Results of the CRESST Commissioning Run 2007

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CRESST (Cryogenic Rare Event Search with Superconducting Thermometers) is a low-temperature experiment dedicated to the direct dark matter detection via nuclear recoil. It is located in Hall A of the Laboratori Nazionali del Gran Sasso, Italy. Scintillating $CaWO_4$ crystals operated at a few mK are utilized as target for WIMPs (Weakly Interacting Massive Particles), which are expected to scatter predominantly on the heavy tungsten nuclei. As for background rejection, CRESST uses the phonon-light technique, where two different quantities of an interaction are recorded: the heat production in the $CaWO_4$ crystal and the simultaneous emission of scintillation light, which is monitored by a second low-temperature detector, the light detector. The information provided by both detectors allows a powerful background discrimination on an event by event basis. After a major upgrade phase, CRESST-II has now successfully completed a commissioning run during 2007, the results of which are presented in this article.

Introduction.- CRESST (Cryogenic Rare Event Search with Superconducting Thermometers) is an experiment aimed at the direct detection of dark matter in the form of WIMPs (Weakly Interacting Massive Particles). It is located at a depth of 3500 m.w.e. (meter water equivalent) in Hall A of the Laboratori Nazionali del Gran Sasso, Italy. Highly sensitive low-temperature detectors operated at a few mK are used to measure the small recoil energies of a few keV expected in a WIMP-nucleus scattering. In the past, CRESST [1] was already able to obtain competitive results along with other direct detection low-temperature experiments like CDMS [2] and EDELWEISS [3]. However, the experiment necessitated major changes concerning the experimental setup in order to face the challenges connected to the next phase of exploration of the WIMP-nucleon scattering cross section scenario. First results obtained during the commissioning phase in 2007 are presented in this article.

Detection Principle.- CRESST uses detector modules as depicted in Fig. 1. Each module consists of two individual low-temperature detectors. A large detector with scintillating $CaWO_4$ as target provides an accurate measurement of the total energy deposited by an interaction, while the simultaneous measurement of the light yield with the second detector allows a powerful rejection of events that are not nuclear recoils [4]. This method, which is referred to as the heat-scintillation or light-phonon technique is the key to our rare event search since a background discrimination on an event by event level is realized. Nine such detector modules were installed for the commissioning run in 2007; whereas only two were used for the dark matter analysis presented in section Results.

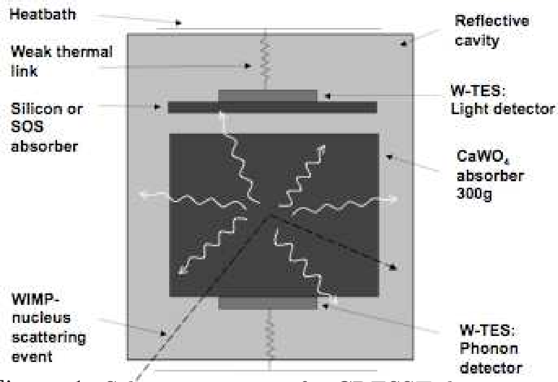

Figure 1: Schematic setup of a CRESST detector module. The module is made of two independent low-temperature detectors: one consisting of a $CaWO_4$ target crystal, which provides a total energy measurement (phonon channel), and one silicon-on-sapphire (SOS) or pure silicon wafer for measuring the scintillation light emitted by the target crystal (light channel). For a highly efficient light collection the two detectors are enclosed in a reflective and scintillating cavity.

Experimental Setup.- The setup of CRESST prior to the upgrade is described in detail in [5]. The changes made during the upgrade to CRESST-II included the installation of a PE neutron shield, a muon veto, a new detector support structure, a new 66-channel SQUID read out with associated data acquisition (DAQ), and a calibration source lift. Figure 2 shows the setup after the upgrade and is described in detail in [6]. The CRESST-II setup now allows to operate a total of 33 detector modules, i.e. 33 phonon and 33 light channels simultaneously, i.e. $\sim$10kg of target mass.

