Laboratorio Subterráneo de Canfranc
STRATEGIC PLAN 2025-2028

Summary

ANALYSIS OF ACCOMPLISHMENTS OF PREVIOUS STRATEGIC PLAN (2021-2024)

An analysis of accomplishments of objectives reported in the previous strategic plan follows.

ANAIS. The experiment has been taking data steadily (more than seven years of data taking). It is internationally renowned as the best experiment refuting the DAMA/LIBRA results with the same experimental technique. The analysis of three years data has been published and preliminary results of the six-years exposure have been presented to the LSC Scientific Committee members and in international conferences. Work on scintillating quenching factors has also been published. This objective has been accomplished.

Biology Platform. Two biolabs have been built, one on surface and one underground, in the period 2021-2024. The evaluation approval and support to the biology experiments at the LSC is managed in the Biology Platform, with a subcommittee of biology experts providing their reports on the running experiments and the new proposals to the Scientific Committee members. Eight experiments have already been completed or are currently undergoing, ranging from the evolution of viral infection, the mechanisms of cellular aging or the transition to multicellularity. This objective has been accomplished.

CROSS. The experiment CROSS has been taking data to complete the R&D phase with several crystals based on Te-130 and Mo-100. Significant results on light copper structures and faster scintillating light collection to reject background have been published and will improve the science potential of CROSS and the future CUPID experiments. The long run with the full tower of crystals is still pending. This objective has been partially accomplished.

DArTinArDM. DArT cryostat has been built and tested for operation inside the ArDM detector, which will be serving as the veto system for DArT. LSC has signed agreements with ETH, Zurich and with the DarkSide Collaboration for defining the LSC ownership rules of the ArDM detector and for establishing the conditions to properly exploit this installation, respectively. The science program is still holding because the DarkSide collaboration could not provide the underground Argon samples. This objective has been partially accomplished.

HENSA. The High Efficiency Neutron Spectrometry Array collaboration have installed ten ^{3}He-filled proportional counters embedded in High Density Polyethylene moderators with different sizes, which allows to unfold the neutron spectrum from the counting rates and the response matrix. The detectors array has been taking data in Hall B, next to the ANAIS experiment, for more than three years. In parallel, a smaller array, located in the center of Hall A, has been taking data during the same period. This objective has been accomplished.

HYPERKAMIOKANDE*. The LSC coordinates the Spanish contribution to the construction of HK, financed by MICIU. An international collaboration was formed to build a larger water tank detector (8 times the size of SK), which with the near detectors and the upgraded JPARC neutrino beam should be able to discover CP violation in the neutrino sector, search for proton decay and observe the Universe in neutrinos in the next three decades. The Spanish groups have designed the PMT protective covers against the chain reaction induced by implosion, the data processing blocks, the geomagnetic compensation and ventilation systems and the radioactive sources and will take care of the fabrication and validation of these components of the far detector.

*NOTE: LSC CONTRIBUTION TO INTERNATIONAL EXPERIMENTS LOCATED IN OTHER UNDERGROUND LABORATORIES

JASC. In collaboration with the Jagellonian University team led by G. Zuzel, the LSC installed a new HPGe with a much lower background in a dedicated clean room with reduced vibrations, which allows mBq sensitivity in the determination of the Uranium content (assuming secular equilibrium) in materials required for the construction of experiments underground. This is currently the world's most sensitive HPGe detector for gamma screening of small components in the underground experiments. This objective has been accomplished.

NEXT. The main objective was to build and operate the LSC flagship NEXT-100 experiment. NEXT-100 detector is currently taking data with excellent performance. Critical elements such as the bigger TPC and electroluminescence amplification mesh are properly working, which constitutes a big success of the experiment. In parallel, a big program of R&D shows significant progress for future stages of the NEXT program: replace PMTs by SiPMs and add fibers to read light outside the vessel so as to reduce the background budget, use of ASICs to reduce the number of feedthroughs to extract all SiPM channels and demonstrate barium capture by organic molecules in dry medium to make progress towards the demonstration of the barium tagging technique, among others. This objective has been accomplished.

TREX. The experiment TREX was successfully reinstalled in Lab2500 and it has been taking data to improve the detector's performance and to further reduce background. A new micromegas detector with thick GEM hole multiplier looks very promising to reduce the energy threshold and become a competitive technology in the low mass dark matter searches. The science program is still holding. This objective has been partially accomplished.

During the time frame of the previous strategic plan, two experiments have finalized their activities. SuperKGd program was completed as there will not be more Gd added to the SuperKamiokande detector. Geodyn experiment has been finalized due to the lack of activity by the research groups involved in the experiment. On the other hand, a new experiment was approved, BabyIAXO-D1, an experiment dedicated to the characterization of the X-ray background of the BabyIAXO components and two expressions of interests based on the exploitation of superconducting circuits to explore the influence of cosmic radiation in qubits and axion searches with LEKIDS. In addition, it is worth noting that:

- A new ICPMS-QQQ has been installed and operated in the ISO-5 clean room underground. The ICPMS service has demonstrated ppq sensitivity to the Uranium content in copper and has measured Potassium with ppb sensitivity in zone-refined Sodium Iodine crystals in collaboration with LNGS and USA partners.
- A new computer cluster (1000 cores, 1PB SSD) has been purchased and installed underground by using single phase immersion cooling. It is currently operative for LSC users.
- LSC purchased 15 tons of fresh copper in (cathode plates) and developed, in collaboration with the DIPC and Spanish companies, clean methods for copper shaping (welding, forging, machining) of large pieces, currently used in NEXT-100.

MISSION AND VISION

The present strategic plan details the vision, mission, and goals of the LSC for the period 2025-2028.

MISSION

World-class scientific results are expected to be delivered by the LSC through the scientific program to be carried out. This is the main mission of the LSC in the period of time considered for this document. The science program of the LSC will enhance the position of Spain in the international framework of astroparticle physics and biology carried out in underground.

