Laboratorio Subterraneo de Canfranc

Strategic Plan 2017-2020

Summary

Analysis of accomplishments of previous strategic plan (2013-2016)

In the following an analysis of accomplishments of objectives reported in the previous strategic plan follows.

ROSEBUD. The experiment has been completed and decommissioned. This objective has been accomplished. The anechoic chamber where the experiment was installed will be used for CROSS (see below)

ArDM. The experiment has taken data in single phase successfully and, at present, is taking data in two-phase mode. Results from single phase run have been published. This objective has been accomplished.

NEXT. The experiment has been commissioned with argon and depleted xenon. Risk assessment has been completed for the underground installation. Calibration measurements have been carried out. Background measurements are underway. Results from commissioning and calibration phase have been published. This objective has been accomplished.

Superk-Gd. Several measurements of gadolinium salt have been carried out. This work has helped in identifying the best Company which can produce a high radio-pure salt for the project SuperKamiokande-Gd. This objective has been accomplished.

GEODYN. The infrastructure has gone through a number of maintenance and refurbishment activities. It is, at present, in data taking. This objective has been accomplished.

CUNA. An effort has been done to understand the interest in the physics case, in funding, and manpower. In order to discuss this project on a broad and international platform a workshop has been organized at the LSC in February 2016 (https://indico.cern.ch/event/484637/). The physics case has been considered of high interest. The funding possibility is poor for the needed MeV range accelerator. The Spanish community is not very much engaged in this enterprise. This objective has not been accomplished as expected.

LAGUNA-LBNO. This project has been completed. This objective has been accomplished.

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

- Installation and commissioning in Hall A of a radon abatement system which can delivery 220 m^3/h of radon-free air. This system will be used to delivery radon-free air to experimental set-ups and facilities in operation underground at the LSC.
- The BiPo set-up has continuously taken data and will be turned into a unique facility for the LSC to carry out radio-purity assay of detectors components.
- A new building, named *Casa de los Abetos*, has been refurbished on surface. This new building will be used for outreach activities, divulgation, and for Workshops.

Mission and vision

The present strategic plan details the vision, mission, and goals of the LSC for the period 2017-2020.

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, and 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 nuclear astrophysics (CUNA).

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 strong connections with the University of Zaragoza, IFIC in Valencia, CIEMAT, and UAM. **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 delivery world-class science at international level is a benefit to Spain.

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 the underground laboratories is under consideration. Strong connections already exist between LSC and LNGS (Italy), SNOlab (Canada), Boulby (UK), LSM (France), Kamioka (Japan), and CallioLab (Finland). Future generation experiments require share of work load 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 under completion in 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)
- BiPo for radio-purity assay on planar geometry samples
- 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
- 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. In the next future the ULSB will be upgraded with a well germanium detector. 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 and one temporary Staff are working on this Service. A second permanent 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. 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, **it is crucial to support this Service.** The Service can be upgraded with a new set-up to be installed underground in the clean room. Depending on the work load a temporary position would be crucial.

The BiPo facility

This is a unique low background facility installed at the LSC. The facility has been installed at the LSC by the SuperNEMO collaboration. SuperNEMO is desgined to search for neutrinoless double beta decay in ^{82}Se. The SuperNEMO detector makes use of thin selenium foils, enriched in ^{82}Se. In order to determine the surface contamination in uranium and thorium at μBq/kg level the BiPo facility has been built. The basic idea is to use the Bi-Po β–α sequence in the ^{238}U and ^{232}Th radioactive chains to measure the contamination at this ultra-low level. In BiPo a sample foil in deployed between an array of plastic scintillators over 3.6 m^2 surface. Each scintillator is viewed by one photomultipliers on both sides of the sample foil. The set-up is able to detect the decay sequence of β and α from ^{214}Bi-^{214}Po and ^{212}Bi-^{212}Po from ^{238}U and ^{232}Th, respectively. The A=212 sequence is faster with half-life of the order of 300 ns. A prompt β–like signal is followed by a space and time correlated α–like delayed signal. Detection the prompt and delayed signals allows to reach a sensitivity on about 10 μBq/kg. The BiPo facility is being used by other collaborations besides SuperNEMO. In 2018 BiPo becomes a general use and unique facility for the LSC. **It is crucial and strategic to support this facility**. **The long term management of the BiPo facility asks for a MoU with the SuperNEMO collaboration, dedicated manpower, and investment**. Manpower to handle the facility can be shared with the ULBS Service. Investment concerns mainly nitrogen to purge the inner part of the detector. The cost for nitrogen is about 60k€ per year. A possible cost reduction can come in using radon-free air instead of nitrogen or installing a nitrogen supply line underground, based on a liquid nitrogen tank, evaporator, and distribution line (see investments table).

