Laboratorio Subterráneo de Canfranc

STRATEGIC PLAN 2021-2024

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Summary

Analysis of accomplishments of previous strategic plan (2017-2020)

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

NEXT. The experiment NEXT-White has been taking data with depleted and enriched xenon. Data demonstrated that the technique is successful in both measuring the total energy of the two electrons and reconstructing the tracks of electrons. Double beta decay with neutrinos of Xe-136 has been measured. NEXT technique has been selected as one of three methods to build the next generation of double beta decay experiments. Several publications have shown all these accomplishments. This objective has been accomplished.

CROSS. The experiment CROSS was successfully installed and commissioned in 2019. The experiment is running steadily with several crystals based on Te-130 and Mo-100, with and without superconductive aluminum films. First science data have shown the properties of scintillating bolometers with Al surface covers. This objective has been accomplished.

ANAIS. The experiment has been taking data steadily (more than three years of data taking). It became the best experiment worldwide refuting the DAMA/LIBRA results with the same experimental technique (competing with the Korean COSINE experiment and the USA/Italy SABRE experiment). There important results have been published. This objective has been accomplished.

ArDM. The experiment has been completed and decommissioned. The experiment has taken data in single phase and a doble phase successfully. Results from all runs have been published. This objective has been accomplished.

DArT. ArDM detector is going to serve as the veto system for the new experiment DArT. The construction of DArT has been significantly delayed. Construction will start in 2021. This objective has not been accomplished.

TREX. The experiment TREX was successfully installed in 2018, but it has incurred in significant delays in the commissioning phase, due to uncontrolled electronic and background noises, since 2018. The science program is still holding. This objective has not been accomplished.

Superk-Gd. Measurements of gadolinium salt have been carried out. This work helped in identifying the best Company which produce a high radio-pure salt for the project SuperKamiokande-Gd. The results were published with LSC members in the author list. This objective has been accomplished.

GEODYN. The infrastructure took good data in 2018 and 2019 but has gone through a number of maintenance and refurbishment activities. It is, at present, not running. This objective has partially been accomplished.

Biolabs. The biolabs were not installed in the period 2017-2020 due to budget restrictions (no federal program approved in Spain since 2018). This objective has not been accomplished.

In addition, during the time frame of the previous strategic plan it is worth underlining the following.

- Installation and commissioning of the new copper electroforming installation. This system will be used to massively produce ultraclean copper for a copper printer machine.
- A liquid nitrogen machine was installed. It is steadily producing liquid nitrogen underground.
- A clean tent ISO-5 and ISO-6, to house NEXT-100 in the coming years, was installed in Hall A.
- The support structure and the cooling system were installed for CROSS in Hall B.
- A cloud chamber was installed in the LSC exhibition room.
- Lead was procured to shield several experiments.

Mission and vision

The present strategic plan details the vision, mission, and goals of the LSC for the period 2021-2024.

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 neutrino physics, dark matter, geophysics 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 search of dark matter, and on geophysics. More opportunities could be of interest for the LSC, such as a program in biology 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 world-class 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 by 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 and UPV in Valencia, DIPC in San Sebastian, IFCA in Santander, IGFAE in Santiago, IFAE and IMB-CNM in Barcelona, CIEMAT and UAM in Madrid. In the last 3 years, the LSC has created the researchers in-residence (multi-year stages) program. At the end of 2020, three researchers from DIPC, CIEMAT and Jagiellonian Univ. 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.

The International Landscape. The 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 require 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, workshop), offices and meeting rooms are also available on the surface 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 users both from collaborations working on-site and interested in the service the LSC can provide:

- Material radio-purity measurements with very low background HPGe detectors (Ultra Low Background Service, ULBS)
- Radio-pure copper parts manufacturing service using the electroforming technique (Copper Electroforming Service, CES)
- Underground clean room class ISO 6 and class ISO 7 (Clean Room Service, CRS)
- ICP-MS for radio-purity assay

- Environmental Service
- Two Conference rooms for institutional meetings with 98 seats each.

Main general support infrastructures are also present at the LSC:

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

Ultra Low Background Service (ULBS)

At the LSC this facility consists of seven HPGe detectors for gamma spectroscopy. This facility is of great use to carry out radio-purity assay of detectors components. This assay work 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. The ULSB has been upgraded with a well germanium detector paid by the Jagiellonian University. Strong connections with other similar facilities at LNGS (Italy), Boulby (UK), and HADES (Belgium) already exist. **It is crucial that this Service is supported and upgraded**. At present, one permanent staff is working on this Service. A second position is fundamental. New investments can be considered to upgrade the Service, namely: turn the facility into a radon-free clean room; equip the facility with an XIA alpha counter; support the development of a next generation HPGe in collaboration with LNGS and Jagiellonian University in Krakow.

