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Update of the Proposal to the LNGS for a Second Phase of the CRESST Dark Matter Search

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Contents

1 CRESST and the Dark Matter Problem

The goal of the CRESST project is the direct detection of elementary particle dark matter and the elucidation of its nature. The search for Dark Matter and the understanding of its nature remains one of the central and most fascinating problems of our time in physics, astronomy and cosmology. There is strong evidence for it on all scales, ranging from dwarf galaxies, through spiral galaxies like our own, to large scale structures. The history of the universe is difficult to reconstruct without it, be it big bang nucleosynthesis [1] or the formation of structure [2].

The importance of the search for dark matter in the form of elementary particles, created in the early stages of the universe, is underlined by the recent weakening of the case for other forms such as MACHOS, faint stars and black holes [3]. Particle physics provides a well motivated candidate through the assumption that the lightest supersymmetric (SUSY) particle, the "neutralino", is some combination of neutral particles arising in the theory and it is possible to find many candidates obeying cosmological and particle physics constraints. Indeed, SUSY models contain many parameters and many assumptions, and by relaxing various simplifying assumptions one can find candidates in a wide mass range [4]. Generically, such particles are called WIMPS (Weakly Interacting Massive Particles), and are to be distinguished from proposals involving very light quanta such as axions. WIMPS are expected to interact with ordinary matter by elastic scattering on nuclei and all direct detection schemes have focused on this possibility.

Conventional methods for direct detection rely on the ionization or scintillation caused by the recoiling nucleus. This leads to certain limitations connected with the relatively high energy involved in producing an ionization and with the sharply decreasing efficiency of ionization by slow nuclei. Cryogenic detectors use much lower energy excitations, such as phonons, and while conventional methods are probably close to their limits, cryogenic technology can still make great improvements. Since the principal physical effect of a WIMP nuclear recoil is the generation of phonons, cryogenic calorimeters are well suited for WIMP detection and, indeed, the first proposals to search for dark matter particles were inspired by early work on cryogenic detectors [5]. Further, as we shall discuss below, when this technology is combined with charge or light detection the resulting background suppression leads to a powerful technique to search for the rare nuclear recoils due to WIMP scatterings.

2 Present Status of CRESST

The task set for the first stage of CRESST was to show the operation of four 262 g sapphire detectors with an energy resolution of 200 eV at 1 keV and a threshold of 500 eV under low background conditions [7]. Meeting this goal involved two major tasks:

- The development of massive, low background detectors with low energy thresholds and
- the setting up of a low background, large volume, cryogenic installation.

2.1 Detector Development

The detectors developed by the CRESST collaboration consist of a dielectric crystal, in which the particle interaction takes place, and a small superconducting film evaporated onto the the surface, serving as a thermometer. The device is operated within the superconducting-to-normal transition of the thermometer, where a small temperature rise ΔT of the thermometer leads to a relatively large rise ΔR of its resistance. The ΔT induced by a particle is usually much smaller than the width of the transition, which leads to an approximately linear relation between ΔT and ΔR. The resistance of the film ($\sim$0.1 Ω) is measured by passing a constant current through a circuit in which the strip is in parallel with a small ($\sim$0.05 Ω) resistor and the pickup coil of a SQUID. A rise in the film resistance is then measured via the current rise through the SQUID input coil.

To a good approximation, the high frequency phonons created by an event do not thermalize in the crystal before being directly absorbed in the superconducting film [6]. Thus the energy resolution is only moderately dependent on the size of the crystal, and scaling up to large detectors is feasible. The high sensitivity of this system also allows us to use a small separate detector of the same type to see the light emitted when the absorber is a scintillating crystal.

The detectors employed in the first series of runs in Gran Sasso used tungsten (W) films and 262 g sapphire (Al_2O_3) absorbers, running near 15 mK. In the upgrade currently in progress in connection with the move of the installation the scintillating crystal $CaWO_4$ will be used. It is important for the following, however, to realize that the technique can in fact be applied to a variety of materials.

2.1.1 Sapphire Detectors

The 262 g sapphire detectors were developed by scaling up a 32 g sapphire detector [8]. Due to optimized design, and because of the non-thermalization of the phonons, this scaling-up could be achieved without loss in sensitivity, in agreement with expectations. These sapphire CRESST detectors have the best energy resolution per unit mass of any cryogenic device now in use. Figure 1 shows the spectrum of an X-ray fluorescence source measured with a 262 g CRESST sapphire detector, showing an energy resolution of 133 eV at 1.5 keV.

Figure 2 shows a 262 g sapphire detector mounted in its copper housing. The $4\times4\times4.1$ cm^3 crystal rests thermally insulated on sapphire balls (see discussion on sapphire balls in next paragraph). Some of the balls are loaded with plastic springs. Thermal contact between the holder and the detector is provided by 20μ Au wires bonded between a Au pad in the middle of the W thermometer and the Cu holder. The electrical connection is established by superconducting Al wires bonded from Al pads on both ends of the thermometer to isolated contact pads on the holder. To avoid radioactive solder joints the superconducting wires connecting the thermometer to the readout circuit are screwed to the contact pads. A Au wire bonded between small Al contact pads on the sapphire crystal and the Au pad in the center of the W thermometer (too small to be clearly visible) serves as a heater to control the temperature of the detector. It is additionally usesd to inject electrical heater pulses for monitoring the long term stability of the energy calibration and for measuring the trigger

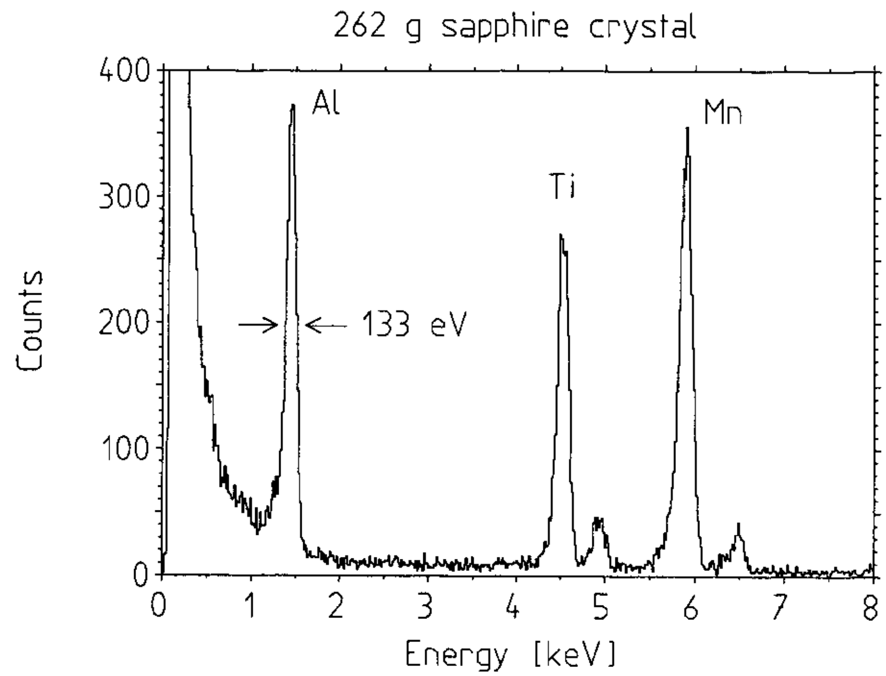


Figure 1: Pulse height spectrum of a 262 g detector with an X-ray fluorescence source installed inside the cold box to provide the X-ray lines of Al, Ti, and Mn. The large background towards lower energies, which was not present in earlier spectra [15], is attributed to damage later noticed to the thin Al sheet meant to absorb Auger electrons from the source.