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 and use of this detector**. An ICP-MS can reach ppt sensitivities for specific isotopes. Therefore, is a very valuable instrument for an infrastructure such as the LSC. At present, the work load is shared between a permanent and a temporary Staff. 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.

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, and geophysics. 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 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 TeO_2.

The main **objectives** are to **deliver data by the constructed NEXT prototype (NEW)**, to **build and operate** the LSC flagship **NEXT** 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 running in calibration mode since October 2016 with depleted xenon, showing a high operational stability and demonstrating energy resolution and tracking capabilities.

Compared to liquid, gaseous xenon has a much lower fluctuation in the production of ionization charge, which results in more than ten times better intrinsic energy resolution for the ionization signal only. Electrons moving through xenon gas lose energy at an approximately fixed rate until they become non-relativistic. At the end of the trajectory, a high energy deposition is placed in a compact region. This topological signature can be used to distinguish background single-electrons from signal double-electrons. NEXT is an electroluminescent high-pressure ^{136}Xe gas TPC with about 100 kg of active material that will search for the neutrinoless DBD of ^{136}Xe by exploiting a very good energy resolution, better than 1% FWHM at the energy of interest, and a background rejection based on track reconstruction.

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. NEW data will make possible the validation of the NEXT background model, currently based on MonteCarlo simulation and material-screening measurements. If the estimated background is correct, **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.

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 witha 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 installation and 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, ArDM and DarkSide-20k, 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: **ArDM**, **ANAIS**, 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 first 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.
ArDM/DarkSide-20k 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 WIMP interacting in the liquid argon produces scintillation light (prompt signal) and electrons. The detector operates with an electric field, which drift the electrons toward a small volume of gas argon. The electrons in gas move under a second electric field, which amplifies the scintillation and makes a delayed signal. The different specific response of the detector to electron-like events, from different background components, and to WIMP-like events make the liquid argon TPC a fundamental experimental set-up to search for DM WIMPs. Radiogenic neutrons are an irreducible background. Therefore, the radio-purity of the detector components is critical.
ArDM is at present the largest two-phase TPC using liquid argon and installed in an underground laboratory. ArDM is in data taking in two-phase mode. Within 2018 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.
ArDM has achieved fundamental results on the pulse shape discrimination in liquid argon for DM search. Data from the second run in 2018 will improve present results and our general understanding on how to operate a massive two-phase liquid argon TPC.
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.

At present a temporary position is dedicated to ArDM and DART. Considering the relevance of the scientific program at international level and safety issues related to liquid argon in underground, this temporary position should be turned into a permanent one.

The ArDM collaboration claims data transfer is difficult from the LSC. In future years this problem could affect other collaborations. Therefore, **an investment to improve the internet connection to the remote location of LSC is fundamental**. The optimal solution would be to deploy an optical fiber connection to LSC.