The science program at the LSC is currently mainly focused on double beta decay for neutrino physics, on direct searches of dark matter, and on biology in low background radiation. More opportunities could be of interest to the LSC, such as a program in detectors based on superconducting circuits in a low background environment.

The mission of the present strategic plan is also to **strengthen the position of LSC as world-class research infrastructure at international level**.

Strategy

To deliver its mission the LSC will:

1) develop and maintain world-class facilities and infrastructures;

2) commit to achieve a high standard in safety for the staff, users, and visitors;

3) facilitate users to put forward the scientific program proposed;

4) support new R&D programs which could arise within the science community and enable worldclass underground science;

5) support collaboration and synergy with other underground laboratories;

6) promote diffusion of science through a public and educational outreach program.

The National Landscape. As a national unique research infrastructure, the LSC benefits from connections to institutions, research centers and universities within Spain. This national connection is crucial to provide a framework where the LSC can develop and exploit world-class science. LSC, at present, has connections with the University of Zaragoza, IFIC, I2SysBio and UPV in Valencia, DIPC and UPV in San Sebastian, IFCA and US in Santander, University of Oviedo and Girona, IGFAE and USC in Santiago, IBE, IFAE and IMB-CNM in Barcelona, CBMSO, CIEMAT and UAM in Madrid. At the end of 2024, five researchers from IBE, CIEMAT and the NEXT collaboration were based at Canfranc. **The limited manpower resources at the LSC requires a strong connection with the national community. Maintaining and increasing this connection at national level is crucial for the LSC and its scientific program.**

The LSC is a unique facility and its mission to deliver world-class science at international level is a benefit to Spain. The LSC has become the Spanish hub in low background techniques and experiments underground and has strengthen the collaboration with other unique infrastructures.

The International Landscape. Research groups from institutions in Finland, France, Germany, Italy, Israel, Japan, Poland, Portugal, Romania, Switzerland, Ukraine, United Kingdom and the United States of America contribute to the LSC program. Moreover, LSC belongs to a network of underground laboratories at international level. The possibility to establish an Underground Global Research Infrastructures organization between underground laboratories is under consideration. Strong connections already exist between LSC and LNGS (Italy), Kamioka (Japan), SNOlab (Canada), Boulby (UK), LSM (France) and CallioLab (Finland). Future generation experiments will require the share of workload and facilities between underground laboratories. **Maintaining and**

improving high quality facilities at the LSC is extremely important for the role of LSC at international level.

The Scientific Advisory Committee (SAC) at the LSC is an international peer review group, which provides connections to the international community besides exploiting its institutional role by monitoring the research activity program of the LSC. **Supporting the activity of the SAC is crucial for the LSC to play a leading role at international level through its scientific program**.

The LSC is equipped with a number of facilities to support the research activity carried out by experimental collaborations. **Supporting these facilities is crucial for the LSC**. Laboratories (electronics, chemistry, biology, workshop), offices and meeting rooms are also available on the surface facilities at the LSC. An exhibition room is in operation at 'La Casa de los Abetos'. In addition, the LSC provides, at present, the following services to the collaborations of LSC approved experiments and to external users (requires approval by the director, after the positive evaluation by the access committee members):

- ULBS: Radio-purity record sensitivity measurements with ultralow background HPGe detectors.
- MS: Radiopurity assays with ppq sensitivities of U in copper, ppb sensitivities of K in NaI.
- CES: Electroformed radiopure copper manufacturing service.
- CRS: Access to underground clean rooms class ISO 6&7.
- Two Conference rooms for institutional meetings with 98 seats each.

Main general support infrastructures are also present at the LSC:

- Radon abatement system installed underground, which can provide 220 m^3/h radon-free air.
- Radon detector system with 1 mBq/m^3 sensitivity.
- Liquid Nitrogen generator and Nitrogen gas support.
- Workshop, Biology, Chemistry and Electronics labs.
- Two diesel generators to supply electrical power in case of failure on the main external network.
- Waste repository and disposal Service.
- Fire detection system underground.

Ultra Low Background Service (ULBS)

At the LSC, this facility consists of seven HPGe detectors and GeRysy, a new record sensitivity well-type detector for gamma spectroscopy screening, developed in collaboration with the team led by G. Zuzel. This facility is crucial for detectors designed to search for rare processes. The sensitivity of detectors in the ULBS is of the order of 0.5-1 mBq/kg in uranium and thorium, and of the order of 1-10 mBq/kg for GeRysy detector. Strong connections with other similar facilities at LNGS (Italy), Boulby (UK), Kamioka (Japan) already exist. **It is crucial that this Service is supported and upgraded**. At present, one permanent staff is working on this Service. New investments can be considered to upgrade the Service, namely: turn the facility into a clean room; equip the facility with an XIA alpha counter; increase and further develop the most sensitive HPGe detectors, as demonstrated with the successful GeRysy detector installed in collaboration with Jagiellonian University in Krakow.

Mass Spectrometry (MS)

A QQQ-ICPMS instrument was installed in the clean room underground in 2023. This mass spectrometer offers a complementary method to HPGe detectors to perform radio-purity assay of detectors components. **It is crucial to support the operation of this detector and the further improvements needed to reduce the current backgrounds, mainly introduced in the sample preparation**. Under these improved conditions, an ICP-MS can reach ppq sensitivities for specific isotopes. Therefore, it is a very valuable instrument for an infrastructure such as the LSC.

Copper Electroforming Service (CES)

At present, the CES is a unique facility among operating underground laboratories. Copper electroforming is a well-known process to obtain high radio-purity copper. In this process the copper is produced through electrodeposition onto a mold. The LSC at present has two set-ups on surface to make electroformed copper with an improved massive production system. At the LSC the technique used is direct fixed-current-density electroplating. The materials employed are OFHC copper bars. Considering the international interest in electroformed copper, particularly with the new copper printer machines, **it is crucial to support this Service,** currently installed in the clean room underground.

We plan to incorporate new services to strengthen the low radioactivity techniques available in the underground lab .

