# EURECA

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EURECA (European Underground Rare Event Calorimeter Array) is an astro-particle physics facility aiming to directly detect galactic dark matter. The Laboratoire Souterrain de Modane has been selected as host laboratory. The EURECA collaboration unites CRESST, EDELWEISS and the Spanish-French experiment ROSEBUD, thus concentrating and focussing effort on cryogenic detector research in Europe into a single facility. EURECA will use a target mass of up to one ton, enough to explore WIMP – nucleon scalar scattering cross sections in the region of $10^{-9}$ – $10^{-10}$ picobarn. A major advantage of EURECA is the planned use of more than just one target material (multi target experiment for WIMP identification).

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# 1. Introduction

## 1.1 Motivation

Substantial experimental evidence, with ever improving precision, suggests the existence of a significant fraction of the Universe being dark matter [1, 2]. The expected event rate in direct search experiments is low, owing to the WIMP-nucleon cross section at or below the electroweak scale. Identification of WIMP interaction in a detector is therefore challenging, and once a signal is suspected there will have to be means of verifying this as originating from interaction of dark matter particles. Any experiment with sensitivity beyond the level already demonstrated in existing data must be ultra-low background in terms of the detectors and their immediate surroundings and housed in an underground laboratory of sufficient depth to reduce as best as possible contributions from muon-induced neutrons near the detector. In addition, the detector technology has to be capable of detecting the small recoil energies produced by elastic WIMP-nucleus scattering, which tend to be in the range of a few keV to a few tens of keV.

In order to address the above experimental challenges, a new generation of cryogenic detectors has been developed, exhibiting powerful background discrimination in combination with unprecedented energy threshold and resolution [3 – 5]. These detectors allow high-precision identification of nuclear recoils (caused by WIMP and also neutron interaction) by eliminating electron recoils due to radioactivity. Such detectors are currently installed in the EDELWEISS-II and CRESST-II dark matter search experiments, producing science output and allowing for testing and optimization for their future use in EURECA.

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 $10^{-8}$ picobarn, the range covered by EURECA (extending to $10^{-10}$ picobarn) is currently most favoured by theory [6]. At the sensitivity limit, this translates to only a few events per ton per year in typical targets, requiring ultra-low background environments and excellent event type discrimination, neutron moderation and muon vetos.

EURECA is based on cryogenic calorimeters, operating at millikelvin temperatures, a technology that has demonstrated its maturity and is inherently scalable due to the modular arrangement of individual detector modules. The detectors exhibit excellent energy resolution and true event-by-event discrimination, both of which are important for identification of any residual background. Their excellent performance has been demonstrated within the CDMS, CRESST and EDELWEISS experiments.

EURECA, together with SuperNEMO, plans its installation into the extension of the Laboratoire Souterrain de Modane (LSM, or Fréjus laboratory). This extension should be ready for occupation in 2014, but some initial testing of EURECA components can be carried out in the existing laboratory, where EDELWEISS is currently operating. EURECA selected the LSM for its low muon flux, easy access, well-developed infrastructure and expertise in hosting low-background experiments.

### 1.2 Cryogenic Detector Technology

EURECA's detectors will be based on those presently used in the CRESST, EDELWEISS and ROSEBUD experiments. The detectors are low-temperature calorimeters, operating in the millikelvin temperature range. Complementary techniques are used for discrimination of nuclear and electron recoil events. Detectors based on charge-phonon discrimination [3] are used by EDELWEISS. 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 ionisation and the heat signals provides an efficient method for the identification of the event type. Detectors based on scintillation-phonon discrimination [4] are used by CRESST and ROSEBUD. The thermal signal in CRESST detectors (currently tungstates) is measured with a superconducting transition edge sensor (TES) on the crystal surface. Simultaneously, scintillation is detected with thin planar calorimeters also using a TES sensor, but optimized for detection of scintillation.