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 material 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.** The Service can be upgraded with a new setup to be installed underground in the clean room.

The ICP-MS

An ICP-MS instrument has been installed at the LSC on surface in December 2017. 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 sub-ppt sensitivities for specific isotopes. Therefore, is a very valuable instrument for an infrastructure such as the LSC. At present, the workload lies fully onto a temporary staff member. It is crucial that the temporary position is turned into a permanent one.

Environmental Service

This work is carried out by Laboratorio de Bajas Actividades (LABAC) from the University of Zaragoza. Measurement of radon, temperature, humidity, atmospheric pressure, and water quality are performed regularly on surface and underground. A summary of the results are submitted to the LSC Director frequently. In particular, this work has proved a correlation between radon and humidity in underground.

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

The Radium Tagging Service

Based on single molecule fluorescence imaging, the LSC is going to open a new service able to characterize radium in samples at the level of 10^{-18} g/g. The project has already been approved with an initial budget of 390 k€. Members of the NEXT collaboration have already designed, synthetized and tested a new molecule that changes color from green to blue when chelated with Barium cation. The installation includes an intense picosecond laser, optics, microscope, CCD, mass spectrometer, vacuum lines and a radium calibration system. A new lab is assigned to this service in the main building on surface. **It is crucial to support the installation of RITA, which would serve as the most sensitive radium technique and an important prototype to the success of the barium tagging technique to be developed by NEXT.** This would be a very valuable installation for an infrastructure such as the LSC

The High Efficiency Neutron Spectrometer

Two nuclear physics collaborations have been taking data on the neutron background with their experiments at the LSC. Their data show a neutron flux which depends on the position in the lab and changes along the year. Unfortunately, these neutrino monitors will be moved to other labs and locations. It is needed a long-term neutron monitoring 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 Expresion of Interest has been approved by the SAC at the LSC, which aims to determine the physics of these phenomena and techniques to reduce its impact. A set of experiments with improved qubits will be taken on surface at IFAE in Barcelona and underground at the LSC when the cryogenic service would be in operation. KIDs are becoming a novel superconducting device which aims to be 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. A team of CMB and particle physics scientists and engineers from IFCA and University of Zaragoza are proposing a new experiment at the LSC. Other proposals of exploiting the cryogenic service include the use of qubits and KIDs as particle physics 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 astro-particle physics, neutrino physics, geophysics and biology. 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 to **build and operate** the LSC flagship **NEXT**-100 experiment and to **probe new projects** (CROSS). 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 NEW detector is a high-pressure ^{136}Xe Time Projection Chamber (TPC), which consists of a cylindrical stainless-steel vessel, with a 6 cm think 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 SensL 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, every microsecond. NEW purposes are to validate the technology choices for the 100 kg detector (NEXT), and to measure the background and the two-neutrino mode. NEW has been successfully running with both depleted and enriched xenon, showing a high operational stability and demonstrating a very good energy resolution, better than 1% FWHM at the energy of interest, and an excellent background rejection based on track reconstruction, by exploiting the high energy deposition at the end of the trajectory.

NEXT detector active volume is a 1.15 m^3 cylinder, able to hold 100 kg at 15 bar. The energy plane will be composed of 3-inch PMTs specially developed for low- background operation by Hamamatsu, which will be located behind the cathode of the TPC, covering approximately 30% of its area. The tracking function in NEXT will be 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. High-pressure ^{136}Xe gas TPC development is the subject of the ERC Project NEXT. **NEXT could reach the present-day upper bound on the neutrinoless DBD** and show itself as the best 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. The BOLD project aiming to build a detector based on single molecule fluorescence imaging has been granted with an ERC SyG (9.3M€, 2021-2026). 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.