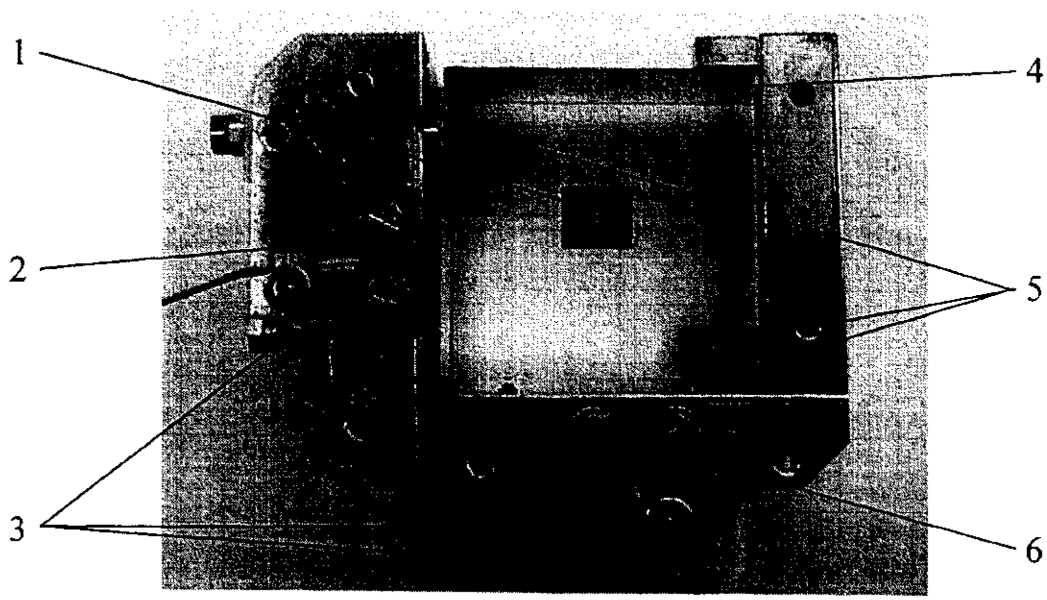


Figure 2: Picture of a 262 g sapphire detector. (1) Tungsten thermometer. (2) Holder pads with screw contacts for connecting to the heater circuit. (3) Plastic springs. (4) Sapphire crystal. (5) Sapphire balls. (6) Holder pads with screw contacts for connecting to the SQUID read-out circuit.

efficiency close to threshold.

In the runs of early 2000 the origin of the vexing high level of noise signals reported previously was finally identified. It turned out the signals were due to the spontaneous formation of microscopic cracks under the great pressure between the crystal and the sapphire balls. Due to the extremely small contact area of the balls an excessive pressure resulted from the forces needed to tightly hold the crystal. As soon as the balls were replaced by plastic stubs, which have a larger contact area with the crystal, the background of spurious signals completely disappeared. The use of these stubs did not lead to a noticable loss of sensitivity, despite their larger contact area.

2.1.2 Phonon/Light Detectors

As explained more in detail below, great improvements in sensitivity are possible if the detector is capable of distinguishing the electron-photon background from the nuclear recoil signals. To this end a program of development of detectors with scintallation light output in addition to the thermal signal has been underway. As reported earlier [9, 10], test results were very encouraging. In the year 2000 we developed a prototype of a 300 g detecotor module, which will be the basis of the 10 kg detector for the second phase of CRESST.

2.2 Present CRESST Installation

The central part of the CRESST low background facility at the LNGS is the cryostat. The design of this cryostat had to combine the requirements of low temperatures with those of low background. The first generation cryostats in this field were conventional dilution refrigerators where some of the materials were screened for radioactivity. However, due to cryogenic requirements some non-radiopure materials, for example stainless steel, cannot be completely avoided. Thus for a second generation low background cryostat, the design shown in fig. 3 was chosen, in which a well separated "cold box" houses the experimental volume at some distance from the cryostat. The experimental volume can house up to 100 kg of target mass. The cold box is made of low background copper, with high-purity lead used for the vacuum seals. It is surrounded by shielding consisting of 14 cm of low background copper and 20 cm of lead. Special consideration was given to the space between the dilution refrigerator and the cold box. The separation was chosen large enough so that the "neck" of the external shielding, together with the internal shields, eliminates any direct line of sight from the outside world into the cold box. The low temperature of the dilution refrigerator is transferred to the cold box by a 1.5 meter long cold finger protected by thermal radiation shields, all of low background copper. A 20 cm thick lead shield inside a copper can is placed between the mixing chamber and the cold finger, with the low temperature transmitted here by the copper can. This internal shield, combined with another one surrounding the cold finger, serves to block any line of sight for radiation coming from the dilution refrigerator into the experimental volume.

To avoid activation of the copper by cosmic rays we minimized the amount of time that the copper of the shielding and the cold box spent above ground. After the electrolytic

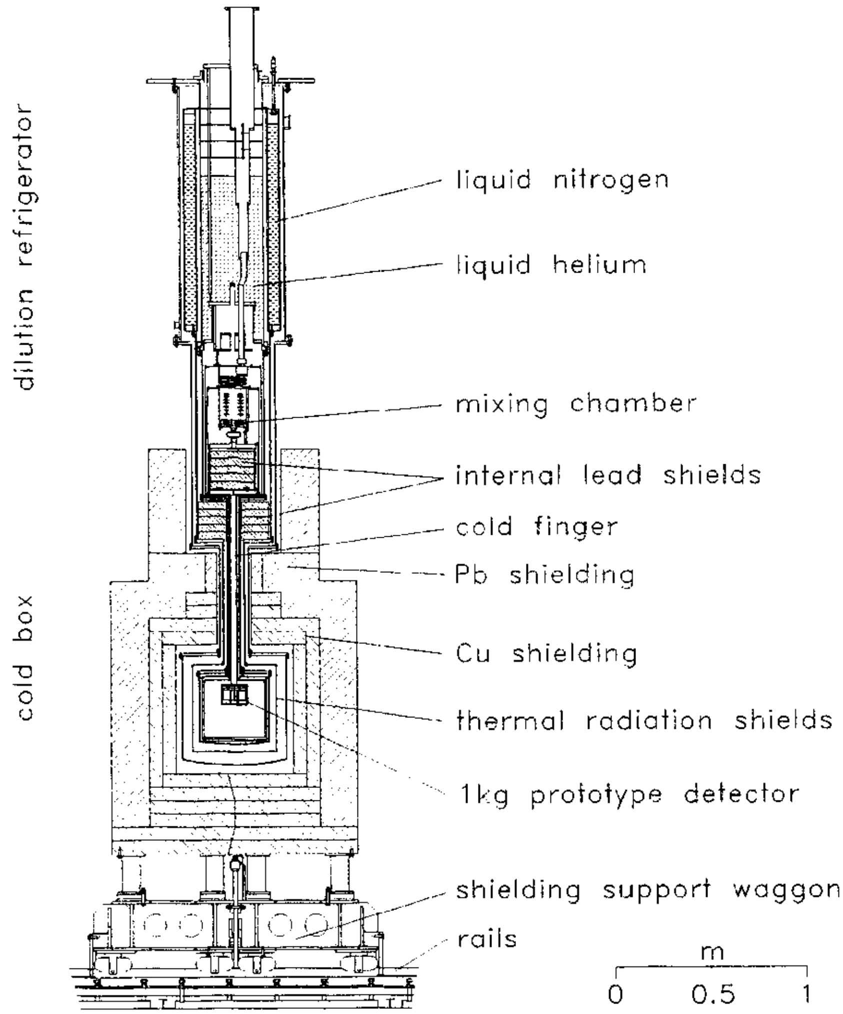


Figure 3: Layout of dilution refrigerator and cold box.

production the copper was placed in the cellar of a beer brewery near Munich, where it was shielded from cosmic rays by more than 10 m water equivalent. This reduces the hadronic component of the cosmic rays by a factor of about 500. Each piece was only brought out of the brewery cellar for the few days needed for its machining, and then returned to the cellar. Including the time spent for machining, the total above-ground exposure of the copper was about 10 weeks.