The High Efficiency Neutron Spectrometer

HENSA collaboration has been taking data on the neutron background with their experiments at the LSC. Their data shows a neutron flux which depends on the position in the lab and changes along the year. Unfortunately, these neutron monitors will be moved to other labs and locations. A long-term neutron monitoring is needed in the neighborhood of ANAIS experiment and also of experiments at Hall A, including the biology experiments. **It is crucial to support the installation of a neutron spectrometer based on He-3 counters and including ultrapure CLYC crystals.** This would be a very valuable instrument for an infrastructure such as the LSC.

The Dilution Refrigerator Service

The cryogenic service will consist of a multipurpose ultra-low background dilution refrigerator placed underground which can be used by several experimental proposals. It has been recently demonstrated that cosmic radiation degrades the performance of superconductive qubits. A new Expression of Interest has been approved by the SAC at LSC, which aims to determine the physics of these phenomena and techniques to reduce its impact. A set of experiments with improved qubits have been carried out on surface at IFAE in Barcelona and would be taken underground if service available. A new Expression of Interest led by the CADEx team is using LEKIDs as a novel superconducting device to become the best detector technique for the high frequency microwave bands, with potential applications to detect the radiofrequency generated by O(meV) axions in magnetic fields. This service would allow LSC to host experiments aiming at exploring the use of superconducting circuits as ultralow background particle detectors. **It is crucial to support the installation of a multipurpose dilution refrigerator underground to host experiments based on qubits and KIDs.** This would be a very valuable infrastructure at the LSC.

The LSC science program

The LSC is a multidisciplinary research infrastructure. The research program at LSC aims to address some fundamental questions in astroparticle physics, including neutrino physics, dark matter searches, and biology in low background radiation. We briefly review the current and short-term scientific program.

Double Beta Decay at the Laboratorio Subterráneo de Canfranc

Strategic goal

Support, maintain and execute a world-class research program in Double Beta Decay (DBD). Current status of neutrinoless double beta decay searches and natural conditions of the LSC make possible to reach the leading laboratories in this research field.

Neutrino oscillation experiments have already demonstrated that neutrinos have masses. Being a neutral fermion, the question arises on the nature of the neutrino mass. All other fermions source their mass by interacting with the Higgs field, but neutrinos may have a unique extra mass mechanism if they are their own antiparticles, which would source the Majorana mass term. DBD is a radioactive decay in which the nucleus transforms simultaneously two protons into two neutrons. Ordinary DBD has been observed in several isotopes, where two electrons and two antineutrinos are emitted from the decaying nucleus. If neutrinos are their own antiparticles, another DBD is possible, yet to be discovered and named neutrinoless DBD, where only electrons are emitted, violating the lepton-number conservation.

The LSC has an active program on DBD searches. At the LSC, DBD experiments make use of two different techniques: searches with pressured Xenon gas and R&D with oxide bolometers. **NEXT is the flagship experiment in the LSC**, which aims to **lead the search for neutrinoless DBD worldwide by demonstrating the best scaling low-background technique needed to reach half-lifes longer than 10^{27} years.** The CROSS demonstrator aims to do R&D of large bolometer detectors with particle identification based on Li_2MoO_4.

The main **objectives** are: 1) **operate** the LSC flagship **NEXT**-100 experiment, 2) **design and build infrastructures** underground to host the **NEXT-HD 1-ton scale** detector and 3) complete the science program of the **CROSS** demonstrator. To succeed in this objective, the LSC will deliver state-of-the-art tools (radon free air, clean room environment, shielding, and radio-purity assay) and plan new ones.

The NEXT-100 detector is a high-pressure ^{136}Xe Time Projection Chamber (TPC), which consists of a cylindrical stainless-steel vessel, with a thick inner radio-pure copper shield, mounted on a seismic pedestal and surrounded by a 20 cm thick lead castle. The readout planes consist on Hamamatsu photomultipliers tubes (PMTs) on one side and silicon photomultipliers (SiPMs) on the other. A charged particle propagating in the gas deposits its energy through both excitation and ionization of the gas molecules. The scintillation light coming from the relaxation of the molecules is registered by PMTs on the cathode of the TPC and sets the starting time of the event. The ionization electrons are drifted by an electric field all the way through the drift region until they enter a small region of moderately higher field where they are accelerated and secondary scintillation occurs, below the ionization threshold, named electroluminiscence (EL) which results in an amplification of the signal. PMTs detect the EL light, giving a precise measurement of the energy of the event. On the anode side, SiPMs placed behind the EL area give a 2D projected image of the track. NEXT-100 is composed of 3-inch PMTs specially developed for low- background operation by Hamamatsu located behind the cathode of the TPC, covering approximately 30% of its area. The tracking function in NEXT-100 is provided by an array of 7168 SiPMs regularly positioned at a pitch of 1 cm, located behind the fused-silica window and mounted on flexible circuit boards made of Kapton and copper. **NEXT, currently taking data, could reach the present-day upper bound on the neutrinoless DBD** and show itself as a viable **technique to scale up** and probe the theoretically motivated expected half-life based on neutrino oscillation data and cosmological total mass bounds. NEXT Xenon gas technique may allow to also identify the Barium atom produced in DBD. If successful, this technique with the track reconstruction may pave the way to go beyond one ton-scale detector without background and reach sensitivities above 10^{28} years. **NEXT-100 and future NEXT-HD ton-scale detector are the LSC flagship experiments. Strong support of experimental activities of NEXT-100 and construction of the needed infrastructures to host NEXT-HD is critical to the current and future international leadership in DBD of LSC.**

CROSS demonstrator will search for double beta decay with bolometers using a specific mechanical structure to hold the crystals, developed and validated during the R&D phase. Given the role of bolometric photodetectors for particle identification and random coincidences rejection, CROSS demonstrator will use upgraded light detectors, featuring thermal signal amplification via the Neganov-Trofimov-Luke effect, also developed and validated during the R&D phase. The CROSS R&D program is **recognized as part of the CUPID R&D activities towards a ton-scale DBD detector based on bolometers**. CROSS will complete the science program with the measurements of a tower of $^{130}TeO_2$ and Li_2MoO_4 bolometers. **It is crucial to support CROSS full running for the international visibility and leadership in DBD of the LSC.**

Neutrino Physics and Astrophysics

Strategic goal

Become the national hub in astroparticle physics for large international projects. Current needs of neutrino physics and astrophysics experiments require good coordination of national efforts in single international large detectors to lead the field in the next decades.