Results.- As discussed in more detail in Ref. [6], for the dark matter analysis, data taken with the two detector modules (Zora/SOS23) and (Verena/SOS21) between March 27th and July 23rd 2007 was used. The results are shown in Fig. 3. The cumulative exposure was 47.9 kg-days. For tungsten only, this corresponds to an exposure of 30.6 kg-days. The analysis is performed on the assumption of coherent or spin-independent scattering for the WIMP. This process strongly favors tungsten recoils due to the $\sim A^2$ factor in the WIMP-nucleus cross section. The acceptance region on the plots is based on: firstly, the quenching factor for the light yield and secondly, on the maximum energy expected for tungsten recoils. A similar region for "all nuclear recoils" can be defined using the quenching factors for Ca and O. The quenching factor boundaries are shown on the plots of Fig. 3. Below the dashed curve 90% of all nuclear recoils are expected, and below the solid curve 90% of the tungsten recoils are expected. The energy boundaries are indicated by the vertical lines. The upper limit at 40 keV is set by form-factor [7] effects, which effectively limit the energy transfer to the tungsten nucleus. The lower limit is set at 10 keV, where "leakage" from the electron recoil band becomes evident and recoil discrimination between electron and nuclear recoils becomes inefficient.

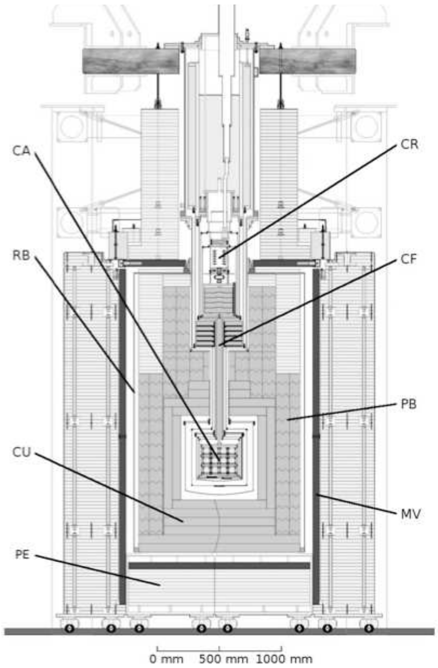

Figure 2: ^{3}He-^{4}He dilution refrigerator and shielding as upgraded for CRESST-II. The detector carousel (CA) is connected to the mixing chamber of the cryostat (CR) by a long copper cold finger (CF) in order to reduce background originating from the dilution refrigerator itself. The gas-tight radon box (RB) encloses the low-background copper (CU) and low-background lead shielding (PB). It is covered by a plastic scintillator muon-veto (MV) and a 45 cm thick polyethylene neutron moderator (PE). Additional granular PE is placed between the baffles in the upper part of the cryostat to close the line of sight for neutrons coming from the top.

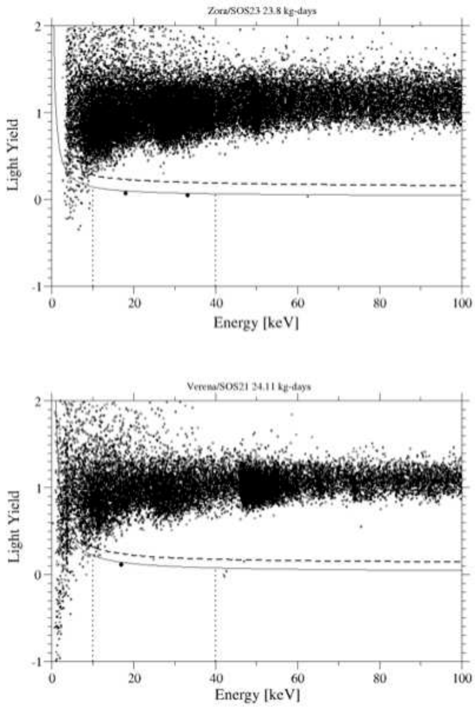

Figure 3: Low-energy event distribution measured with two 300 g $CaWO_4$ detector modules during the commissioning run. The vertical axis represents the light yield, and the horizontal axis the total energy, as measured by the phonon channel. Below the dashed curve 90 % of all nuclear recoils, and below the solid curve 90 % of the tungsten recoils are expected. The heavy black dots show the events in the "tungsten recoils" acceptance region. The intense regions of the electron recoil bands are due to γ and β-background.