It is not sufficient to use high-purity materials. Their surfaces must also be kept clean during use, and we have taken care to design our facilities in Gran Sasso to make this possible. The Faraday cage which surrounds the experiment was chosen large enough so that all work on the low-background components of the experiment can be performed inside the cage. The cage is divided into two levels. The lower level is equipped as a clean room with a measured clean room class of 100 to protect the low-background components. The external lead and copper shields are in two closely fitting halves, each supported on a "wagon" so that the shielding can be opened without handling the individual pieces. The entire shielding is enclosed in a gas-tight Radon box that is flushed with N_2 and maintained at a small overpressure. In its retracted position (shown in fig. 4) the shielding is outside the dilution refrigerator support

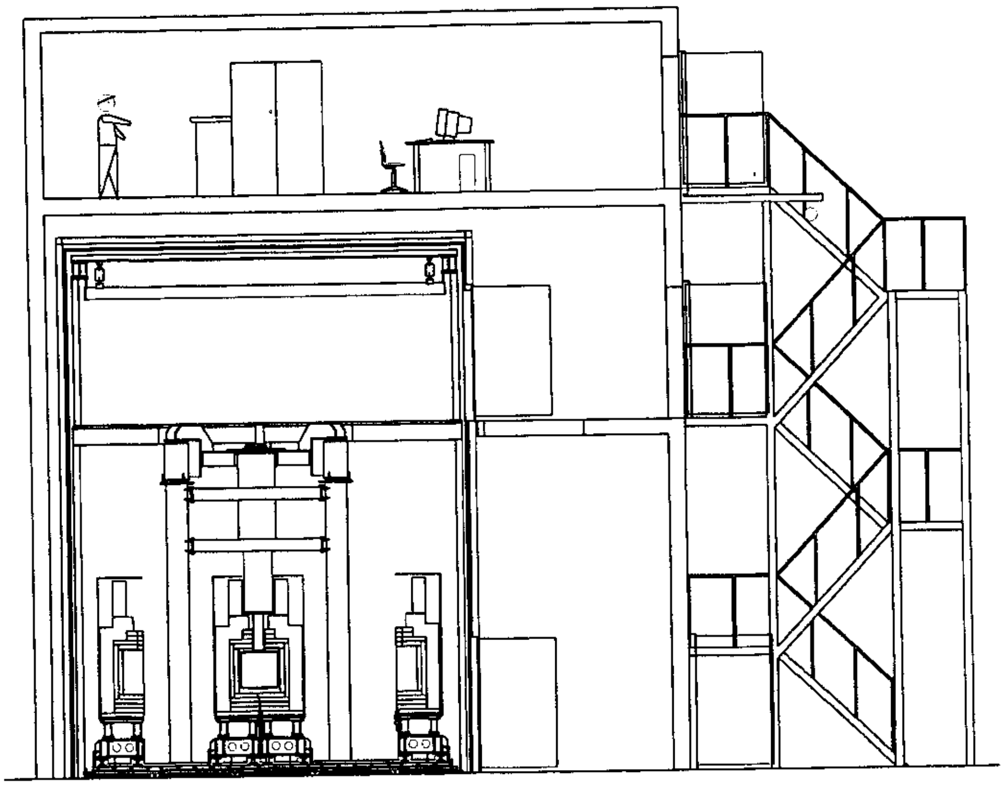


Figure 4: Cross section of CRESST building in Hall B.

structure but still inside the clean room and sufficient room is then available to disassemble the cold box .

Entrance to the clean room is through a changing room external to the Faraday cage (not shown in fig. 4). The upper level of the Faraday cage is outside the clean room and allows access to the top of the cryostat for servicing and to the electronics. To save on floor space in Gran Sasso, the counting room and a laminar flow work space for handling the detectors is placed on top of the Faraday cage. All of this equipment is inside a building in Hall B.

The installation in Hall B was completed at the end of 1998, when the prototype cold box of normal copper was replaced by a radiopure version of the same design. The purpose of the prototype cold box was to test the cryogenic functioning of the design and to provide a well shielded environment for completing the development of the 262 g detectors. After machining, the new low background cold box was cleaned by electropolishing and subsequent rinsing with high purity water. The pieces were then brought to Gran Sasso in gas tight transport containers made of PE and flushed with nitrogen.

During 1999, a series of first measurements with four 262 g detectors under low background conditions was performed in the new cold box. The measured background was by far to high and not caused by radioactivity. The origin of this background was investigated in a series of runs during the year 1999 and finally traced back to the spontaneous formation of microscopic cracks in the sapphire crystal at the points where it was supported by sapphire balls. Due to the extremely small contact area of the balls an excessive pressure resulted from the forces needed to tightly hold the crystal. As soon as the balls were replaced (spring 2000) by plastic stubs with a larger contact area, the background of spurious signals completely disappeared.

2.3 Results with Sapphire Detectors

To study the background and obtain first dark matter limits, several runs were performed in 2000, with the longest one lasting for about 3 months. The high reliability, long term stability and uptime during these runs demostrated convincingly that the system fulfills the demands of the next phase of CRESST.

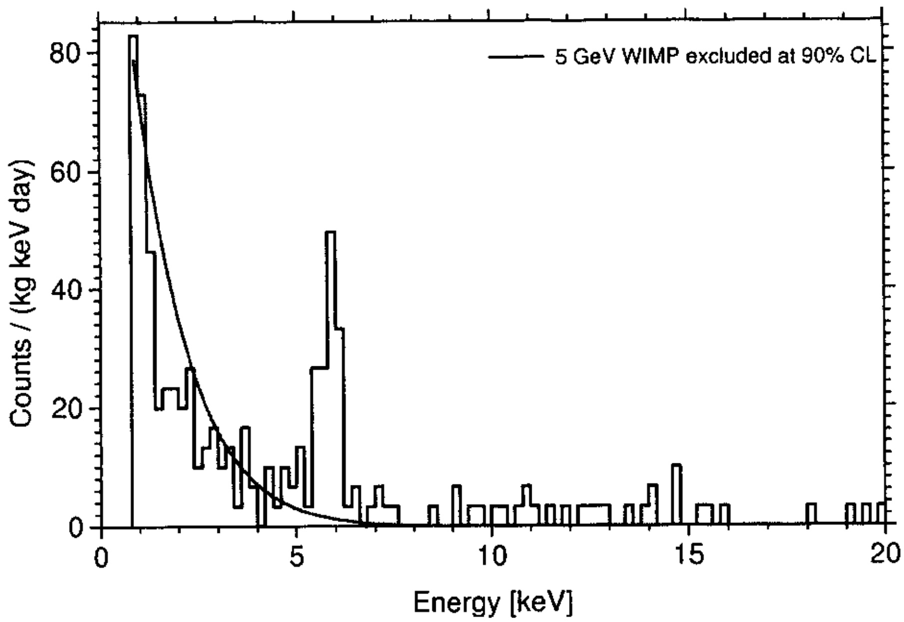


Figure 5: Background spectrum (1.51 kg days) from a 262 g sapphire detector. For illustration a 5 GeV WIMP excluded at 90 % C.L. is shown.

In Fig.5 we show the spectrum from one of the detectors. In the energy range from 15 to 20 keV there are 7 counts which translate into a background of (0.93 $\pm$ 0.35) counts/kg/keV/day in this range. The background drops to about 0.2 counts/kg/keV/day around 100 keV. The stability of the energy calibration and the trigger efficiency close to threshold was continuously monitored by periodic injection of heater pulses covering the whole dynamic range of the detector. A trigger efficiency of 100 % was measured down to an energy of 580 eV. For a software threshold above 800 eV the events follow a perfect poissonian time distribution. The spectrum shows a peak at 5.9 keV with (7.0 $\pm$ 1.2) counts/day. The position of the peak suggests a cointamination with Fe^{55} in the surrounding of the crystal. Fe^{55} emits Mn X-rays at 5.9 keV and no γ's and was previously used as a source for characterizing the performance of the detectors. The spectra measured with the other detectors are very similar with nearly the same count rates in both, the peak and the continuous part of the spectrum.