Next generation neutrino oscillation experiments may discover CP violation in the neutrino sector, a fundamental parameter in the Standard Model of Particle Physics, and a needed property which could explain the matter-antimatter asymmetry. These very large detectors are also neutrino telescopes, which can observe the sky in neutrinos, including among others, solar, atmospheric, supernova and supernova background neutrinos. Two major initiatives are HyperKamiokande (HK) and DUNE projects.

LSC coordinates the project "**Spanish Contribution to the Construction of the HK experiment**", with main contributions in design, validation and production monitoring by the Spanish institutions LSC, DIPC, UdG, UO, UPV and USC. Agreements between the Univ of Tokyo and LSC and between LSC and the Spanish institutions define the responsibilities of the participant institutions. In total, researchers from nine Spanish institutions would have the right to participate in the exploitation of the detector , as expreseed in the MoU between the Spanish MICIU and Japanese Tokyo Univ. and KEK.

Hyper-Kamiokande (HK) will be the next generation experiment in the successful Kamiokande neutrino programme, dedicated to the search for nucleon decay and the study of neutrino phenomena and neutrino sources. HK project builds on this world-leading neutrino program, with a new 260kton (188 kton fiducial, 8 times bigger than SK detector) water Cherenkov detector (the Hyper-Kamiokande Far Detector will consist of a cylindrical tank 71m in height and 68m) that will give unprecedented statistics of neutrinos from astrophysical sources, alongside upgraded beam and near detectors for a long-baseline program as a far detector to measure oscillations of neutrino and anti-neutrino beams generated at the J-PARC facility 295km away (current 800 kW beam will be upgraded to 1.3 MW by power supply upgrade and doubling repetition rate). More than 600 scientists and engineers from all around the world are contributing to the construction, installation and exploitation of it.

Cherenkov light generated from events in the inner detector region will be read out by an array of inward looking photomultiplier tubes (PMTs). 20,000 50cm diameter PMTs will provide 20% surface area coverage. These PMTs have been developed by Hamamatsu with a box and line style dynode to give 2.6ns timing resolution. Mass production of these PMTs is taking nearly 6 years to complete and has achieved 2/3 production with a program of quality assurance established for the PMTs as they are delivered. In addition to the 50cm PMTs, the same number of protective covers, based on UV-transparent acrylic (above 75% transparent at 300 nm) domes and conical steel bodies have been designed by LSC, DIPC and UdG and tested against the potential propagation of a chain reaction by a PMT implosion mechanism. The efficiency of PMTs response requires a homogeneous magnetic field environment, which has been designed by the team from Universidad de Oviedo and will be tested in the near future. In HK design, signal from PMTs must be digitized and processed in one thousand underwater units. The data processing blocks have been designed and validated by the team from the Universidad Politécnica de Valencia.

This project proposes the plan and needs to perform the installation of the components build as the Spanish contribution to the construction of HK, which must be completed in 2027, and will lead to the phase of exploitation of HK by the collaboration, including the nine Spanish research centers participating in HK. Three complementary actions must be delivered in time by the three institutions participating in this call: validation and assembly of electronics at CERN and validation and installation in Japan, assembly, and installation of the compensation system in Japan, assembly and installation of PMT in covers in Japan.

The main **objectives** are to receive and **distribute** the necessary **funds**, to **coordinate** the timely **fabrication and logistics** of the Spanish contribution and to **coordinate** the **assembly and installation** with the HK collaboration.

Dark Matter Searches at the Laboratorio Subterráneo de Canfranc

Strategic goal

The LSC program on direct Dark Matter (DM) detection is meant to support, maintain, and execute a world-class research by exploiting data from a number of experiments, namely, ANAIS, DArTinArDM in DarkSide program, and TREX, and to search for new opportunities, such as DAMIC and support the Global Argon Program.

The idea of DM was conceived about a century ago. At the beginning, evidence of DM came from observations of the dynamics of galaxies and clusters of galaxies. Recently, observations of the large-scale structures, the anisotropies of the cosmic microwave background, and the accelerated expansion rate of the Universe, all suggest the existence on non-luminous, non-baryonic, non-relativistic, stable matter, which we call DM. Non-baryonic DM accounts for some 85% of the matter in the Universe. At present, the LSC research program on DM aims to contribute in understanding the nature of DM by exploiting direct detection experiments. One of the most favored DM candidates is a Weakly Interacting Massive Particle (WIMP), a heavy thermal relic of the Big Bang. The identification of the nature of DM is at present a fundamental quest.

LSC has an active program on direct detection of DM. At LSC, DM is searched for by three different experiments: **ANAIS, DArTinArDM** and **TREX**. **The DM program gives international visibility to the LSC.** Different techniques are being used at the LSC for DM research. **Within the next four years** we expect to complete the full scientific program results of ANAIS, to characterize all underground argon in DArTinArDM, needed to complete and start data taking in DarkSide-20k, currently in construction at LNGS, and have taken data with TREX both with argon and neon. All results will be crucial to plan future activities on dark matter direct detection at the LSC and worldwide. **ANAIS is the first DM experiment that can directly verify the DAMA/LIBRA annual modulation with high significance. DArTinArDM will give a contribution to the international effort on next generation massive liquid argon detectors. TREX aims to contribute to the search for low mass WIMP at international level.**