Both technologies have their specific advantages. Germanium, for example, has a long history in ultra-low background applications and is a well-studied material. There is a sizable market associated with this material and hence commercial companies exist with the necessary expertise to participate successfully in the production of a large number of detectors that will have to be procured for the construction of the ton stage of EURECA. Regarding event type discrimination, this is not restricted to distinguishing between electron and nuclear recoil. Recent progress on EDELWEISS with germanium detectors equipped with interleaved electrodes made it possible to identify bulk events and reject surface events with high precision [7]. Solid scintillators have the advantage that there are many of them, hence allowing tuning of the target material to be an optimum fit to the suspected WIMP mass. The wide choice of materials allows exploration of spin-dependent versus spin-independent interactions and optimizing WIMP detection by selecting a target nucleus with mass similar to the mass of a WIMP, once this is narrowed down. Most of the scintillators are composite materials which allow studying several nuclei within one target (and hence within the same radio-pure environment, using the same sensors and readout). CRESST is currently operating $CaWO_4$ and $ZnWO_4$ targets for this purpose [8, 9].

Europe is quite strong in the area of cryogenic dark matter detectors, having a long tradition in the field and a large number of groups and individuals pursuing this technology. All these groups, and in addition others with relevant expertise, have joined EURECA. The other grouping of experts in mainly US-based and working on superCDMS/GEODM. A memorandum of understanding has already been signed between EURECA and superCDMS/GEODM to encourage global collaboration in areas of mutual benefit. The cryogenic effort is complemented by experiments involving liquid noble gases. Having more than one technique for detecting WIMP particles is important for cross-check and verification when a WIMP signal is suspected, but it also will allow studying more efficiently properties of the dark matter particles.

## 2. EURECA – Status and Current Studies

The work towards the design of EURECA has started and is based on previous, preliminary studies that provided some information and guidance, leading to a baseline design for the EURECA facility. The EURECA baseline design includes the water tanks with immersed cryostats (Figure 1). Preliminary studies show (to be confirmed by a more detailed analysis) that a water shield of 3 metres thickness, surrounding the detector accommodation on all sides satisfies our requirements for residual radioactivity from outside. There should be two cryostats to maximize exposure with time. One cryostat could initially be used to only house detectors that perform very well regarding low-background and high sensitivity / low threshold. This cryostat would run for long periods (typically for one year), while the other cryostat could have a larger number of shorter running periods to validate and commission detectors as they become available. Once the detectors are validated, they would then be moved to the cryostat with longer running intervals. Eventually, also the cryostat with shorter running periods would move to increasingly longer ones, moving fully to science runs eventually. This strategy should allow fastest progress, where, and that one should not forget, the level of sensitivity we aim for has not been demonstrated yet. Otherwise, the experiment would have been completed already. With any large scale dark matter search experiment one explores previously unchartered territory and as such there is no hard and fast transition from commissioning to exploitation mode. On the contrary, as sources of background are identified and removed or dealt with, new backgrounds are likely to appear, but of course at increasingly lower level. Being able to react fast and addressing any new issue that may appear is vital and has to be designed into the facility from the start. Hence our strategy, as outlined.