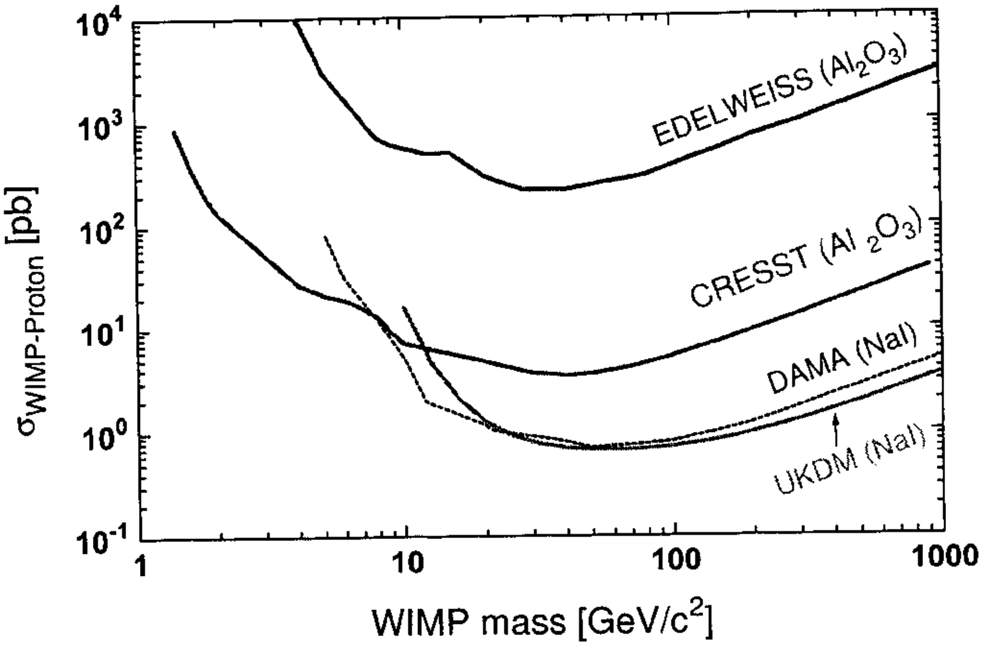


Figure 6: Equivalent WIMP-proton cross section limits (90% C.L.) for spin-dependent interaction as a function of the WIMP mass form 1.51 kg days exposure of a 262 g sapphire detector. A software threshold of 800 eV was used in the analysis. For comparison limits for spin dependent interaction from the EDELWEISS dark matter search with cryogenic sapphire detecors [11], from the DAMA [12] and the UK dark matter searches [13] with NaI detectors are also shown.

In Fig. 6 we show the WIMP exclusion plot based on the data in Fig. 5. For illustration a 5 GeV WIMP excluded at 90 % C.L. is shown in Fig. 5.

3 The second phase of CRESST

3.1 The New Detector Concept

Passive techniques of background reduction – deep underground site, efficient shielding against radioactivity of surrounding rocks and use of radiopure materials inside the shielding– are of course imperative in WIMP Dark Matter searches. However, there is a remaining background dominated by β and γ emissions from radioactive contaminants inside the detectors and its surrounding. These produce exclusively electron recoils in the detector. In contrast WIMPs, and of course also neutrons, lead to nuclear recoils. Therefore, dramatic improvements in sensitivity can be achieved if, in addition to the usual passive shielding, the detector itself is capable of distinguishing electron recoils from nuclear recoils and rejecting them.

A particle interaction in a scintillating crystal produces mainly phonons and scintillation light. Low energy nuclear recoils create much less scintillation light than electron recoils of the same energy. Thus a measurement of the energy branching between scintillation light and phonons has the potential to clearly distinguish between nuclear and electron recoils. Our new detector concept exploits this possibility.

In Munich we have developed and are improving detectors using $CaWO_4$ scintillating crystals as the absorber where the scintillation light is measured in parallel to the phonons. In this detector a large calorimeter with the scintillating absorber crystal is placed next to a second small calorimeter which serves as a light detector. Both the absorber and the separate light detector are instrumented with W phase transition thermometers.

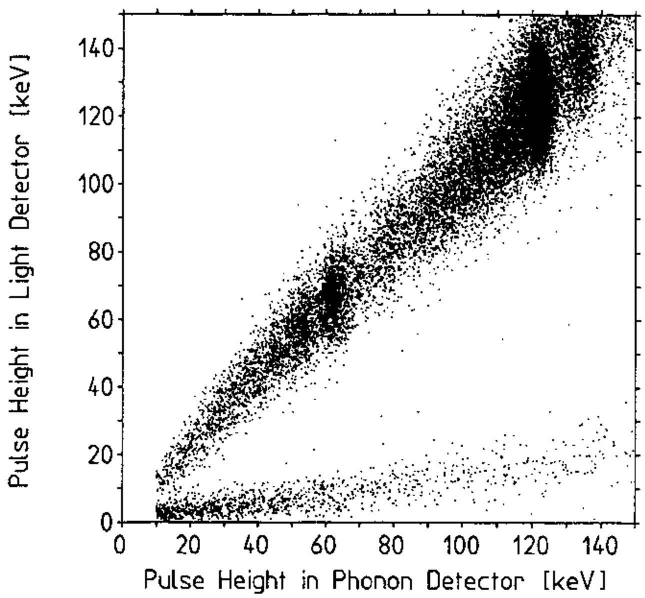


Figure 7: Pulse height in the light detector versus pulse height in the phonon detector measured while the detector was irradiated with photons, electrons and neutrons. The lower band is caused by neutron induced nuclear recoils, the upper band by electron recoils from β's and γ's

Figure 7 shows a scatter plot of the pulse height in the phonon detector versus the pulse height in the light detector, recorded with a test detector when it was irradiated with photons, electrons and neutrons. The plot shows two well separated bands. The lower band is caused by neutron induced nuclear recoils while the upper band is caused by electron recoils induced by γ's and β's. As explained in more detail in the appendix, this allows a rejection of photon and electron events with an efficiency of better than 99.7 % for nuclear recoil energies above 15 keV.

While this method is analogous to the simultaneous measurement of ionization (charge) and phonons used by other groups, it has the important advantage not to suffer from the "dead layer" problem. With charge measurement, an incomplete collection of the charges from events near the surface of the crystal may lead to a misidentification of electron recoils as nuclear recoil [16]. Our result shown in fig. 7 was obtained by a simultaneous irradiation with photons *and* electrons. There is no visible difference between electron recoils at the surface and in the bulk.

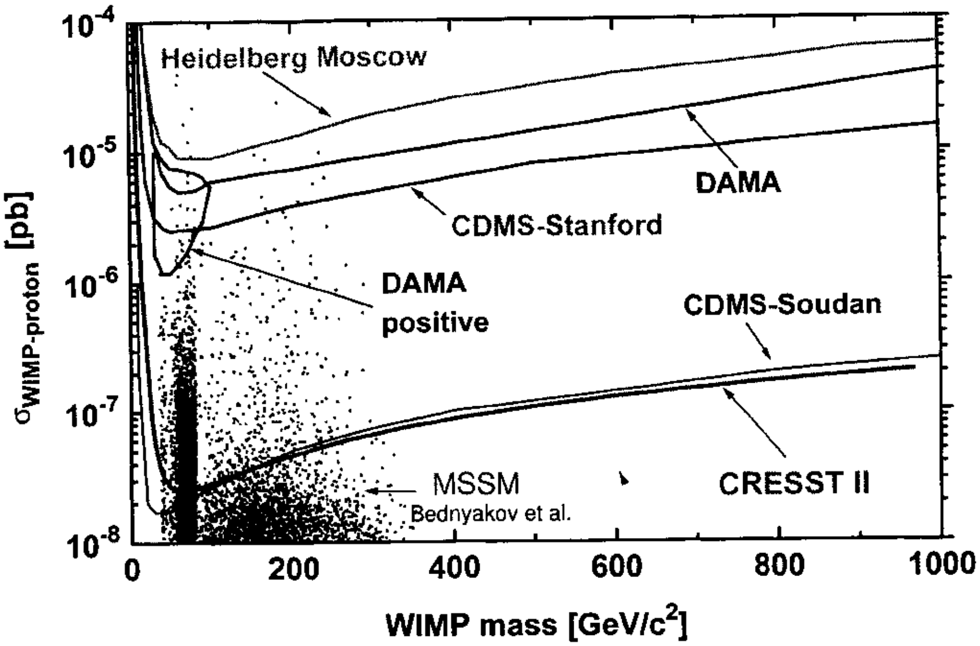


Figure 8: WIMP-nucleon cross section limits (90% CL) for scalar (coherent) interactions as a function of the WIMP mass, expected for a 10 kg $CaWO_4$ detector with a background rejection of 99.7% above a threshold of 15 keV detector and 3 years of measurement time in the CRESST set-up in Gran Sasso. For comparison the limit from the Heidelberg-Moscow ^{76}Ge experiment [18], the DAMA NaI limits [17] (with the contour for positive evidence [23]), the CDMS Stanford limit [20] and the projection for CDMS Soudan [21] is also shown. The dots (scatter plot) represent expectations for WIMP-neutralinos calculated in the MSSM framework with non-universal scalar mass unification [19]

For the second phase of CRESST we propose to install this new type of detector with a total mass of about 10 kg. It will consist of 33 modules each based on a 300 g $CaWO_4$ crystal. All modules will fit easily in the present cryostat. However the number of SQUID readout channels has to be upgraded to 66. Additionally we plan to install an external muon veto and a passive neutron shield.