ANAIS is an array of 9 NaI(Tl) high radio-purity scintillators, each with a mass of 12.5 kg. A single scintillator is installed inside a copper housing and viewed by two photomultipliers. All detectors are installed inside a passive ancient lead shielding and an active muon veto. The goal of the detector is to search for the annual modulation expected by a generic DM particle while the Sun is moving around the center of the Galaxy. This is a model independent signature. Such a modulation has been observed with an array of NaI(Tl) crystals deployed at the Gran Sasso Laboratory in Italy by DAMA/LIBRA. The longstanding observation of DAMA/LIBRA is in tension with WIMPs DM searches made with different techniques. Therefore, a verification of the annual modulation is of fundamental value. ANAIS is expected to probe the DAMA/LIBRA signal at about 5sigma sensitivity in a timescale of 8-9 years. Seven years' data have been taken. Therefore, in the next 1-2 years ANAIS will be focused on completing data taking. Correlation with neutron monitoring and other experiments will be done to understand possible explanations of the DAMA/LIBRA modulated signal. LSC provides support to the ANAIS Collaboration so that the data taking is kept stable and independent from parameters such as the ventilation of the underground space, the temperature, the general power supply, and from activities of construction and commissioning of other projects. LSC is also considering the installation of a NaI crystal growing facility which could provide the lab with new cleaner crystals to replace the current ANAIS crystals. **With ANAIS experiment, LSC has an opportunity to complete a crucial contribution to the understanding of the longstanding DAMA/LIBRA finding. The LSC is expected to further support this activity in the coming two years.**

DArTinArDM makes use of the ArDM detector (transferred property from ETH to LSC until future decommissioning), a two-ton liquid argon TPC inside a passive polyethylene shielding, as the veto system of the DArTinArDM experiment. The liquid argon is viewed by two arrays of photomultipliers. The sensitive volume consists of about 800 kg of liquid argon. The set-up is being refurbished to become an important facility in DarkSide-20k, in the framework of the Global Argon Program, which is an international project to develop a massive liquid argon detector for direct DM search. DarkSide-20k will make use of underground argon, which is depleted in ^{39}Ar. LSC, SNOLab, and LNGS signed an agreement to support the development of DarkSide-20k and the technology for next generation massive liquid argon detectors in the framework of Astroparticle physics. DArTinArDM set-up will serve to measure with extreme sensitivity the depletion factor in ^{39}Ar in the underground argon. The detector will exploit new technologies for the next generation of liquid argon detectors in searching for DM. At the center of the ArDM a small (1kg) TPC is installed to measure the depletion factor in ^{39}Ar in underground argon extracted from CO_2 wells. The small TPC will exploit SiPM read-out and new electronics to be installed in DarkSide-20k. The DArTinArDM installation is expected to be completed in 2025 and new data taking to last for about two years. **With DArTinArDM contribution to the DarkSide-20k experiment, LSC has an opportunity to give a contribution to an international effort on direct DM detection. LSC is expected to support this activity in the next years.**

TREX is a high pressure gas TPC in a copper vessel filled with argon depleted in ^{39}Ar or neon to search for low mass WIMPs (< 10 GeV/c^2). The TPC is designed to contain some 0.3 kg of Ar at 10 bar. WIMPs interacting in the target gas will produce an electric charge. The TPC is made with a central cathode and two drift volumes. The anode planes at both ends of the TPC are equipped with a Micromegas readout, which measures both the energy and topology of the event. A crucial parameter of the detector is the overall radio-purity. After some R&D phase, with promising results in low energy threshold by using thick GEM amplification, TREX should complete the data taking on background with both neon (first) and argon in the next four years. Depending on the finding and background level a second phase with a larger mass or improved technology and radio-purity could be taken into account. **With TREX experiment, LSC has an opportunity to make a crucial contribution to the understanding of the low mass WIMP research and pave the way for the next generation of experiments in the quest of DM. LSC is expected to support this activity in the next years.**

Related to DM experiments, **DAMIC-ES** is an Expression of Interest to host a detector for radioactivity characterization of surfaces based on DAMIC technology. **DAMIC** uses totally depleted thick CCDs reading ionization signals with an extremely low energy threshold (a few eV). A challenging evolution of DAMIC, dubbed DAMIC- M, aims at a target mass of 1kg to be installed in the Modane underground laboratory and to be operated in the coming year. The experiment will use about fifty CCDs with a thickness of 1mm and 20g each. The goal of DAMIC-M is to achieve a rms noise of 0.1 e- per pixel and a residual background of 0.1 dru (shots / kg / day / keV), a substantial improvement over the performance achieved by DAMIC. With the announced performances, the DAMIC-M project has the potential to be very competitive in the low mass zone for WIMPs. The requests to LSC are sensible and beneficial both to DAMIC and to the laboratory. DAMIC collaboration has installed a detector with Skipper technology in Canfranc, as a silicon activation monitor, of use for DAMIC-M CCDs characterization and many other low background detectors based on silicon**. With DAMIC-ES, LSC has an opportunity to give a contribution to an international effort on low mass direct DM detection and develop low background surface screening techniques. LSC is expected to support this activity in the next years.**

Biophysics at the Laboratorio Subterráneo de Canfranc

Strategic goal

Support, maintain and execute a world-class research program in biology focused on the biological response to the lack of radiation, to address questions such as cellular aging, infection mechanisms and multicellularity and with applications in space science.

Pioneering work by Sata's team in the LNGS has demonstrated the strong influence of the lack of environmental radiation in the DNA reparation system of cultured cells of different origins (yeast, rodent, and human). Their results have been independently confirmed by other groups and corroborate the hypothesis that environmental radiation contributes to the development and maintenance of defense mechanisms in organisms living today. To investigate the biological effects and the underlying mechanisms, it is mandatory to precisely characterize the radiation field in the environments where the in-vitro and in-vivo experiments are carried out.

First results of experiments completed at LSC show the influence of the lack of radiation as an abiotic stress that leads to oxidative stress and inefficient DNA reparation. In particular, experiments on viral infection of C. elegans demonstrated the significant stress induced by lack of radiation thanks to the replica experiments on surface and underground. Other experiments are exploring the importance of the lack of radiation in cellular aging, in microbial resistance to antibiotics, in the efficiency of several DNA reparation mechanisms or as a source of multicellularity aggregation. The number and variety of experiments have enlarged the potential of underground biology experiments and support the investment in new instruments and facilities. In particular, LSC currently owns a clinostat to test biology in microgravity underground, which allows to single out this stress factor of importance for future long duration space missions. In the coming years, LSC plans to coordinate biology activities to complete biology experiments in microgravity underground with exposure to protons to mimic the exposure to radiation in space conditions.