CROSS demonstrator consists on a composite bolometer with pulse-shape sensitivity to the surface interaction by using a superconducting thin film temperature sensor. It is **recognized as part of the CUPID R&D activities towards a ton-scale DBD detector based on bolometers**. Athermal phonons released by a particle interaction within a few mm from the surface can break the Cooper pairs in a superconducting film and produce quasiparticles with a considerably long lifetime, of the order of milliseconds. The energy stored in the quasiparticle system is then re-emitted into the absorber with a delay, which leads to a longer leading edge of a bolometric signal. The athermal phonons generated by the bulk interaction are more degraded in energy, therefore they are less efficient in the production of the quasiparticles. This gives the possibility to distinguish a bulk event from a surface one by pulse-shape analysis. The feasibility of this technique for double-beta decay detection has been successfully demonstrated with a TeO_2 bolometer with deposited Aluminium film and NbSi read-out. The technique of Al thin film acting as a signal shape modifier is a subject of the ERC-approved project CROSS aiming at development of $^{130}TeO_2$ and Li_2MoO_4 bolometers with surface background rejection capability. **It is crucial to support CROSS full running for the international visibility and leadership in DBD of the LSC.**

Dark Matter Search 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, DArT in

DarkSide program, and TREX, to search for new opportunities, such as DAMIC and support the Global Argon Program.

The idea of DM was conceived more than 80 years ago. At the beginning evidence of DM came from observations of rotational curves of galaxies and clusters of galaxies. Recently, large-scale structures, anisotropies of the cosmic microwave background, and the accelerated expansion rate of the Universe, all suggest the existence on non-luminous, non-baryoic, non-relativistic, stable matter, which we call DM. Non-baryonic DM accounts for some 23% of the Universe total mass.
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.
The LSC has an active program on direct detection of DM. At the LSC at present the DM is searched for by three different experiments: **ANAIS, DArT** 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 deliver full program results from ANAIS, to have in operation ArDM refurbished in the framework of DarkSide-20k 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.

ANAIS aims to be the first DM experiment that can directly verify the DAMA/LIBRA annual modulation. DArT has an opportunity to give a contribution to the international effort on next generation massive liquid argon detectors. TREX aims to give a contribution to low mass WIMP search at international level.

ArDM is a two-ton liquid argon TPC inside a passive polyethylene shielding. 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 have 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. In the next four years the refurbished ArDM set-up will serve to measure with extreme sensitivity the depletion factor in ^{39}Ar in the underground argon. This experimental effort is named DART. The refurbished 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 will be 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 DART installation is expected to be completed by 2018 and new data taking to last for a few years.

With ArDM/DarkSide-20k the LSC has an opportunity to give a contribution to an international effort on direct DM detection. The LSC is expected to support this activity in the next years.

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 has been in data taking since August 2018. ANAIS is expected to probe the DAMA/LIBRA signal in a timescale of 5 years. Three years data have been taken. Therefore, in the next two years ANAIS will be focused on data taking. Correlation with neutron monitoring and other experiments will be done to understand possible explanations of the DAMA/LIBRA modulated signal. The LSC has to provide 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. The 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 the 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 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 Micromega readout, which measures both the energy and topology of the event.
A crucial parameter of the detector is the overall radio-purity. Therefore, the main goal of TREX in an early phase was to deploy a demonstrator at the LSC and measure the overall radio-purity. The detector was installed in 2018. The TPC was installed inside a passive shielding. TREX exploits a complementary technology with respect to ArDM, which is more sensitive to large mass WIMPs. In the next four years we expect TREX will commission and complete the data taking on background with both neon(first) and argon. 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 the LSC has an opportunity to give 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. The LSC is expected to support this activity in the next years.

DAMIC is a low-mass dark matter experiment searching for less-than-10-GeV WIMPs as well as particles from the hidden sector. The experiment uses totally depleted thick CCDs reading ionization signals with an extremely low energy threshold (a few eV). A challenging evolution of the present search, dubbed DAMIC- M, aims at a target mass of 1kg to be installed in the Modane underground laboratory and to be operated within 5 years. 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, but even more for particles from the hidden sector. The DAMIC-M technology is unique and deserves to be supported. The requests to LSC are sensible and beneficial both to DAMIC and to the laboratory. DAMIC collaboration will install a detector with the so-called Skipper technology in Canfranc in the next years, which will serve as a silicon activation monitor, of use for DAMIC-M CCDs characterization and many other low background detectors based on silicon.

With DAMIC the LSC has an opportunity to give a contribution to an international effort on low-mass direct DM detection. The LSC is expected to support this activity in the next years.

Geophysics at the Laboratorio Subterraneo de Canfranc

Strategic goal
The LSC program on geophysics is meant to support, maintain, and execute a world-class research by exploiting long term data from GEODYN.