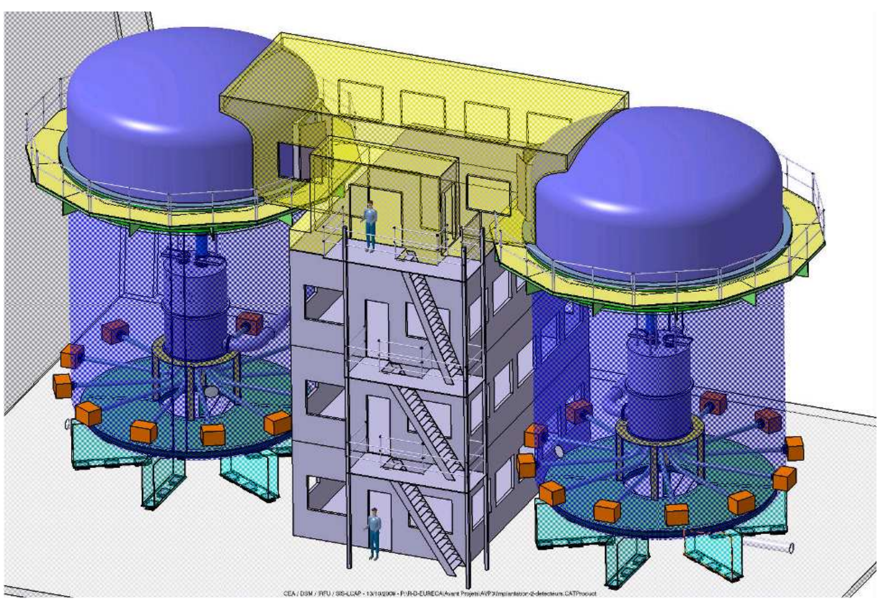

*Figure 1: The two cryostats of EURECA, each inside its individual water shielding, with the central building between. The top level of the building, together with the space covered by the domes, is a cleanroom.*

### 2.1 Infrastructure and Cryostat

We anticipate that a volume of 15 m × 30 m × 15 m would probably be enough to accommodate all required infrastructure as shown in Figure 1, though some specific requirements will need to be detailed as part of our ongoing design study.

The design of the cryogenic and shielding infrastructure needs detailed studies and careful planning. EURECA requires significant improvements in the radiopurity of the internal environment in direct vicinity of the detectors to achieve the very low background rate required. This concerns gamma ray background and neutron-induced background. We estimated that isotope concentrations not exceeding 10 ppt for U/Th and 10 ppb for natural potassium should be adequate to meet our constraints on internal radioactivity and hence this specification will have to be achieved in materials close to the detector array.

Dilution refrigeration will be used to cool the ton-scale cold mass of EURECA. Studies are under way to determine the cooling power required of the dilution refrigerator of EURECA. First results indicate a considerable heat load, which is in good agreement with experimental values obtained for large cold masses of similar size in other experiments. The proximity cryogenics must satisfy the stringent requirements resulting from remote operation in underground laboratories. In addition, much has been learned from the rather different design concepts of CRESST and EDELWEISS. The lessons learned from the operation of these experiments will impact on the design of the EURECA cryogenic system.

### 2.2 Electronics

We also have baseline designs for cryogenics cabling and front-end electronics. Based on experience with the running experiments we have been analysing already how to achieve scaling up by a factor of ~100 in a cost-effective manner. The cabling shown in Figure 2 (right panel), for example, is a prototype of what could achieve the cost savings we are looking for. The question whether this type of cable can be used in the immediate vicinity of the detector array, or whether it will be capable of operating at the low noise levels required, is currently being addressed within our design study.

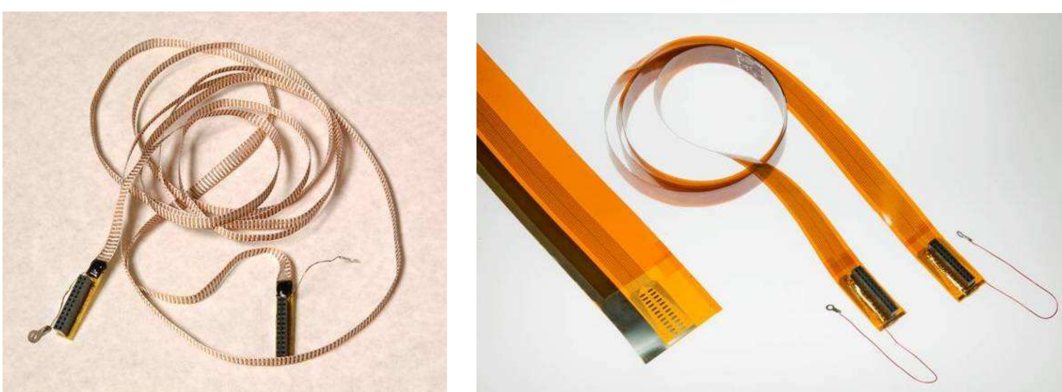

*Figure 2: The left panel shows a cryogenic cable as used in the CRESST-II setup. The right panel shows a prototype of a cable on a Kapton base.*