Biology experiments at LSC open a new window of research opportunities and bring a new community of scientists to the ICTS to do experiments with high economic and social impact. It is crucial to strengthen the dedicated personnel and instrumentation in the two biolabs at LSC.

Supercondcuting Circuits Cryogenics at the Laboratorio Subterráneo de Canfranc

Strategic goal

Support, maintain and execute a world-class research program in low temperature detection techniques based on superconducting circuits and develop methods to use these technologies as future ultrasensitive particle physics detectors.

Quantum microwave electronics using superconducting circuits has emerged as one of the leading candidates for the implementation of a coherent quantum processor. Despite the rapid growth in the early years of superconducting qubits, the reality is that the best coherence times obtained already date from 2011. Quasiparticles (QPs), induced by muons, have been proven to be one of the main contributors to decoherence in flux-like qubits, but also in certain transmon qubits, which are currently the quantum computing industry standard. Besides qubits, there is larger community with interests in reducing quasiparticles: the Kinetic Inductance Detectors (KID) used in cosmic microwave background observations and dark matter searches in underground laboratories, and the superconducting nanowire single photon detectors (SNSPD) which are widespread in quantum communications. Reduction of QPs implies better sensors for the KID community with a lower amount of noise, and better detectors for the SNSPD community with a lower dark count rate.

Two Expression of Interests approved at LSC will explore the potential of these technologies to understand the influence of cosmic rays and their potential to become particle physics detectors. In particular, the Canfranc Axion Detection Experiment plans to explore the cosmological axion with masses in the W-band, a radiofrequency band where current technologies show limited sensitivity.

Cryogenic experiments based on superconducting circuits can strengthen the international position of LSC. Strong support of experimental activities is critical with the procurement and operation of a large dilution fridge underground.

VISION

The experimental research program at LSC is dynamical and evolves on the basis of the international requirements. In the next four years the LSC aims to be positioned to host one of the 1-ton double beta decay experiments, to host important contributing activities to the multi-ton dark matter experiments, to lead biology experiments in low background radiation and to run unique world-class low radioactivity techniques. In addition, the LSC aims to deliver long term data taken with the geodynamical infrastructure and to lead the low background biology experiments worldwide.

In a timescale of four years:

a) LSC aims to deliver results with NEXT-100 experiment. Results from NEXT technology could pave the way for future double beta decay 1-ton (and beyond) experiments;
b) build a program to host the NEXT-1ton detector, which include the construction of infrastructures and procurement of one ton of xenon enriched in Xe-136,
c) LSC aims to complete the CROSS program. CROSS can pave the way to the next generation of bolometer-based double beta decay experiments.
d) Complete the Spanish contributions to the construction of HK and assemble components and complete installation of the experiment with all other contributions to start data taking in 2027.
e) ANAIS aims to complete the physics program and verify/refute the DAMA/LIBRA modulation signal at five sigma.
f) The role of DArT in DarkSide-20k experiment will be executed. TREX and DAMIC will complete background studies and hopefully deliver physics results important for the future low mass WIMP experiments.
g) Identify cellular mechanisms stressed by the lack of radiation and exploit the science and technological applications of these findings.
h) Promote the development of experiments based on superconducting circuits with the exploitation of an underground dilution fridge.
i) Improve and develop world-class radiopurity assay installations (HPGe, ICPMS, XIA).

SWOT

Strengths

- **Advantages**. The management and organization of LSC offer several advantages in supporting the science program based on recommendations from the SAC.
- **Experience**. The LSC management and staff is experienced at an international level which is crucial to carry out the science program
- **Unique characteristics**. Some experimental activities underway at the LSC are unique: NEXT, CROSS, TREX, Biology. Some service facilities are unique: the copper electroforming set-up; the use of the train tunnel.
- **Reputation**. The LSC has a positive international reputation from the results obtained from the activity carried out so far and from the international level of its SAC.
- **Location**. The location of LSC is enjoyable with modern infrastructures for users.

Weaknesses

- **Disadvantages**. The remote location at present does not allow a good network connection. The depth of the underground laboratory, when compared with others, is not very competitive for some of the experiments, mainly for dark matter experiments.
- **Staff**. Considering the growing number of activities underway the number of positions should be increased and supported for a long term or turned to permanent positions.
- **Location**. LSC is in a mountain remote location. It is difficult to bring good candidates to continue their careers at LSC.
- **Gap in experience**. Due to the limited staff, LSC needs support from research institutes or universities and cannot fully exploit the economic and social impact of the research program.
- **Funding**. In the last years, some LSC infrastructures have not been sufficiently funded at national level, and therefore LSC research program could not be delivered. LSC participation in regional, national and international calls should be strengthened.

Opportunities

- **Partnerships**. The LSC has connections with other underground laboratories. It is important to keep and strengthen the connection.
- **APPEC**. LSC can play a leading role in APPEC in the coming years.
- **Leadership**. Leading laboratory in neutrino-less double beta decay with NEXT and CROSS, in the coordination of the Spanish contribution to the HyperKamiokande detector and in biology experiments in cosmic silence.
- **Use of train tunnel**. The dismissed railway tunnel offers opportunities for new excavations. A new excavation could be used to host a future large experiment once the current program is completed. The tunnel also offers a variable depth location to test the impact of cosmic rays on qubits or life as a function of muon flux.

Threats

- **Funding**. Part of the funding needed to complete the Spanish contributions to HK is not yet guaranteed. Funding for needed installations is not guaranteed.
- **Competition**. Competition with experiments in other laboratories which aim to exploit the same technique as the ones underway at the LSC could take place.
- **National and international funding**. If research groups (national and international) at installation and exploitation of experiments do not receive sufficient funding (for example NEXT upgrades to reach NEXT-HD), the future program of the LSC is compromised.
- **Rock stability**. A full understanding of the rock stability in Hall B is crucial.
- **Train tunnel**. A decision to re-open the train tunnel is a major issue for the LSC.