3.2 Expected Performance

The second phase detectors with light-assisted background suppression will have target nuclei of large atomic number such as tungsten, making them particularly sensitive to the coherent interaction of WIMPs. Here the WIMP cross section profits from a large coherence factor of the order A^2, (A = number of nucleons). Combined with the strong background rejection, this makes these detectors particularly sensitive to low WIMP cross sections.

Figure 8 shows the expected sensitivity of the second phase. The curve is based on a background rate of 1 count/(kg keV day), an intrinsic background rejection of 99.7 % above a recoil threshold of 15 keV, and an exposure of 30 kg years. For comparison present experimental limits from the Heidelberg-Moscow ^{76}Ge-diode experiment [18], the DAMA NaI experiment

[17], the CDMS experiment at Stanford [20] , and the projected sensitivity of CDMS at the Soudan mine[21] are also shown together with the contour for positive evidence [23] from the DAMA experiment. It is interesting to note that the CDMS Stanford result was obtained with a cryogenic detector within an exposure of only 10.6 kg days. This detector, which has an excellent background rejection, a mass of only a few hundred grams, and is operated at a shallow underground site, can nevertheless compete with conventional detectors three orders of magnitude larger and running for periods of several years deep underground. This clearly shows how cryogenic detectors with good background discrimination are well adapted to the requirements of Dark Matter searches.

In a 10 kg $CaWO_4$ detector, 60 GeV WIMPs with the cross section claimed in [23] would give about 46 counts between 15 and 25 keV within one month. A background of 1 count/(kg keV day) suppressed with 99.7% would leave 9 background counts in the same energy range. A 10 kg $CaWO_4$ detector should allow a test of the reported positive signal with 1 month of measuring time.

3.2.1 CRESST in the case of a positive signal

In addition to improving limits on dark matter, it is important to have means for the positive verification of a dark matter signal as well as for the elucidation of its nature. Once a dark matter signal is suspected, it can be verified by CRESST through the following effects.

- Varying the mass of the target nucleus leads to a definite shift in the recoil energy spectrum. For example, in the case where the WIMP is substantially lighter than the target nucleus, the recoil *momentum* spectrum has an unchanged shape from nucleus to nucleus. Hence there is a simple rescaling of the recoil energy spectrum. The observation of the correct behaviour will greatly increase our confidence in a positive signal. Here the significant advantage of the CRESST technology, that it can be applied to different target materials, comes into play. In this context, the wide variety of materials that may be used for simultaneous light and phonon measurement is extremely important. We have already measured the relative scintillation efficiencies of $CaWO_4$, $PbWO_4$, BaF and BGO crystals at low temperatures and found similarly encouraging results for all materials.
- Another verification of a dark matter signal is to be expected through an annual modulation of spectral shape and rate, which results from the motion of the earth around the sun. With efficient active background rejection, even a 10 kg $CaWO_4$ detector may be large enough to reach a significant statistical accuracy. However, this method requires an extremely good long term stability of the detectors.
- Given the detection of a dark matter particle, an important task will be to determine its nature, e. g. for SUSY the gaugino and higgsino content, which gives rise to different strengths of the spin-dependent interaction. Significant steps in this direction can be taken by using different target materials (see e.g. fig. 24 in ref. [4]).

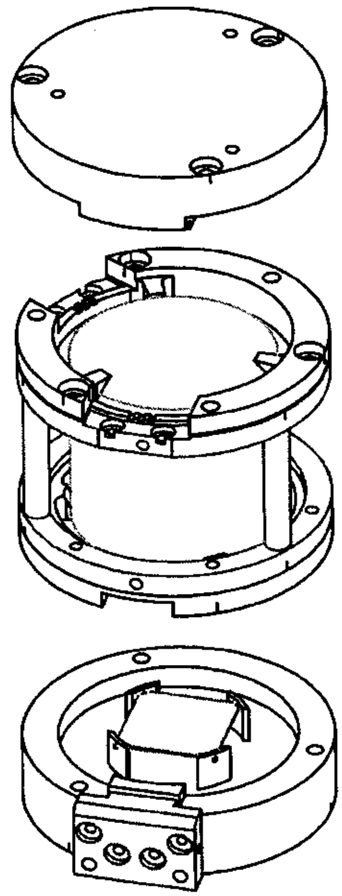


Figure 9: 300 g phonon+light detector module.

3.3 Detector Design

A 300 g $CaWO_4$ phonon and light detector system is presently being developed in Munich. We have demonstrated (see appendix) good light collection with such a 300 g crystal, sufficient to realize a prototype detector. A first test of a 300 g prototype detector with W-thermometer is in the CRESST setup at LNGS is in progress. A second module with an Ir/Au-thermometer is being tested in Munich. Such a 300 g $CaWO_4$ light+phonon detector will then be the basic module of the new detector.

Figure 9 shows a single 300 g module. One flat face of the cylindrical 300 g $CaWO_4$ crystal (both diameter and height 40 mm) carries a W superconducting phase transition thermometer. This crystal is mounted together with the light detector inside a highly reflective housing made of specularly reflecting plastic foil and of diffusive reflecting Teflon endcaps. The light detector consists of a $20 \times 20 \times 0.4$ mm^3 sapphire substrate with a small W thermometer evaporated onto one side. The other side of the substrate is covered by sputter deposited Si to improve the light absorption. The 300 g modules will be mounted in detector planes which will hold 17 modules. For the 10 kg detector of the second phase two such planes will be stacked.

We have already studied the intrinsic radioactivity in a 300 g $CaWO_4$ crystal with a low background Ge-detector at LNGS. No contamination was found. The detection limits correspond to 20 counts/(kg keV day) for the thorium chain and 1.6 counts/(kg keV day) for the uranium chain in the energy region relevant for the WIMP dark matter search. The high γ absorption coefficient of $CaWO_4$ makes a further improvement of these detection limits rather difficult.

3.4 Detector Fabrication and Test

Fabrication of the 33 detector modules will take place during 2001 and 2002. To ensure optimum quality of all $CaWO_4$ crystals the scintillation properties of each crystal will be routinely checked in Oxford. Both the light output and the spectrum will be measured at low temperatures. The 300 g detector modules will then be fabricated at the MPI using these tested crystals.

Before shipping the modules to Gran Sasso their performance will be checked in the recently installed dilution refrigerator in the shallow underground site of the TUM group at Garching. This site will also be used for storing detector components between fabrication steps. During 2002 these modules will be shipped to Gran Sasso as they become available. The mounting will be done in larger groups to minimize downtime.

4 Planning, Resources and Timeline

4.1 Planning of the Move within Gran Sasso

To free Hall B for the new long baseline neutrino experiments, CRESST has to move to another location in Hall A. At the same time we will carry out a major upgrade of the experiment, including installation of the new type of thermal/scintillating detectors, substantially more detector mass, neutron shielding, and a muon veto.

In order to avoid a severe delay in the experimental program of CRESST with respect to the competing projects it is necessary that this move be performed in a fast and efficient manner. Critical in this respect is the availability of the experimental building, ready at the new location before the start of the move.

This is proceeding in a timely manner and we would like to thank the LNGS for the excellent cooperation in this. If the new building is ready at the end of February, CRESST will leave Hall B in four months.

A detailed timeline is shown on the next page. Major milestones are:

- Completion of the new experimental building at the end of February 2001.
- Present building in Hall B empty and ready for dismounting at the end of June 2001.

- Experimental setup in Hall A operational at the end of 2001.

With this schedule, the interruption of data taking will be limited to one year and the experiment can be restarted early in 2002. Funding for a major prerequisiste for the move, a new Faraday cage, was provided for by the Max-Planck-Institute in 2000. As mentioned, the LNGS has been proceeding effectively with the construction of the new building and we look forward to its help with the further logistics of the move.

4.2 Planning and Investments for the Second Phase of CRESST

To reach a mass of 10 kg with the new detector an increase in the number of readout channels to 66 is needed. This is possible with the existing cold box and cryogenics, so that the major costs are the provision of new SQUIDs, data acquisition modules and electronics. The cost of a 66 channel SQUID system at present prices will be on the order of 800 k Euro. The responsibility for the SQUID system will be shared between Oxford and TUM. The electronics consists of specialized modules such as fan out boxes for the wiring, thermal feedback controllers, and current sources for biasing the detectors . These will be fabricated in the workshop of Oxford University, with material costs of about 80 k Euro.