In the framework of the Global Argon Program a new infrastructure could be installed at the LSC to produce depleted argon. A distillation purification system is being installed in the shaft of a former mine in Sardinia, Italy. On the basis of depleted argon request by the Scientific Community in future years, it might be possible to investigate the possibility to install a similar purification plant for argon in a sector of the shaft which takes air to the underground tunnel at LSC. A distillation tower will be installed inside the shaft to purify argon.

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. Therefore, in the next four years ANAIS will be focused on data taking.
To exploit properly the collected data ANAIS has to measure the quenching of the scintillating crystals. This crucial measurement will be carried out in the USA in the next three years.
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.

With ANAIS the LSC has an opportunity to give a crucial contribution to the understanding of the longstanding DAMA/LIBRA finding. The LSC is expected to support this activity in the four 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 is to deploy a demonstrator at the LSC and measure the overall radio-purity. The detector is being installed and operated in 2018. The TPC will be 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 delivery data 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.

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 and ETSEC.

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.

ETSEC. The University of Warsaw, Warsaw University of Technology, University of Zielona Góra, University of the Balearic Islands, University of Valencia, Institute of Space Sciences (CSIC-IEEC) are collaborating to study the Newtonian noise underground at Canfranc. This work is of interest for future gravitational waves detectors. At present, six seismometers are deployed along the train tunnel from LAB2500 in the direction for France.

It is critical that the LSC exchanges information regularly with the GEODYN and ETSEC collaborations in order to monitor in underground the occurrence of episodic or continuous sources of human or mechanical-generated noise, which might affect the interpretation of data.

As suggested by the SAC it is crucial to establish a solid and continuous collaboration between GEODYN and ETSEC. **The LSC management should encourage this collaboration**. Considering the uniqueness of the above installations **it is crucial that the LSC supports the activities on GEODYN and ETSEC**.

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.

Biological effects of sound waves at audible and lower frequencies (ultrasound waves) have also been explored and exploited in the last years. In particular, bacterial cell proliferation after ultrasonic treatment has been investigated with focus on the influence of different physical and environmental conditions. More recently, some works have claimed modulation of fermentation with sound waves, which will have a tremendous economic impact in the industrial bio-production of added valued substances.

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 physics of radiation (ultrasound waves, I3M, CSIC-UPV), electromagnetism (IMA, UCMADIF-CSIC), as an example, are organizing a research platform named Lives In Waves (LIW) to coordinate all their efforts with the goal to uncover the mechanisms involved in observed responses of life to radiation fields. Some of the infrastructures of the LSC are of interest to this coordinated group like the Faraday and acoustic isolated room underground.

The LSC has already hosted biological experiments. GOLLUM experiment has identified and characterized the microbial communities living in the rocks (limestone) along the train tunnel. In these extreme environments, characterized by poor nutrients, bacteria and archaea species have been identified

Biophysics experiments in the LSC open a new window of research opportunities and bring a new community of experts to the ICTSl to do experiments with high economic and social impact. It is crucial to establish a solid collaboration between the LSC and the LIW platform, with the LSC acting as the umbrella installation of the LIW platform.

Vision

The experimental research program at LSC is dynamical and evolves on the basis of the international requirements. In the next three-four years the LSC aims to delivery crucial results for future developments in dark matter and double beta decay. In addition, the LSC aims to delivery long term data taking with the geodynamical infrastructure.

In a timescale of three-four years:

a) DarkSide-20k experiment will be installed at the Gran Sasso Laboratory. The role the LSC is playing with DART will be crucial;
b) LSC aims to delivery results with the NEXT demonstrator with enriched gas and have NEXT-100 in data taking. Results from NEXT technology and data taking could pave the way for future double beta decay experiments;
c) LSC aims to have CROSS in data taking. CROSS can pave the way to the next generation of bolometer-based double beta decay experiments;
d) TREX will have completed background studies and hopefully delivered physics results on low mass WIMPs.