OBJECTIVES

In the following a number of objectives which are crucial for delivering the LSC mission are reported. The discussion includes the strategy and actions to fulfill.

DESCRIPTIONS OF OBJECTIVES

1. Staff establishment

Administration staff is composed by three permanent positions and by two other, project admin and logistics, financed with funds from a currently approved project. It is crucial that the administration team can be strengthened by stabilizing these positions. This is the most important objective in human resources for the proposed strategic plan. LSC is weak in long-term technicians supporting and maintaining equipment and services, whose activities are currently performed by personnel completing their PhD programs at the LSC. LSC needs a technician working on daily needs of the cryogenics services and in samples management in the physics, chemistry and biology labs. Among the scientific personnel, LSC requires long-term engineers established at the LSC to design, supervise construction and deliver large infrastructures to host the program of large experiments. Without this manpower support, the LSC cannot fulfill the objectives discussed in the present document. Funds to support Human resources are beyond the scope of this document, which require identifying opportunities, as there are not regular calls for human resource in Spanish public consortia.

2. Risk assessment

It is crucial the LSC invests in safety assessment analysis related to the installation and operation of NEXT-100, NEXT-HD, TREX, and DArT, critical to the long-term operation of the installation.

3. Improve existing and create new LSC research supporting facilities

a) **The ULBS should be completed with two new HPGe based on the successful GeRysy detector,** which is the world record screening instrument of low background radiation in small samples. LSC plan includes the development and installation of the best HPGe facility worldwide, ready for the challenges posed by the requirements future experiments. **It should also be equipped with a XIA alpha counter**.

b) **LSC should have a multipurpose dilution fridge facility underground,** to host R&D and experimental needs based on superconducting circuits.

c) Based on the use of the currently installed liquid nitrogen generator and the increasing needs by the experiments and services, it is crucial to equip the LSC with a **new larger liquid nitrogen generator** and a new compressor. This system will supply the ULBS and all experiments and facilities which require nitrogen.

d) A new **high sensitivity neutron spectrometer**, based on He-3 counters (and CLYC crystals, if successful R&D), is needed to monitor the neutron spectra in different locations. This will become a fundamental service for long term experiments like ANAIS and NEXT and for biology experiments.

e) A program of **radon reduction** is ongoing. A radon emanation instrument is in commissioning and some improvements are needed to make it fully operational. A new noble gas separation instrument, intended to remove Radon from Xenon and Argon, is being built. It is crucial to support the delivery and installation at the LSC of technologies to improve radon suppression.

f) **Improving the network connection** at the LSC is fundamental.

4. Support and improve the Science program to keep a high international visibility

- Double beta decay. It is crucial that the NEXT-100 detector completes data taking. An investment is foreseen to support a new copper plate for NEXT-100, to further develop high purity copper shielding for NEXT-HD. Copper is valuable for the LSC and can be re-used for other activities in the long term.

- Dark Matter. LSC will support ANAIS to complete its data taking. LSC should work with the ANAIS collaboration to monitor environmental parameters and to improve background content in their crystals with the first ultra-pure NaI growing facility to be installed in collaboration with Princeton University and LNGS. DArTin ArDM program should be supported with the maintenance of ArDM detector and safety elements.
- The LSC should further develop the **biology labs** equipment both on the surface building and underground, open to a new community which performs experiments with high economic and social impact.
- The LSC should be open to **new proposals** which could be an opportunity to increase the visibility of the LSC. Some budget could be left over for an investment which can be foreseen for this work.
- The LSC will give support to the gravitational waves community. It is strategic the LSC supports this activity given the plans to host the gigantic Einstein Telescope project in Europe.

5. Monitoring underground rock stability

Rock stability measurements are carried out regularly in the various halls at the LSC underground. This action has been ongoing since 2010 and must be maintained to continuously monitor and validate a safe access to the underground installations. Measurement results show that Hall B is under a slow relative movement. To understand this behavior a study has been done by a consultant Company. The LSC must continue supporting this activity and carry out actions, if needed, to better understand current trend.

6. Outreach, broader impacts of research activity at the LSC

The proposed research activity at the LSC will continue to involve undergraduate and graduate students from experimental collaborations. The LSC will host collaboration meetings and organize international Workshops. The LSC is engaged in outreach activities. The LSC is supposed to organize one open day per year. In this occasion the laboratory is open to the public and lectures are given to participants on the research activity carried out at the LSC. A strong collaboration with the local Major and the Somport Control Office is supposed to continue.

ACTIONS TO FULFILL OBJECTIVES

In order to delivery world-class science the LSC must fulfill the following actions.

Staff establishment

LSC must ensure funding for the five positions emphasized above, hopefully turn them into permanent positions. The number of long-term resident scientists should be maintained or increased.

Risk assessment

The LSC Director and safety manager will ensure that a proper risk assessment is carried out prior to underground installations and operations; 2) The LSC Director will ensure each experiment has identified an expert in matter of safety (GLIMOS).

LSC research supporting facilities

1) It is crucial for the LSC to enhance the network connectivity.
2) The LSC will upgrade the copper electroforming facility and the ICPMS lab in the clean room and maintain collaboration with the LNGS, GADMC and Jagiellonian University on low background techniques.

Science program

Double beta decay

1) LSC must support the construction of NEXT-HD to deliver DBD results with enriched gas; 2) LSC must complete the science program of CROSS.

Dark Matter

1) LSC must support the data taking of TREX demonstrator (0.5 kg scale) to deliver data with neon and depleted argon and must support the construction of the DAMIC test detector; 2) LSC must support ANAIS to complete its data taking and dismantling; 3) LSC must support the ArDM infrastructure, property of LSC until dismantling the DArTinArDM experiment.