The data acquisition arrangement will be be based on commercial VME-modules and on specialized ones built at the MPI workshop, with a cost of about 165 k Euro.

The neutron shielding, consisting of 60 cm of polyethylene, will be provided by the Technical University. Anticipated costs are 75 k Euro. For the recently installed dilution refrigerator in the shallow underground site at Garching the TUM group has invested 200 k Euro. This cryostat will be used for testing the new detector modules before shipping them to Gran Sasso.

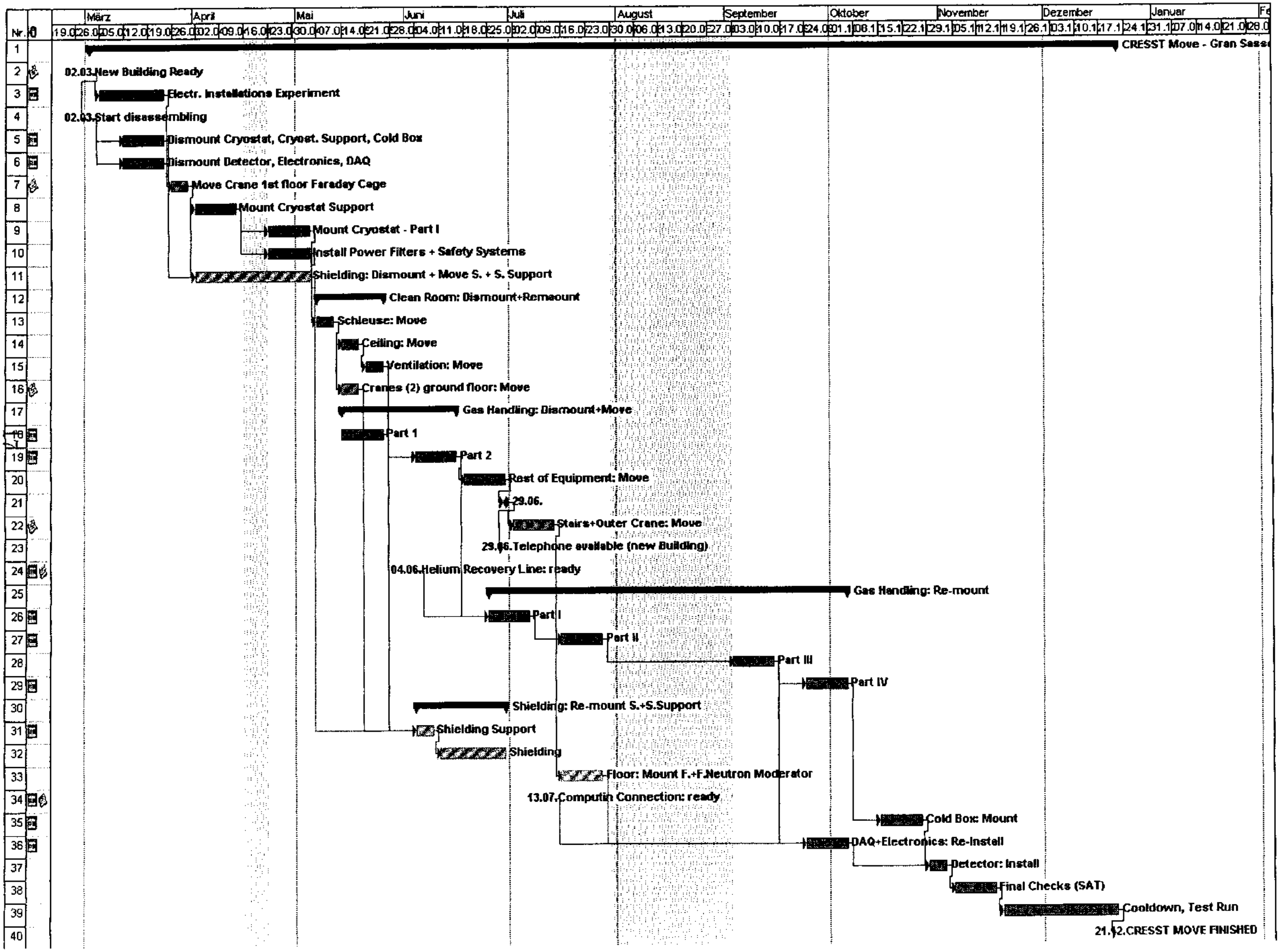
The cost for 10 kg of $CaWO_4$ crystals will be on the order of 165 k Euro at present prices and will be shared between MPI and TUM/SFB.

The investments and responsibilities for the upgrade to the second phase of CRESST are summarized in table 1.

As the result of a number of positive developments in the last year, the future basis of the CRESST project may now be regarded as assured.

These developments include:

- Approval of the second phase of CRESST by the Board of Directors at the Max-Planck-Institute after an internal review process.
- Availability of funding for the project up to Euro 750 K Euro at Oxford.
- Extension of the Munich "SFB Astroparticle Physics" until the end of 2003 after a review by the *Deutsche Forschungsgemeinschaft*. This signifies 85 K Euro set-up funding and yearly support of 100K Euro .



März
April
Mai
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November
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Nr.
CRESST Move - Gran Sasso
02.03.New Building Ready
Electr. Installations Experiment
02.03.Start disassembling
Dismount Cryostat, Cryost. Support, Cold Box
Dismount Detector, Electronics, DAQ
Move Crane 1st floor Faraday Cage
Mount Cryostat Support
Mount Cryostat - Part I
Install Power Filters + Safety Systems
Shielding: Dismount + Move S. + S. Support
Clean Room: Dismount+Remount
Schleuse: Move
Ceiling: Move
Ventilation: Move
Cranes (2) ground floor: Move
Gas Handling: Dismount+Move
Part 1
Part 2
Rest of Equipment: Move
29.06.
Stairs+Outer Crane: Move
29.06.Telephone available (new Building)
04.06.Helium Recovery Line: ready
Gas Handling: Re-mount
Part I
Part II
Part III
Part IV
Shielding: Re-mount S.+S.Support
Shielding Support
Shielding
Floor: Mount F.+F.Neutron Moderator
13.07.Computin Connection: ready
Cold Box: Mount
DAQ+Electronics: Re-Install
Detector: Install
Final Checks (SAT)
Cooldown, Test Run
21.12.CRESST MOVE FINISHED

Table 1: Investments (k Euro) and responsibilities for the upgrade

		2000	2001	2002	2003
Faraday cage in hall A	MPI	80			
testing of SQUIDs	Oxford	40			
SQUID system	Oxford		725		
SQUID system	TUM/SFB		135		
electronic modules/interfaces	Oxford		80		
data acquisition modules	MPI		85	80	
neutron shield	TUM/SFB			75	
muon veto	TUM/SFB				100
$CaWO_4$ crystals	MPI	30	20	40	
$CaWO_4$ crystals	TUM/SFB		50	25	
clean room detector fabrication	MPI		80		
costs for move	MPI		100		

- The creation of a new federal funding program "astroparticle physics" in Germany where CRESST is one of the designated projects. This gives university groups the opportunity to join the project. First discussions with interested university groups are underway.

All these developments may be regarded as indications of a strong potential for the future.

In detail the investments discussed are covered by the running budgets and the funding of the SFB 'Astroparticle Physics indicated in section 4.3, with the exception of the SQUID responsibility taken over by Oxford. The SQUID system will be developed in cooperation with an industrial partner. A funding via PPARC for this cooperation is approved. The total funding of the SQUID system is a joint effort of Oxford and TUM with all contributions approved. Furthermore, the Oxford group has achieved a substantial increase in the experiment's funding for the testing of the SQUIDs and electronic components.

At the Max-Planck-Institute CRESST funding in recent years has been at the level of 300-400 k Euro yearly, with a group consisting of 8-12 physicists. Astroparticle physics has been confirmed as one of the major experimental research directions at the Institute.

The SFB "Astroparticle Physics", is a federally funded research center which includes two Max-Planck-Institutes and the two Munich universities. It supports CRESST as one of its two large experimental projects, and after further reviews may be further extended to 2006. In addition to the investment contribution to CRESST, about two positions are available from the SFB. The support from TUM and SFB includes about four physicists. Similarly, Oxford University's basic level of support includes about five physicists.