In the data presented, three candidate events (heavy black dots) are observed in Fig. 3 for the "tungsten recoils" acceptance region. The individual events are at 16.89 keV (Verena/SOS21) and at 18.03 keV and 33.09 keV (Zora/SOS23). The corresponding rate is 0.063 per kg-day. From this rate and using standard assumptions on the dark matter halo [8, 9] (WIMP mass density of 0.3 GeVcm^{-3}), an upper limit for the coherent or spin-independent WIMP-nucleon scattering cross-section may be obtained using the maximum energy gap method [10]. This limit is plotted as the solid curve in Fig. 4. The minimum of the curve, for a WIMP mass of $\sim$60 GeV, is at 4.8×10^{-7} pb.

The question arises, however, as to the nature of the three observed tungsten or nuclear recoil candidates. One possibility could be remaining neutrons. Simulations [15] would give a rate of only $\sim 10^{-5}$ per kg-day and therefore much less than the few observed events. A possibility could be that during the run a weak spot in the neutron shielding above the muon veto was identified and patched only after data taking was completed. Another conceivable source for neutrons could be some non-operational modules which were present during the run. These can act as non-vetoable neutron sources for the operational modules. However, an estimate for the background events from an inactive detector module is well below 1.4×10^{-5} per kg-day. Apart from neutrons, another possibility arises from incomplete coverage of the inner surfaces of the detector module with scintillator, which could lead to unvetoed nuclear recoils from surface α-decays [16]. Therefore, it is now planned to paint some possibly uncovered areas (e.g. springs that hold the $CaWO_4$ crystals) with scintillating material.

Concerning the impact of muons, estimates [15] of muon-induced neutrons in the setup result in only 2.8×10^{-3} per kg-day. No muon signals were found in coincidence with nuclear recoil events.

In conclusion no satisfactory explanation for the few candidate events from conventional radioactive or particle sources can be given. Further work such as the enhancement of the reflective cavities is underway to clarify this issue.

Conclusions.- New elements of the CRESST-II apparatus were installed and operated. CRESST-II successfully completed its commissioning run in 2007. Data were taken with two detector modules for a total of ∼48 kg-days. Three candidate events of uncertain origin are present in the acceptance region for tungsten recoils, yielding a rate of 0.063 per kg-day. A factor of ∼ 10 improved performance is found with respect to previous work for the "all nuclear recoils" acceptance region. A limit on coherent WIMP-nucleon scattering, is obtained, which at its lowest value, assuming $M_{\mathrm{WIMP}} \approx 60$GeV, is 4.8×10^{-7} pb.

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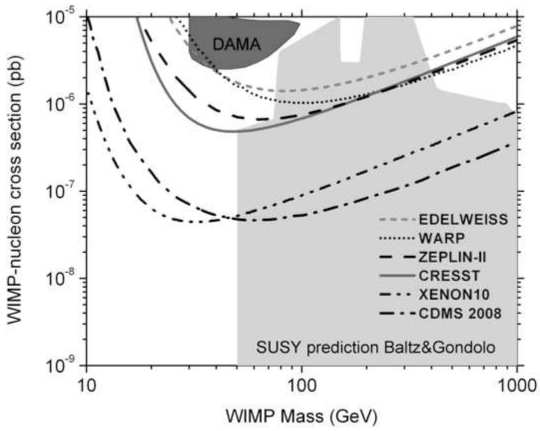

Figure 4: Coherent or spin-independent scattering cross section exclusion limit derived from the data of Fig. 3 using the maximum energy gap method. For comparison the limits from other experiments [2],[11],[12], [3],[13] and the range predicted by some supersymmetry models [14] are also shown.