Biology

LSC must host underground activities in biology to test the impact of muons and natural radioactivity reduction in life; 2) LSC must acquire the equipment needed to replicate experiments on surface and underground.

Monitoring underground rock stability

LSC must ensure that data is taken regularly to monitor the rock stability.

Outreach, broader impacts of research activity at the LSC

1) LSC will organize one *open day* event per year; 2) LSC will run the exhibition room in La Casa de los Abetos; 3) LSC will organize at least one international science workshop per year to foster the laboratory at an international level.

Technological and industrial program

LSC must contribute to the industrial exploitation of the technologies developed and hosted in the lab. Since 2022, LSC participates in events connecting science and technology with industry. Current activities related with the production of the Spanish contribution to the HyperKamiokande construction helps to strengthen the relation with industry. In the period of this strategic plan, a number of programs will be explored in collaboration with external partners:

- Production and applications of ultrapure crystals for gamma and neutron monitoring.
- Biological applications of processes in cosmic silence.
- Processing of ton-scale ultrapure copper elements.
- High sensitivity analysis of radioelements.
- Cryogenic testing of materials and superconducting circuits in cosmic silence.

TIMETABLE AND FOLLOW-UP

	2025	**2026**	**2027**	**2028**
Delivery science				

NEXT-100	data taking	data taking	improvements	data taking
NEXT-HD	R&D	R&D	infrastructures	infrastructures
CROSS	data taking	data taking	new proposal	new proposal
HK*	fabrication	fabrication	assembly	data taking
ANAIS	data taking	decommission		
TREX	data taking	data taking	data taking	decommission
DArTinARDM	data taking	data taking	decommission	
Biology	data taking	data taking	data taking	data taking
Facilities				
Copper e-forming	underground	underground	underground	underground
Neutron spectrometer		Installation	data taking	data taking
New clean tents	installation			
Dilution refrigerator		installation	running	running
New liquid nitrogen plant			Installation	
New R&D for DAMIC		installation	data taking	data taking
Equipment				
Copper shielding	procurement			
XIA alpha counter		Installation		

*NOTE: LSC CONTRIBUTION TO INTERNATIONAL EXPERIMENTS LOCATED IN OTHER UNDERGROUND LABORATORIES

INVESTMENTS

LSC FINANCIAL RESOURCES

The LSC Consortium has been guaranteed funding until the end of 2031 through the Collaboration Agreement signed in 2021:

	2025	2026	2027	2028	TOTAL
MINECO Running expenses	1.056.608€	1.056.608€	1.056.608€	1.056.608€	4.226.432€
MINECO Investment	50.000€	50.000€	50.000€	50.000€	200.000€
Gobierno de Aragón Investment	510.742€	510.742€	510.742€	510.742€	2.042.968€

TOTAL	1.617.350€	1.617.350€	1.617.350€	1.617.350€	6.469.400€

The amounts shown in the table are sufficient to cover the funding of both the personnel running expenses and the running cost of the LSC during the stated period. The Consortium has remaining resources which can be valued in 1.500.000 €.

PLAN FOR INVESTMENTS

In the following table the investments which have been discussed in this document are summarized. Costs do not include VAT.

Facilities and work to support research	**Cost**	**Priority**
New Nitrogen supply system based on liquid nitrogen	200k€	High
XIA alpha counter	150k€	High
Neutron spectrometer based on He-3	300k€	Very High
Copper electroforming	100k€	High
ICPMS in ultra-clean environment	100k€	Very High
Science program		
New generation of HPGe	600k€	Very High
Dilution refrigerator for detectors based on superconducting circuits	800k€	Very High
Copper shielding procurement	500k€	Very High
Water tank infrastructure	2 M€	Very High
Water purification system	200k€	Very High
Biology lab equipment	500k€	Very High
High Performance Computing	300k€	Very High
Support new R&D proposals	200k€	High
Long term plan		
Spanish contribution to Hyper-Kamiokande*	15M€	Medium term
1ton Xe-136 procurement	20M€	Medium term

* 9.2 M€ have been funded as the Spanish contribution to the HK construction (2021-2026).

REMARKS ON LONG-TERM INVESTMENTS

The LSC is involved in two big projects, very important for the long-term future of the lab, which involve hosting a world-class experiment and contributing to an international neutrino telescope:

- a long-term research program to build NEXT-1ton is under consideration, boosted by both the big success of the NEXT technique (good energy resolution and track reconstruction) and the international context where NEXT represents one of the three technologies competing to reach sensitivity close to 10^{28} years.
- The LSC is the coordinator of the Spanish contribution to the Hyper-Kamiokande international telescope, which allow the LSC to play a fundamental role in the industrial contribution and exploitation of the Hyper-Kamiokande telescope.

FOLLOW-UP INDICATORS

Indicator	2025	2026	2027	2028
Staff establishment: *Total number of people working at the LSC (permanent + temporary staff + resident researchers)*	28	30	31	33
Quantitative Evaluation:				
Risk assessment: *Number of evaluation reports and actions taken (by request)*	1	1	1	1
LSC research supporting facilities: *Number of new facilities installed*	1	1	1	1
Running Experiments: *Number of experiments completed and decommissioned*	0	1	1	1
New Experiments: *Number of new EoI and experiments approved*	2	2	2	2
Budget application submissions: *Number of calls*	2	2	2	2
Agreements/Collaborations in R&D with industry	1	1	2	2
Outreach, broader impacts of research activity at the LSC *Number of visitors*	2000	2000	2000	2000
Events organized	2	2	2	2

The overall evaluation of the program is achieved by:

- Advisory committee reports (each semester). They evaluate the progress of experiments and services (described by the director) based on the scientific and technical results. The committee identifies milestones achieved and potential drawbacks in the planned actions.
- Director´s reports to the Executive committee. Twice per year the director reports on the progress of experiments and services to the executive committee, presents human resources needs and consumed budget.
- Annual budget plan and annual strategic plan. Once per year the director and manager present both the scientific and business plan to the executive board, which should be evaluated and approved, based on the progress and consistency with the four-years strategic plan.