Dark Matter Search with CRESST-II

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The CRESST-II Dark Matter experiment aims at the direct detection of WIMPs via scattering off nuclei in $CaWO_4$ crystals which are operated as cryogenic detectors. The phonon signal and the scintillation light signal are recorded simultaneously. The light output of these crystals is used for active discrimination between background events and possible WIMP-induced nuclear recoils. The recently finished 730 kg-days experimental run indicates an excess of events in the signal region which is hard to explain with known backgrounds and could hint towards light WIMPs.

1 Experimental approach of CRESST

Astrophysical experiments and observations indicate a large abundance of non-baryonic matter in the Universe. Well motivated theoretical concepts propose weakly-interacting massive particles (WIMPs) to be the origin of the *Dark Matter*. So far it has not been clearly verified despite a large variety of experiments aiming at its direct detection [1].
The **CRESST-II** (Cryogenic Rare Event Search with Superconducting Thermometers) experiment, located at the Laboratori Nazionali del Gran Sasso (LNGS), Italy, attempts to measure the very rare interactions expected between ordinary matter and WIMPs via elastic scattering off nuclei [2, 3, 4]. Tiny energy transfers to the recoiling nucleus ($\mathcal{O}(10\,\mathrm{keV})$) and ultra-low event rates (<0.1 events/kg/day) require very sensitive detectors with low-energy thresholds as well as excellent shielding against environmental radiation and an active background discrimination technique. Scintillating $\mathbf{CaWO_4}$ crystals as target material operated as cryogenic detectors are suitable for this challenging approach. These crystals are cylindrically shaped, ∼40 mm in diameter and height (∼300 g), each equipped with a tungsten (W) transition edge sensor (TES) stabilized in its transition between the superconducting and the normal-conductive state at a temperature of typically 10-20 mK. This allows to measure the total energy deposition in the crystal (phonon channel). The resulting temperature rise after a particle interaction in the target crystal causes a significant change in resistance of the TES which is read out by a SQUID

system. Thereby sub-keV thresholds and energy resolutions of <500 eV FWHM are achieved in the region of interest for Dark Matter search (typically 10-40 keV).
The kind of interaction can be identified by simultaneously measuring the **scintillation light** output of the $CaWO_4$ crystal, which is typically only a small fraction ($\mathcal{O}(1\%)$) of the total energy deposition. The light output (*light yield*) for electron recoils induced by 122 keV γ's from a ^{57}Co source is normalized to one. Due to quenching effects the light output is further reduced for nuclear recoil events, which is quantified by *Quenching Factors* (QF). During dedicated measurement campaigns the QFs were precisely measured [2]: $QF_O=(10.4\pm0.5)\%$, $QF_{Ca}=(6.38\pm0.65)\%$, $QF_W=(3.91\pm0.48)\%$ and $QF_{e/\gamma}:=100\%$ (by definition). This active discrimination technique features an excellent separation of the dominant e/γ background from possible WIMP-induced nuclear recoils on the individual components O, Ca and W (WIMP mass spectroscopy) and a characterization of neutron backgrounds. The light is collected with a separate cryogenic detector, a silicon on sapphire (or pure Si) disc of 40 mm diameter, again equipped with a W-TES. Target crystal and light absorber are placed in a housing covered by a reflective and scintillating polymeric foil in order to increase the light collection efficiency and to discriminate α-decay events [2]. Up to 33 *detector modules* (see Fig. 1, left) can be installed in the CRESST-II setup for up to 10 kg active target mass.
The detector volume is coupled via a longish (1.3 m) copper cold finger to a ^{3}He-^{4}He dilution refrigerator in order to avoid the presence of non-radiopure materials of the cryostat near the detectors. Layers of ultra-pure copper and lead, active muon veto panels and polyethylene surround the detectors [2, 3, 4]. Together with the 1400 m of rock overburden (3500 m.w.e.) in the underground facilities of the LNGS, the setup provides an efficient **shielding** against ambient and cosmic radiation.

2 Recent experiment: Run32

CRESST-II was successfully commissioned in 2007 [3]. Run32 was the first extensive physics run of CRESST-II with a net exposure of 730 kg-days and a runtime of almost 2 years from June 2009 to April 2011. Eight fully functional detector modules have been used for the Dark Matter analysis and were calibrated by AmBe, ^{57}Co and ^{232}Th sources during dedicated campaigns. Here a brief qualitative discussion of background sources and the final results derived from an extensive likelihood analysis are presented. A detailed description of the analysis is given in [2].

2.1 Backgrounds

In Fig. 1, right a light yield plot of a typical detector module (channel 20) is shown with the relevant event bands to illustrate the background distribution discussed in this section. The acceptance region for WIMP search is defined for this particular module from 12.9 keV to 40 keV including the contributions of the O, Ca and W recoil bands.
The dominant **e/γ background** ($\sim$0.3 events/keV/kg/day) can be well discriminated from the nuclear recoil bands due to its relatively high light output ($QF_{e/\gamma}:=1$). Nevertheless there is an overlap between the bands at low recoil energies which fixes the lower boundary of the WIMP-acceptance region individually [2] for each module (typically 10-20 keV).
Discrete **alpha** lines are observed at MeV energies (e.g. ^{210}Po decay with 5.3 MeV α) at a QF of $\sim$22% and can thus be well distinguished from the nuclear recoil events. If the α emitter is implanted in the surface of the material surrounding the crystal (e.g. bronze clamps that

	e/γ	α	n	^{206}Pb	signal
M1	$8.00^{+0.05}_{-0.05}$	$11.5^{+2.6}_{-2.3}$	$7.5^{+6.3}_{-5.5}$	$15.0^{+5.2}_{-5.1}$	$29.4^{+8.6}_{-7.7}$
M2	$8.00^{+0.05}_{-0.05}$	$11.2^{+2.5}_{-2.3}$	$9.7^{+6.1}_{-5.1}$	$18.7^{+4.9}_{-4.7}$	$24.2^{+8.1}_{-7.2}$

