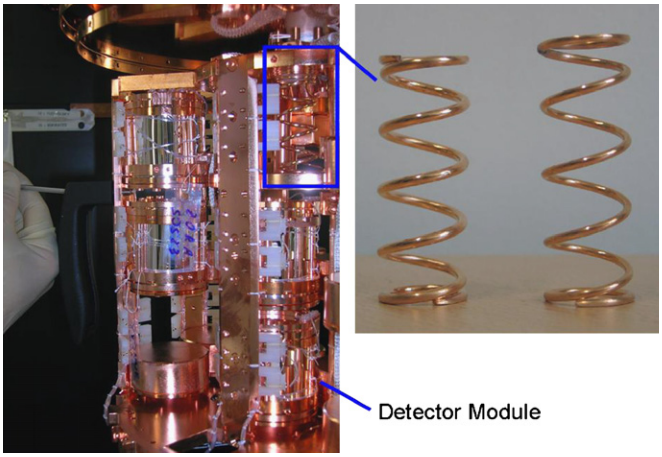

Fig. 1. Left picture: part of the CRESST detector holder structure during mounting at the LNGS. In total 33 detector modules with up to 300 g detector material per module can be placed into the holder structure. Each detector module is accessible individually without having to remove other crystals from the setup. The detector holder structure rests on six $CuSn_6$-bronze springs for decoupling from vibrations. Two detector modules are visible on the top of the left tower, two further on the right tower. The six $CuSn_6$ springs of which one is visible here are at the height of the upper detectors. Right picture: two $CuSn_6$ springs with 3 mm (left) and 2.5 mm (right) wire diameter.

allowed to contain any magnetizable materials, as otherwise the setup could not be cooled down to its operating temperature in the milli Kelvin regime. To maintain a low radioactive background all the materials in the direct vicinity of the $CaWO_4$ crystals must be carefully selected for their radiopurities as otherwise they could considerably contribute to the background of the experiment.

As can be seen from Fig. 1 the compression springs holding the experimental table are positioned in close proximity to some of the detector modules. Therefore, requirements regarding tolerable levels of radiopurity of the springs are rather stringent.

Similarly, severe requirements apply to the clamps holding the $CaWO_4$ crystals and the light detectors (see Fig. 2).

In earlier measurements the $CaWO_4$ crystals were held in place by clamps made from polytetrafluoroethylene (PTFE). However, in these data taking runs events occurred where energy deposition could only be detected by phonons (phonon channel), but the light detectors did not respond (phonon-only-events). These phonon-only-events are attributed to the extreme stiffness of of the PTFE clamps at very low temperatures. In such operating condition, the PTFE clamps can cause tiny fractures in the crystal. Such fractures can be observed in the crystals that were held in place by the PTFE clamps. Whenever a new fracture process occurs, this produces phonons, which can be observed in the phonon channel but the fracture does not create scintillation light, or at least not enough scintillation for detection (Åström et al., 2006).

In the two last runs of CRESST, before the start of the upgrade in 2004, the PTFE clamps had been replaced by Ag-coated copper–beryllium ($CuBe_2$) clamps. As a consequence, the phonon-only-events disappeared. However, as a new feature in the low-energy spectrum a peak around 47 keV appeared (Angloher et al., 2005) originating from the beta decay of ^{210}Pb (see Fig. 3). As the change of the crystal clamps was the only major change in the setup we attribute the 47 keV peak to a contamination of the $CuBe_2$ used for the production of the clamps or its silver coating.

As the most promising suitable material for spring production we found $CuSn_6$-bronze, where both components of the alloy—copper and tin—can be obtained in a controlled high-purity quality.

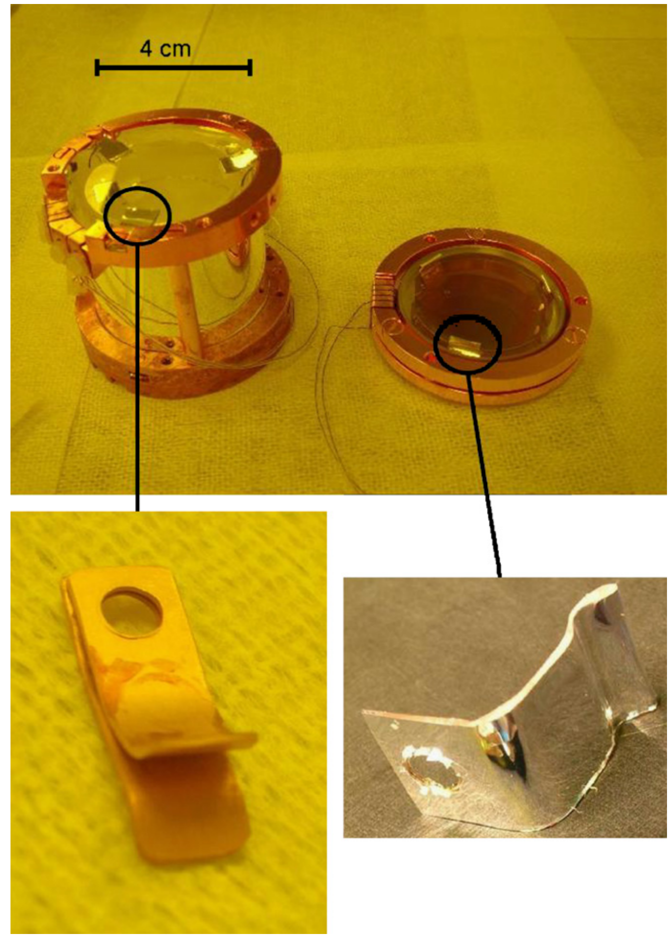

Fig. 2. Upper picture: Cresst II detector module. On the left, the $CaWO_4$ crystal can be seen as it is held inside the copper holder system. It is surrounded with a reflective scintillating foil. The crystal is held inside the structure with the help of $CuSn_6$-bronze springs that are wrapped in scintillating foil. The crystal diameter is 40 mm. On the right, the light detector can be seen. Similarly it is held inside the copper structure using $CuSn_6$ springs. Lower pictures: left: $CuSn_6$ clamps used to fix the $CaWO_4$ crystals. Right: $CuSn_6$ clamp wrapped in scintillating foil to hold the light detectors in their copper holder structure.

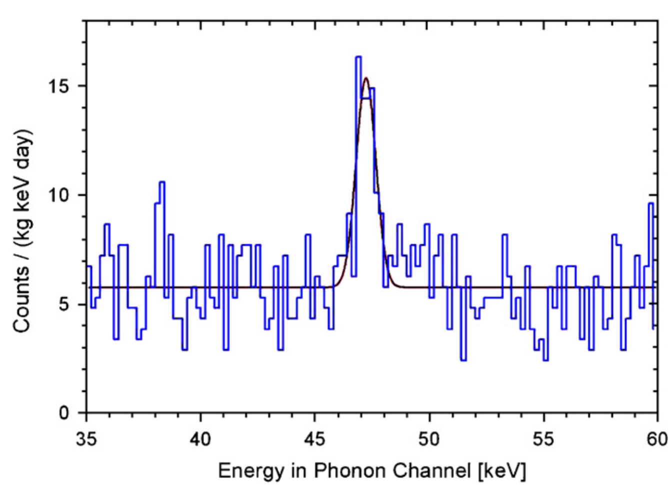

Fig. 3. Low-energy spectrum of one of the detectors taken from the previous run (Angloher et al., 2005). Clearly visible is the peak at 46.5 keV that is attributed to a contamination of the $CuBe_2$ clamps with ^{210}Pb.