EURECA -- the European future of cryogenic dark matter searches

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Abstract. EURECA (European Underground Rare Event Calorimeter Array) is a new project, searching for dark matter, with largely the present groups of the CRESST and EDELWEISS experiments and already a few new groups. The aim is to explore scalar cross sections in the \(10^{-9} - 10^{-10}\) pico-barn region with a target mass of up to one tonne. A major advantage of EURECA is our planned use of more that just one target material (multi target experiment for WIMP identification). In preparation for this large-scale experiment, R&D for EURECA is provided through the current phases of CRESST and EDELWEISS.

1. Motivation
Recent experimental data on the cosmic microwave background, combined with other astronomical and astrophysical data, have significantly improved the precision of the fundamental parameters in our cosmological model [1]. Within that, much of the matter density seems to comprise non-luminous,
non-baryonic particles [2]. Supersymmetry provides weakly interacting massive particles (WIMPs) as appealing and well-motivated candidates for this Dark Matter [3]. The WIMP-nucleon cross section is at or below the electroweak scale and the expected event rates are accordingly low. The identification of WIMP interaction in a detector is therefore challenging, owing to the rate of WIMP interactions being very small compared with the event rates expected from background radioactivity of present detectors with highest purity and from cosmic radiation. In addition, the recoil energies produced by elastic WIMP-nucleus scattering are very small, in the range of a few keV to a few tens of keV.

To address these experimental challenges a new generation of cryogenic detectors has been developed, exhibiting powerful background discrimination in combination with unprecedented energy threshold and resolution [4, 5]. The detectors allow highly efficient identification of nuclear recoils (caused by WIMP and also neutron interaction) by eliminating electron recoils due to radioactivity. The success of cryogenic detectors is clearly demonstrated as even with relatively modest exposure, results from cryogenic detectors now exceed by an order of magnitude the performances of present competing experiments. CRESST and EDELWEISS are currently in the process of completing the construction of their phases II of the experiments, and will subsequently enter the exploitation phase, involving dark matter data taking for several years. Construction and running of EDELWEISS II and CRESST II is providing valuable R&D for EURECA. The aim of EURECA is to design, build and operate at a European underground laboratory a cryogenic detector array with a target mass of several 100 kg to search for Dark Matter particles.

2. CRESST and EDELWEISS technology

EURECA is based on the expertise acquired by the European CRESST and EDELWEISS experiments. Both use low-temperature calorimeters with complementary techniques as far as the discrimination of nuclear and electron recoil events are concerned.

EDELWEISS, operating in the Modane Underground Laboratory (LSM, France), is based on charge-phonon detectors [4]. The thermal signal induced by energy deposition in a germanium detector crystal is measured with a high-impedance thermistor attached to its surface. Simultaneously, the ionization signal is read out via electrodes on the crystal surface. The ratio between the measured ionization and heat signals provides an efficient tool for the identification of the event type.

CRESST, operating in the Gran Sasso Laboratory (LNGS, Italy), is based on scintillation-phonon detectors [5]. The dark matter target is a scintillator (CaWO$_4$ crystal) and the thermal signal is measured with a superconducting transition edge sensor (TES) on the crystal surface. Simultaneously, scintillation light from the CaWO$_4$ is detected with thin calorimeters also using a TES sensor, but optimized for scintillation detection. The scintillation-phonon technique exhibits benefits similar to those of the charge-phonon approach. Both experiments have achieved comparable sensitivity so far and are expected to improve their present sensitivity for direct dark matter detection by one or two orders of magnitude during the exploitation phases of CRESST II and EDELWEISS II.

The aim of the EURECA R&D is to explore concepts and designs appropriate to a large-scale experiment. Moving from ~10 kg Dark Matter targets to several 100 kg of target mass is a challenge as huge as that faced when the experiments were upgraded to their phases II; i.e. from individual detectors to arrays of 30 to 40 targets. The timescale for the R&D and design of EURECA is shorter but similar to the exploitation phases of EDELWEISS II and CRESST II. The collaboration is studying the key topics required for operating efficiently a ton-scale cryogenic Dark Matter experiment.

3. Features of EURECA

EURECA, in short, is a further scaling up and a combination of the CRESST and EDELWEISS experiments. The feasibility of cryogenic dark matter searches has been demonstrated by CDMS, CRESST and EDELWEISS, and an increase of target mass to in excess of several 100 kg requires modest improvements in a number of aspects of the experiment, such as levels of internal radioactivity of absorbers, improvement of scintillation yield, density of readout channels, etc. The mass of the cryogenic Dark Matter target is envisaged to be in the region of several hundred kg up to 1 ton. An experiment of that scale would cover an extensive range of theoretically favoured super-symmetric particle dark matter candidates. EURECA aims to have a target sensitivity a factor >100 better than
projected by current phase II experiments. Although it is not unlikely that a discovery will be made at WIMP-nucleon cross sections above $10^{-8}$ pico-barn, the range between $10^{-8}$ and $10^{-10}$ pico-barn is currently most favoured [6]. At the lower end, this translates to only few events per ton and year in typical targets, requiring ultra-low background environments and excellent event type discrimination, neutron moderators and muon vetos. Key to the success of EURECA will be further improvements to the detectors with very low energy threshold to cover a range as wide as possible of recoil energies and excellent energy resolution to identify any residual mono-energetic background, e.g. through x-ray lines. Discrimination is necessary to identify nuclear recoil in the presence of a background from electron recoils. Improving the robustness of event-by-event discrimination will be crucial and also a detailed understanding of the detector response to various types of events will gain in importance. Reducing radioactive background levels further, especially in the keV range, is an important topic in light of substantial target mass increases. In contrast to the MeV energy range relevant for $\beta$-decay, the rate of undesirable contributions could be considerably higher for the low energy range.

An important feature of EURECA will be its multi-material target. Having several targets is highly desirable for testing the correct A-scaling of WIMP-nucleon interactions and to determine residual neutron backgrounds, if present. Further strong motivation for equipping EURECA with a range of target materials is provided by kinematic considerations due to the unknown mass of the WIMP. A natural initial choice for EURECA is to use germanium and CaWO$_4$ targets, given the expertise of the collaboration. Additional absorbers are being researched; ZnWO$_4$, for example, has been identified as suitable further target, while other scintillators, such as molybdates, are being optimized [7, 8]. Arranging the detectors in a large array of smaller absorbers has the advantage of being able to test for uniform rates within the target and for providing a further dark matter signature due to requiring single interactions only for a Dark Matter candidate event. This should allow identification of residual neutron background through coincidences.

The major task faced by EURECA is the further improvements to the individual detectors by optimizing their size, improving their discrimination power and radiopurity and, given the large number required, mass production issues. Radiopurity and size issues are equally important for the cryogenic equipment producing the milli-kelvin operating temperatures required. Electronic readout and DAQ will have to scale to > 1000 channels. Some of the scalability issues have already been addressed in providing the readout hardware for the present experiments, but a further factor ~10 in higher density and reduction of heat loads is necessary for EURECA. Without doubt, improvements to detectors will continue as long as EURECA is running. It is therefore desirable to design the cryogenic equipment and shielding in such a way that a fraction of the detectors can be replaced while not interrupting operation for the remaining detectors for long periods.

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