Table 1: Contributions of the considered backgrounds and a possible WIMP-induced signal obtained by the maximum likelihood analysis for the two fit maxima M1 and M2 [2].

hold the crystal), α's can loose energy before reaching the detector. These degraded α's are a harmful background as they can leak into the acceptance region due to an overlap of the bands at low energies. The leakage can be estimated using an overlap-free α-reference region of an energy range of 100 keV [2].
An accumulation of nuclear recoil events at ~103 keV slightly below the W-band is observed which were identified as **^{206}Pb recoils** originating from ^{210}Po decays in the clamps holding the crystal. Again an overlap-free reference region is defined and, combined with a SRIM simulation which models the implantation-depth distribution of the ^{210}Po mother nuclei in the clamp material, the leakage into the acceptance region can be derived.
Ambient **neutrons** from spontaneous fission or α-n reactions in the materials surrounding the detector volume are highly degraded and appear mainly as oxygen recoils. As 8 detector modules are operated one can look for multiple detector hits which can be induced by n's but not by WIMPs. The *multiplicity structure* of source-like n-events was determined by neutron calibration campaigns [2]. Another class of events are unvetoed muon induced neutrons as the muon-veto system is not 100% efficient. The multiplicity structure can be studied by analyzing the response of the detectors for events in coincidence with the muon veto. For both classes of n-events the number of (WIMP-like) single hits can be estimated by the observed multiplicity distributions. High-energy neutrons (>10 MeV) generated by muons in the rock surrounding the experiment have been studied in Monte Carlo simulations [2].

2.2 Results and discussion

The contributions of the backgrounds discussed above as well as a possible contribution of a WIMP signal are fully implemented in a maximum likelihood analysis. In total, 67 events are

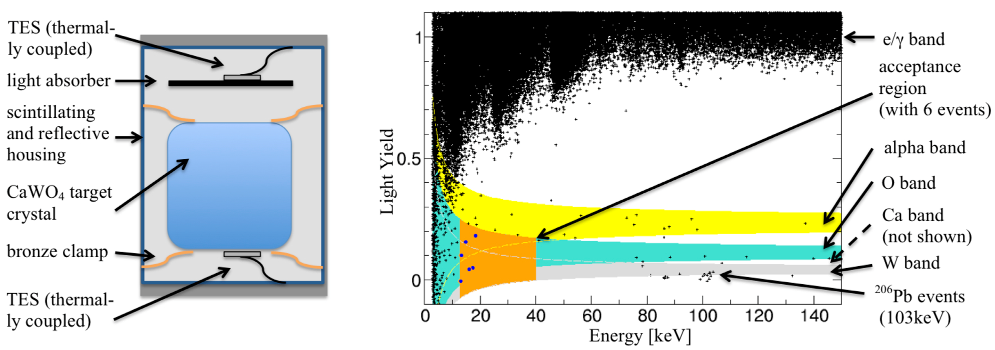

Figure 1: Left: Scheme of a CRESST-II detector module. Right: Typical light yield plot (channel 20) showing the relevant event bands.

observed in the acceptance regions of the individual detectors. The α and ^{206}Pb recoil events are identified to originate from a contamination in the bronze clamps holding the $CaWO_4$ crystals (see Fig. 1, left). The acceptance region is defined such that one γ event per detector module is expected in the acceptance region. The shape of the neutron background is obtained by the calibration. The final result of the maximum likelihood analysis [2, 4] for the contribution of the considered backgrounds and a possible signal is summarized in table 1. Two fit maxima M1 and M2 have been found.

The observed events in the acceptance region cannot be explained by the considered backgrounds only. An additional exponential contribution is needed at a significance level of 4.7σ for M1 (4.2σ for M2). If this excess is interpreted as an indication for a Dark Matter signal the corresponding WIMP parameters can be obtained by the fit for both maxima as listed in table 2.

	m_χ[GeV]	σ_{WN}[pb]	O	Ca	W
M1	25.3	$1.6{\cdot}10^{-6}$	∼7%	∼25%	∼69%
M2	11.6	$3.7{\cdot}10^{-5}$	∼52%	∼48%	∼0%

Table 2: Results of the maximum likelihood fit [2] interpreting the signal excess as WIMPs of mass m_χ and elastic WIMP-nucleon scattering cross section σ_{WN}. For both likelihood maxima (M1, M2) the contributions of O, Ca and W events to the signal are listed.

Such a WIMP signal would be in serious tension with the results of the XENON-100 and CDMS-II experiments [1], while it is consistent with earlier CRESST-II results [3] and their recent re-analysis [5]. Our results - if not an unknown background - would hint to light WIMPs similar to DAMA/LIBRA and CoGeNT [1]. To clarify the origin of the observed excess of events much effort is currently being put into background reduction for the upcoming Run33.

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