GEODYN is a geodynamical facility installed at the LSC. GEODYN aims to monitor seismic activity and tectonic deformation, using two continuous GPS stations at the surface, and a broad-band seismometer, an accelerometer and two high-resolution laser strainmeters installed inside the tunnel. Three different teams: Seismic (CSIC, Barcelona), GPS (University of Barcelona) and Laser Interferometer (University of Salerno) are involved in the GEODYN Structure.e The GPS stations are installed in locations close to the LSC on surface. The broad-band seismometer and accelerometer are installed in LAB780. Many geophysical phenomena are studied through time series related to the velocity and/or acceleration of an Earth point (seismometers) or to crustal deformation (strain meters). While seismometers work quite well for periodic signals having periods shorter than few hundred Hertz, the main advantage of strainmeters is the capability of recording signals whose characteristic time may range from milliseconds to months. Measurements are affected by noise, which is originated by any phenomenon not related to the geophysics. As a consequence **it is fundamental to run the detection apparatus in a location where the signal-to-background ratio is much larger than one, namely in underground**. Signals recorded by set-ups installed on the surface of the Earth show important components related to the so-called “cultural noise”, which is due to human activities, and environmental factors such as the wind, rain, temperature changes, etc. Therefore, a strainmeter installed underground offers an opportunity to search for rare phenomena. The strainmeters are sensitive to local (hydrologically-induced deformation, ocean loading tides, tectonic deformations, seasonal changes) and global (free oscillations of the Earth triggered by large earhquakes, free oscillations due to atmospheric motions and wind-driven ocean waves, seismic core modes, free core nutation due to coupling between core and mantle, due to coupling between inner and outer core) events. At the LSC there are two strainmeters 70 m long one in LAB780 and one orthogonal in GAL16. The nominal resolution of the instrument is of order $\Delta L/L \sim 10^{-12}$. **The combination of a seismometer and a strainmeter at the LSC is an important almost unique combination for an underground research infrastructure**. There is only another deep underground installation of this kind in Kamioka, Japan. **It is crucial to support the GEODYN installation**. An investment can be considered on the basis of data collected with the strainmeters in operation for a few years. The investment foresees and upgrade of the lasers, considering aging effects and better performing instruments available at the present time.

Biophysics at the Laboratorio Subterráneo de Canfranc

Strategic goal
Support, maintain and execute a world-class research program in biophysics focused on the biological response to radiation.

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 origin (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 defence mechanisms in organisms living today. To investigate the biological effects and the underlying mechanisms, it is mandatory to precisely characterise the radiation field in the environments where the in-vitro and in-vivo experiments are carried out.

Not only biological implications of the radiation induced by cosmic rays have been explored. There are multiple studies on the influence of gamma rays, and in general electromagnetic radiation in different frequency ranges, in biological processes including cell division to regulation and expression. The biological effects of electromagnetic radiation can be separated in two broad categories: those that involve functions of the nervous system and those that involve growth and healing processes. In fact, some of effects have been use in monitoring, diagnosis or treatment of diseases. Nevertheless, the underlying mechanism is most often not well understood.

Systems Biology is a biology-based interdisciplinary field that focuses on complex interactions within biological systems, which is having an important development in the science of human health and environmental sustainability thanks to the technological progress in molecular biology and in computational and mathematical modelling (bioinformatics and big data). The first CSIC research institute in Systems Biology (I2SysBio) and several research groups in biology (CBM-SO, CAB, IDIBELL,…) have proposed Expresions of Interest to exploit the low background radiation underground in experiments that explore the mechanisms of living organisms to survive in pure D_2O (toxic), ageing in low background radiation or lack of DNA reparation in model organisms.

Biophysics experiments in the LSC open a new window of research opportunities and bring a new community of scientists to the ICTS to do experiments with high economical and social impact.
It is crucial to establish a solid collaboration between the LSC and the research centers focused on molecular biology.

Cryogenics at the Laboratorio Subterráneo de Canfranc

Strategic goal
Support, maintain and execute a world-class research program in qubits and KIDs detection techniques and develop methods to mitigate the impact of cosmic rays.

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.

An important consequence of the results of these efforts is enabling the operation of qubits in environments with a low background noise such as underground laboratories, particularly from the expected suppression of QPs and their consequences. Highly coherent qubits are therefore potential quantum sensors for rare event physics. Under these conditions, the qubit linewidth combined with its sensitivity to environmental fluctuations turns the qubit into a highly sensitive probe and is already proposed as a sensor in dark matter searches [30] at research centers such as NIST Boulder and Fermilab.