Concerning running costs, the pure running costs of the experiment will be approximately 25 k Euro plus 60 k Euro travel per year. However we expect the running be accompanied by continuous improvements in the detectors and shielding. Therefore we estimate 100 k Euro as the effective operating costs per year for the period from 2002 to 2005.

4.3 General Framework and Financing

The LNGS has contributed to the installation of the infrastructure and the running costs of the experiment and provides an engineer dedicated to the cryogenic experiments.

In addition the groups have computing, technical and workshop personnel. A low background underground test facility and a tandem accelerator is available at Garching. Oxford has set up a facility for testing scintillators at low temperature.

In the past the collaboration has invested approximately 1.5M Euro (without salaries) for the installation of CRESST in Gran Sasso. Investments at MPI and TUM in Munich in facilities for detector development for CRESST (UHV thin film deposition and analysis systems, sputter system, clean room, photo lithography equipment, dilution refrigerators, ...) has been at least 3 M Euro over the past 10 years.

Finally, activities in cooperation with the French Edelweiss group have begun. This is in connection with work involving neutrons, both in relation to backgrounds and neutron scattering experiments to be made at the Garching tandem to calibrate the detectors. The TUM invested 250 k Euro for the cryogenic equipment and the EDELWEISS supplied the neutron detection system and the associated electronics. These first steps to cooperate could be the basis of a more extensive collaboration as the growth of the projects require more substantial investments and manpower.

4.4 Timeline

After the move to hal A te experimental set-up will become operational again at the end of 2001. The experiment is scheduled to start running again in early 2002. It will first run with a small number of detectors to confirm that all systems are functioning properly. In parallel with the work in Gran Sasso, the new detectors will be tested in the Munich low background laboratory at Garching. These detectors and the read-out will be mounted as they become available, the mounting being done in large groups to minimize downtime. Extended running periods will begin when the planned capacity is reached. It is planned to accumulate about 30 kg years of data in the four year period foreseen for the second phase of CRESST.

5 Requests to the Gran Sasso Laboratory

We would like to ask the laboratory:

- To approve the second phase of CRESST through 2005.
- To complete the new experimental building at the new location in a timely fashion and to provide further logistical support during the move.
- To dismount the experimental building in Hall B after the collaboration has moved out.

6 Safety

Concerning safety issues, the next phase of CRESST will not introduce any additional safety risks. In general the safety and environmental risks involving CRESST are fairly low. CRESST does not use any highly flammable or poisonous materials, does not produce waste water or dump heat in the water of the rocks. The only safety issue arises from the use of cryogenic liquids (liquid Helium and liquid Nitrogen). However the amount of cryogenic liquids involved is very small. At the experimental site CRESST uses at maximum about 60 ℓ of liquid Helium (corresponding to about 480 m^3 of gas) and about 200 ℓ of liquid Nitrogen (corresponding to about 1400 m^3 of gas). At the location of the liquefier there is at maximum about 700 ℓ of liquid Helium (corresponding to about 4900 m^3 of gas). Compared to the volume of the Hall and the circulation rate of the ventilation system these values are relatively small and do not imply a significant safety risk. Inside the experimental setup, the CRESST collaboration has installed their own oxygen monitoring and alarm system. The GLIMOS of CRESST is Hans Kraus (Oxford).

7 Appendix

7.1 Light Detection, Proof of Principle

In searches for elementary particle dark matter it is of great advantage to be able to discriminate between electron recoils (caused by photons or by electrons) and nuclear recoils (caused by dark matter candidates and also by neutrons). It is well known that at room temperatures nuclear recoils in scintillators produce much less scintillation light than electron recoils do. Thus the combination of a scintillator, measuring light, and a cryogenic detector, essentially measuring total energy, can discriminate between nuclear and electron recoils by using the ratio of light to thermal output. We have investigated the light output of several scintillators at mK temperatures, concentrating on inorganic intrinsic scintillators since their scintillation efficiency usually increases at lower temperatures. All scintillators so far tested (BGO, BaF_2, $PbWO_4$, $CaWO_4$) appear to function adequately at mK temperatures. Since the scintillation effect in tungstates is connected to the WO4-Ion, presumably also other tungstates may work. Molybdates are also promising candidates.

The arrangement used in a test setup for simultaneous light/ phonons detection is shown schematically in Fig. 10. (Note the arrangment planned for the experiment incoporates certain improvements and is different in a number of points, see text and Fig.9). It consists of two independent detectors. Each one is of the CRESST type: a tungsten superconducting phase transition thermometer with SQUID readout. The main crystal or absorber scintillates at low temperature and a similar but smaller detector is placed next to it to detect the light. In our tests both detectors were operated near 12mK. The scintillating absorber was a 6 g $CaWO_4$ crystal. The light detector was a sapphire wafer, coated with silicon on one side to enhance light absorption. For the tests the $CaWO_4$ crystal was irradiated with the 122keV and 136keV photons from a ^{57}Co-Source and simultaneously with the electrons from a ^{90}Sr-Beta-Source, the two sources contributing about equally to the count rate. The photon lines

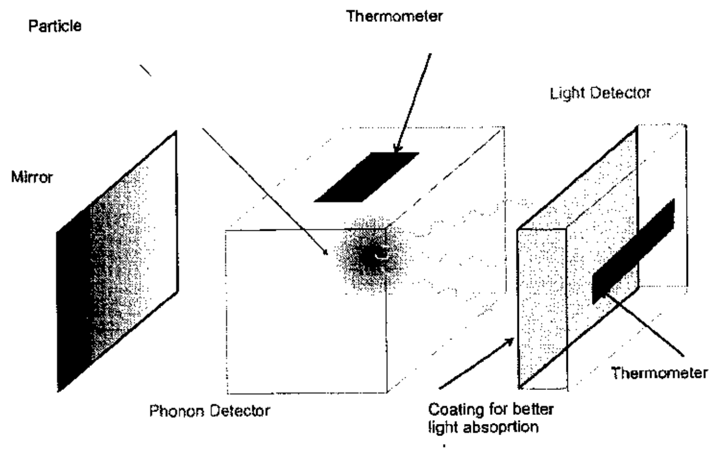

Figure 10: Schematic view of the arrangement used for the simultaneous light and phonon detection

were used for energy calibration (in both detectors). The trigger was given by the phonon detector. The left plot in Fig. 11 shows a scatter plot of the pulse heights observed in the phonon detector versus the pulse height observed in the light detector. The pulse height has been converted to energy using the 122 keV photon peak in both detectors. A clear correlation between the light and phonon signals is observed. In a second test, an additional irradiation with neutrons from an Americium-Beryllium source was introduced (right hand plot). A second line arises, due to neutron-induced nuclear recoils. It is to be observed that electron and nuclear recoils can be clearly distinguished down to a threshold of about 10keV. In Fig. 12 we show a scatter plot in the plane (ratio of pulse height light/ pulse height phonons) versus (pulse height phonons). The lower band in the right plot is caused by nuclear recoils while the upper band with the ratio around 1 is caused by electron recoils. From the two ratios a quenching factor (that is light output electrons/light output nuclear recoil) of 7.4 can be inferred. The leakage of some electron recoils into the nuclear recoil band determines the effectiveness of the electron recoil rejection. If we use a quality factor as defined in ref. [22], a detailed evaluation together with the data without neutrons, as in the left plot of Fig. 12 we find a rejection factor of 98% in the energy range between 10 keV and 20 keV; 99.7% in the range between 15 keV and 25 keV; and better than 99.9% above 20 keV.

Since the device consists of two standard CRESST-detectors, we are confident of being able to produce much larger detectors of similar performance by applying familiar techniques and optimizing the design.

The simultaneous light and phonon measurement has several advantages over the simultaneous measurement of charge and phonons, which is another methodology of the same type. In the measurement of charge and phonons electrical contacts always produce an unfortunate dead layer on the surface, which causes surface events, especially electrons from outside, to leak into the nuclear recoil band. As our measurements with electrons clearly show, this problem does not exist in the light detection.