Electronic readout and DAQ will have to scale to several thousand channels. The issue of scalability has been addressed already in providing the readout hardware for the presently running experiments, but a further reduction of heat load through readout wires, and a significant reduction in the cost per channel are important for the realization of EURECA.

In order to reduce the cost per readout channel to an acceptable level we will need to develop multi-channel front-end electronics to replace the present single-channel systems; and redesign detector bias and control systems to take advantage of economy of scale. Some hardware components can be avoided by providing their function through firmware or software.

Multiplexing systems for cryogenic detectors have been developed for astronomical arrays to reduce the number of readout channels. It is not yet clear if these can be adapted for a dark matter search, but it is likely there will be some sort of multiplexing at some level.

Digitization at an early stage in the DAQ chain will be crucial. This approach reduces cost and adds flexibility. Rather than building trigger hardware, it is foreseen to use parallel sets of field programmable gate arrays (FPGA) in which triggers, arranged by their level of sophistication, are realized. Research and development has started already, with "intelligent" electronics, capable of identifying potentially interesting signals above noise. A trigger system with several levels allows further to balance the available computing power between the levels of sophistication of the trigger condition, successively reducing the volume of the data stream as it propagates through the data pipeline.

A physically larger experiment means longer cables and a greater number of passages through thermal shields and heat sinks. This is less a problem for low-impedance detector readout channels, but might cause problems for high-impedance read-out due to stray and parasitic capacitance. To somewhat alleviate these potential drawbacks, research is ongoing into specific grounding schemes, possibly involving actively driven shields and a comparison of various possible implementations, such as coax cables or strip lines. Avoiding cross talk between channels despite the high density of cables is also an important issue.

We aim to design the readout system and DAQ as modular as possible so that a large number of sections / components will be the same across the range of readout configurations. It should then be possible to run a variable number of detectors with very different design, operation and speed by only changing the front-end and adjustment of parameters in software. Other aspects that need to be considered already in the design include linking the output from the muon veto into the data acquisition system, ensuring synchronisation of time stamp recording with precision at the microsecond level.

Many of the above ideas are already beyond their first stage of research and development and are currently implemented in EDELWEISS-II and CRESST-II. The combination of expertise and experience gained in these two experiments is being harnessed for the next level of scaling up.

### 2.3 Detectors

The aim of EURECA R&D is to explore concepts and designs, based on the existing technologies, appropriate to a large-scale experiment. The exploitation phases of EDELWEISS-II and CRESST-II are aligned with the R&D for EURECA and the design of the experiment.

This should allow us to select the optimum detector technology for EURECA. An important aspect in designing a ton-scale experiment is the inherent scalability of cryogenic detectors. Individual modules have already been developed and optimised; scaling up merely requires the production of more modules and a larger cold space in a dilution refrigerator. Increasing the production rate of modules does not require additional detector development, although further improvement is always possible and likely to occur as a by-product of optimising the manufacturing process.

A modular approach is vital to achieving large detector masses. There are likely to be limitations in large-scale detectors due to radioactive backgrounds present in the target materials. With individual sub-kilogram solid targets, modules with abnormally high backgrounds can be isolated and replaced. Fitting individual readout channels to each target mass also helps keeping the data free from pile-up and makes calibration and monitoring easier.

An important feature of EURECA is 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, as the mass of the WIMP is unknown. A natural initial choice for EURECA is to use germanium and tungstate targets, given the expertise of the collaboration.

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