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 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 three-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) LSC aims to complete CROSS program. CROSS can pave the way to the next generation of bolometer-based double beta decay experiments.
c) ANAIS aims to complete the physics program and verify/refute the DAMA/LIBRA modulation signal at more than 3 sigma.
d) The role of DArT in DarkSide-20k experiment will be determined. TREX and DAMIC will complete background studies and hopefully deliver physics results important for the future low mass WIMP experiments.
e) A new radiopurity installation RITA will be built, aiming at measuring radium content at the 10^{-18} g/g sensitivity.
f) Improved world-class radiopurity assay installations (HPGe, ICPMS, XIA).

Beyond the time frame scope of this plan and on the basis of the above results the LSC aims to:

a) build a program to host the NEXT-1ton detector, which include the procurement of one ton of xenon enriched in Xe-136.
b) contribute to international efforts like the Hyper-Kamiokande detector and the Argon Dark Matter Global Collaboration.
c) Improve the existing and create new LSC radiopurity assay installations (HPGe, ICPMS, RITA, Neutron spectrometer, XIA).

SWOT

Strengths

- **Advantages**. The management and organization of LSC offer some advantages in supporting the science program based on recommendations from the SAC.

- **Experience**. The LSC management and staff is experienced at the 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, Geodyn. 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**. The LSC, at present, has two temporary positions for key activities: ICP-MS measurements, and radio-purity assays. New positions are required, particularly in physics lab RITA and biology lab. 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 get good candidates if hiring conditions are not competitive.
- **Gap in experience**. Due to the limited staff, the LSC could profit of support from research institutes or universities at national level.
- **Funding**. In the last years, some LSC experiments and Expresions of Interest have not been sufficiently funded at national level, and therefore needed some LSC support to develp theor research program. More support from national and international level is needed.

Opportunities

- **Partnerships**. The LSC has connections with other underground laboratories. It is important to keep and strengthen the connection.
- **APPEC**. The LSC should play a leading role in APPEC.
- **Leadership**. To become a leader laboratory in neutrino-less double beta decay with NEXT and CROSS; on direct search for dark matter in participating in the Global Argon Program; on the Spanish contribution to the HyperKamiokande detector.
- **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

- **Agreement with Governing Bodies**. Funding to run the LSC depends on an agreement with Governing Bodies. The present agreement will be signed in 2021.
- **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**. Lack of funding at national or international level for some experiments can limit the future program of the LSC.
- **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 discussed. The discussion reports the strategy and actions to fulfill.

Descriptions of objectives

1. Staff establishment

Considering the work carried out at the LSC and the underground environment it is crucial that several positions are kept for a long period (three years) or turned to permanent positions: a PhD in physics supporting the ULBS and neutron installations, a PhD in chemistry supporting the ICP-MS, a PhD in biology supporting the Biolabs.Other science and technical support can be carried out by long-term researchers established at the LSC. **Without this manpower support the LSC cannot fulfill the objectives discussed in the present document**.

2. Risk assessment

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

3. Improve existing and create new LSC research supporting facilities

a) 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 need liquid nitrogen. **The ULBS should be equipped with a XIA alpha counter**.

b) The Clean Room underground should be equipped with a copper electro-forming set-up similar to the one in operation on surface. Also, the ultra-sensitive ICPMS should be used in a clean room environment to reduce the radon daughters deposited on surfaces. The TREX castle should be equipped with a **clean room tent** to facilitate operation. This equipment eliminates their needs of usingthe main clean room, which is going to be occupied vy the CES and the ICPMS instruments.

c) 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 the biology experiments.

d) A program of **radon reduction** is ongoing. A new 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 in collaboration with the CIEMAT. It is crucial to support the delivery and installation at the LSC of the detector. A new program of noble gas separation with advanced solid materials is ongoing with USA research groups working on isotopic enrichment.

e) **Improve the network connection** at the LSC is fundamental. An important effort on this program should be done. An investment of 1.5M€ + VAT is estimated. EDRF funds could cover from 50% to 100% of the investment

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

- Double beta decay. It is crucial the NEXT-100 detector is put in operation. An investment is foreseen to support the **copper shielding** for NEXT-100. A **muon veto** should be required by the experiment after the first operation runs. The copper is valuable for the LSC and can be re-used for other activities in the long term. The **Radium tagging Lab** is a new method to measure ultra-low radium content and will serve as a prototype of the barium tagging technique in NEXT experiment.
- Dark Matter. It is crucial LSC gives support to ANAIS for completing 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. DArT program should be supported with a lead castle
- The LSC should install **biology labs** both on the surface building and underground, open to a new community which plan to perform experiments with high economical and social impact. The investment will be dedicated to procure the equipment necessary to complete biology experiments on surface and underground.
- 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. A budget of the order of 100k€ could be considered.
- The LSC will continue giving strong support to the Geodyn facility. The full program of Geodyn should be revised to deliver results from a continuous data taking. It is strategic the LSC supports this activity successfully.