Furthermore the large quenching factor of the $CaWO_4$ gives a very effective separation of

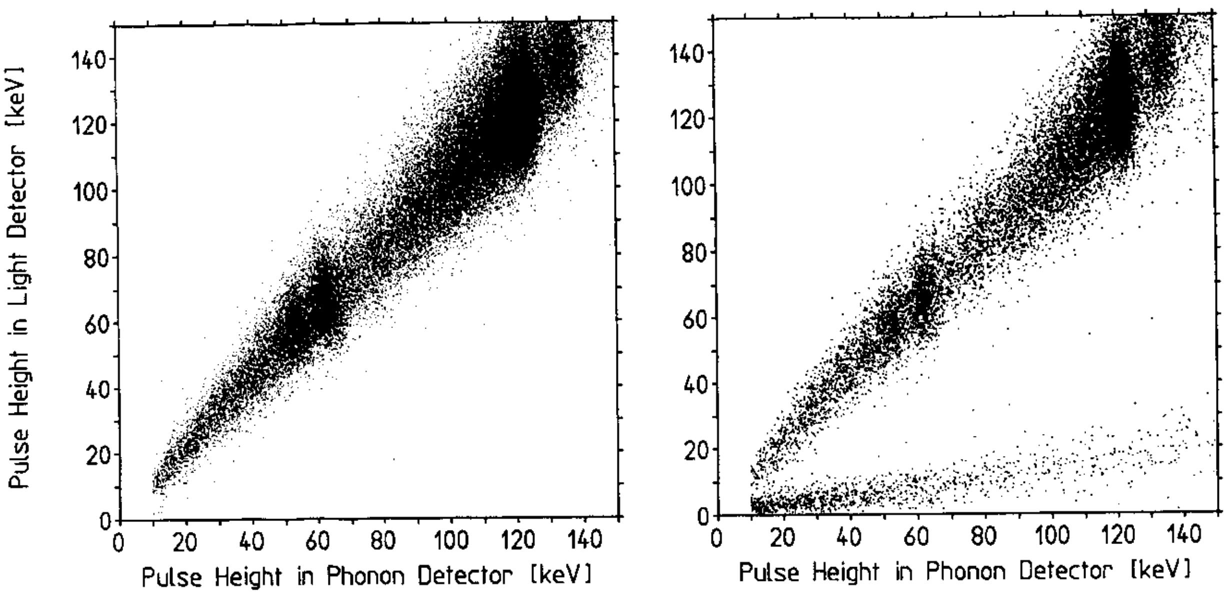

Figure 11: Pulse height in the light detector versus pulse height in the phonon detector. The scatter plot on the left side has been measured with an electron- and a photon, while a neutron source was added on the right.

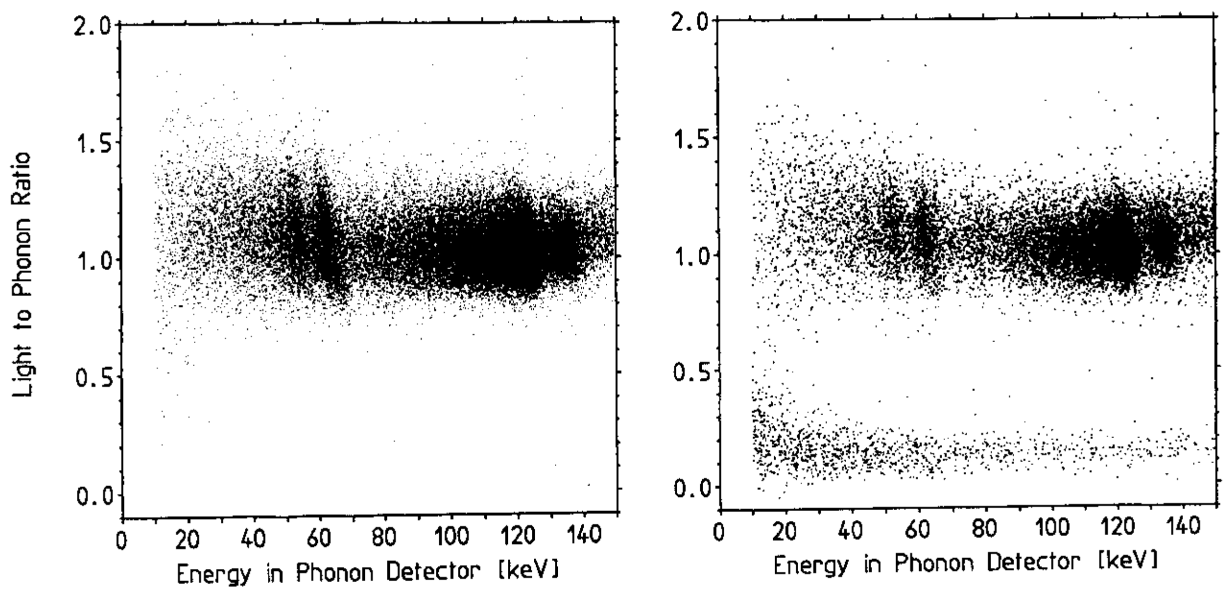

Figure 12: Ratio of the pulse height in the light detector to the pulse height in the phonon detector versus the pulse height in the phonon detector for irradiation with photons and electrons (left) and photons, electrons and neutrons (right).

nuclear recoils from electron recoils. Also light collection does not suffer from problems such as space charge build up, field inhomogeneities or phonons produced by drifting the charges. Due to these advantages, many of the effects known from charge/phonon measurement to cause leakage of electron recoils into the nuclear recoil band are absent. As a result the background suppression efficiency of the light-phonon detection is excellent and it works equally well for photons and electron backgrounds, thus avoiding particle dependent systematic uncertainties in discrimination.

The opportunity to employ different scintillators with different target nuclei, which is possible with CRESST technology, gives a powerful handle for understanding and reducing backgrounds. Even the neutron background, always considered to be the ultimate limitation for such systems, could be understood by varying the target nuclei.

7.2 Scaling Up of the Detectors

For the dark matter search, detector masses of several hundred grams per channel are needed. It is therefore necessary to scale up the 6 g detector used in the above tests without loss of performance.

Scaling Up of the Light Detection

Scaling up the light detection without losses is a critical issue. In light detection three major processes are involved:

- Scintillation and escape of scintillation light from the absorber crystal.
- Light collection by a reflector surrounding the crystal
- Light absorption in the light detection calorimeter and optimization of the light detection calorimeter.

In principle some fraction of the scintillation light can be trapped in the absorber crystal due to total reflection. This effect should depend strongly on the shape of the crystal and in some shapes also on the location of the particle interaction in the crystal. For the refractive index of $CaWO_4$, crystal shapes can be found where trapping should not exist. We have experimentally compared the light output of several [25] $CaWO_4$ crystals with different shapes. In these measurements, all crystal shapes gave the same light output showing that no light is trapped in the $CaWO_4$ crystals. This can be explained by the light absorption length being much larger than the light scattering length, so that a photon is scattered out of trapped configurations before it is absorbed. Due to this the crystal shape has no influence on the light output and so we can use cylindrical crystals, the most inexpensive ones to produce.

The scintillation light escaping from the crystal must be concentrated onto the light detector by means of a reflector. In our first 6g detector we used a simple mirror arrangement, which however, was far from optimal. To optimize the reflector design several arrangements of specular and diffusive reflectors were simulated. We finally decided to use a specularly reflecting plastic foil and diffusive reflectors on both ends, as shown in 9. For the diffuse reflector material we choose sintered teflon, which has a reflectivity of 98 % [26], good cryogenic properties, and is known to be an excellent low background material. The specular reflector is a multilayer plastic foil from 3M with a reflection of 99 %. With such a reflector, a 300g

$CaWO_4$ crystal and a light detector (with only half of the active area of the original 6g set up) we experimentally obtain a light collection efficiency which is 0.8 times the collection efficiency of the 6g detector. Thus we can scale up the crystal mass by a factor of 50 without significant loss in light detection efficiency. At present we are studying a number of schemes for optimizing the absorption in the light detector, including various coatings and materials. By optimizing the absorption layer and the size of the light detector as well as its thermal design we expect further improvements. Such an improved light detector is presently under construction.

Scaling Up of the Phonon Detection

Concerning phonon detection in the scintillating crystal, this process is very well described by our quantitative model [6]. With the help of this model we were able to successfully scale up our sapphire detectors from 32 g to 270 g, with no loss in energy resolution. Some difficulty experienced in growing low T_c Tungsten thermometer films on the $CaWO_4$ has been resolved by providing a thin layer of Al_2O_3 or SiO_2 to grow the films on. The question of an optimal layer is presently still under study. It was possible to grow Ir/Au films with a transition temperature at 35 mk directly on the $CaWO_4$ crystal. There is an ongoing effort to reach lower transition temperatures with Ir/Au.

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