5. *Monitoring underground rock stability*

Rock stability measurements are carried out regularly at the LSC in underground. Measurement results show that the Hall B is under a slow change. To understand this behavior a study has been done by a consultant Company. The LSC is supposed to continue supporting this activity and carry out actions suggested to better understand the trend observed.

6. *Divulgation, 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 assure funding for the three positions emphasized above, hopefully turn them into permanent positions. The number of long-term resident scientist should be maintained or increased.

Risk assessment

The LSC Director and safety manager will assure that a proper risk assessment is carried out before underground installations and operations; 2) The LSC Director will assure 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-100 to deliver DBD results with enriched gas; 2) LSC must complete the science program of CROSS.

Dark Matter

1) LSC must support the commissioning 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 allow ANAIS to take data regularly and smoothly; 3) LSC must support the installation of DArT, particularly in the construction of the lead shielding.

Geophysics

1) LSC must assure GEODYN take data regularly and smoothly for a long term period and deliver results.

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 experiment on surface and underground.

Monitoring underground rock stability

LSC must assure that data are taken regularly to monitor the rock stability.

Divulgation, 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 international level.

Timetable and follow-up

	2021	2022	2023	2024
Delivery science				
NEXT-100		construction, commissioning, data taking .		
CROSS	data taking and results .			
ANAIS	data taking and results ...			
TREX	commisioning		data taking and results	
DART		installation	data taking	data taking
GEODYN		data taking and results		
Biology	installation	data taking	data taking	data taking
Facilities				
Copper e-forming	on surface	on surface	underground	underground
Neutron spectrometer		Installation	data taking	data taking
New clean tent	installation			
Dilution refrigerator		installation	running	running
New liquid nitrogen plant			Installation	
New R&D for DAMIC		installation	data taking	data taking
Equipment				
Lead shielding	procurement			
XIA alpha counter		Installation		

Investments

LSC financial resources

The LSC Consortium has been guaranteed funding until the end of 2021 through the Collaboration Agreement signed for the creation of the LSC. Currently, a new agreement is being discussed which should approve the amounts which each member of the Consortium will compromise to contribute with for the funding of the LSC. It is expected that these contributions will be similar to the ones between 2017 and 2020, shown in the table:

	2017	2018	2019	2020	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 were sufficient to cover the funding of both the personnel running expenses and the running 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	50k€	High
XIA alpha counter	80k€	High
Neutron spectrometer based on He-3 and CLYC crystals	150k€	High
Copper electroforming	100k€	Very High
ICPMS in ultra-clean environment	200k€	Very High
Radon Reduction	200k€	High
New clean tent	70k€	Very high
Network connection	1.5M€ (EDFR 50% contribution)	High
Science program		
Data Center and Computing	600k€	Very High
Dilution refrigerator for ultra-low background detectors: qubits, kids…	650k€	High
Radium tagging Lab	510k€	Very High
Ultra-pure NaI growing facility	100k€	Medium
Copper shielding procurement	300k€	Very High
Muon veto	100k€	High
Water purification system	100k€	Medium

Geodyn	100k€	Medium
Biology lab	300k€	Very High
Support new R&D proposals	100k€	High
Long term plan		
Spanish contribution to Hyper-Kamiokande*	15M€	Long term
1ton Xe-136 procurement **	10-20M€	Long term
Future generation HPGe detector	500k€	Medium/long term

* 7.3 M€ have been singled out (not approved yet) in the MCIN plan 2021-23 as the Spanish contribution to the HK construction (2021-2026).
** procurement of 1 ton of Xe-136 is in preliminary discussions with the MCIN.

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 granted ERC SyG 9.3M€ program to build a Barium detector based on single molecule fluorescence imaging.
- The LSC is currently 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

Staff establishment: Total number of people working at the LSC (permanent + temporary staff + resident researchers). Currently 14.

Risk assessment: Number of evaluation reports and actions taken (by request).

LSC research supporting facilities: Number of new facilities installed.

Running Experiments: Number of experiments completed and decommissioned.

New Experiments: Number of new EoI and experiments approved.

Divulgation, broader impacts of research activity at the LSC. Number of visitors and events organized.

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.