Beyond the time frame scope of this plan and on the basis of the above results one can anticipate:

a) depending on how the interest in depleted argon develops at international level, an argon distillation tower can be installed in the LSC infrastructure (inside the air ventilation shaft) as anticipated above;
b) LSC can deliver a better and world-class radio-purity assay germanium facility by installing all HPGe inside a radon-free clean room;
c) an extension of the underground infrastructure with an additional cavern can be planned for a new Hall along the train tunnel in the case the international community has an interest to deliver a next generation experiment at the LSC, based on results the LSC will deliver in the next four years and the development of the field;
d) a refurbishment of the laser strainmeters with modern instrumentation can be foreseen for a long term activity of this unique infrastructure, depending on the development of the field and delivered results.
e) In case the CUNA project for nuclear astrophysics finds new interest in Spain, it is crucial the LSC supports this activity. A new cavern is needed for CUNA.

The above plan asks for a significant investment. In particular, a new excavation for CUNA or a future new project is estimated, from previous considerations (see Strategic Plan 2013-2016), of the order of 3M€. The investment for the radon distillation tower is estimated of the order of 5M€, based on the cost for a similar plant under installation in Italy for DarkSide-20k. The investment for new laser strainmeters is estimated to be of the order of 100k€.

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 has experience at international level which is crucial to carry out the science program
- **Unique characteristics**. Some experimental activities underway at the LSC are unique: GEODYN, NEXT, CROSS, and TREX. Some service facilities are unique: the copper electroforming set-up; the use of the train tunnel (see deployment for ETSEC, see the possibility to make a new excavation).
- **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.
- **Staff**. The LSC needs a permanent and qualified position to support safety. The LSC, at present, has three temporary positions for key activities: engineering, ICP-MS measurements, and radon emanation and radio-purity assay. Considering the activities underway these positions should be supported for a long term or turned to permanent positions.
- **Location**. LSC is in a mountain remote location. It can be difficult to get to the location in winter.
- **Gap in experience**. Due to the limited and “young” staff the LSC could profit of support from research institutes or universities at national level.
- **Funding**. In the last years experimental projects carried out in astroparticle physics have suffered insufficient investments at national level. More support from national and international level is needed. Lack of funding for the CUNA accelerator (see previous Strategic Plan) has delayed an important science program for the LSC.

Opportunities

- **Partnerships**. The LSC has connections with other underground laboratories. It is important to keep 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, in participating to TREX.
- **Use of train tunnel**. The dismissed railway tunnel offers opportunities for new excavations. A new excavation could be used to deploy an accelerator for nuclear astrophysics science (see the CUNA project). A new excavation could be used to host a future large experiments once results from the present phase of NEXT, CROSS, and TREX is completed.

Threats

- **Agreement with Governing Bodies**. Funding to run the LSC depends on an agreement with Governing Bodies. The present agreement ends 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 experiments can become a serious problem.
- **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

Staff establishment

Considering the work carried out at the LSC and the underground environment it is crucial that the LSC has a permanent position for a **management of safety**. In addition, as discussed above, it is crucial that the following permanent position are kept for the next three-four years or turned to permanent positions:

- a PhD in physics supporting the ULBS and BiPo;
- a PhD in physics or chemistry supporting the ICP-MS and CES;
- an engineer supporting general safety at the LSC and ArDM/DART activities.

Without this manpower support the LSC cannot fulfill the objectives discussed in the present document.

Risk assessment

It is also crucial the LSC invests in safety assessment analysis related to the installation and operation of NEXT-100, TREX, and DART. Based on the work done during the last years, an estimated investments of the order of 5k€/year is needed to fulfill this crucial work.

LSC research supporting facilities

The LSC needs a **storage space on surface**. At present, there is not enough storage space on the main building on surface. In addition, storage underground, if not motivated, must be avoid for safety reasons. A search for storage space in the Canfranc area must be carried out.

It is crucial to perform a study to understand the advantage the LSC will be equipped with a **nitrogen supply system based on liquid nitrogen**. A liquid nitrogen tank can be installed on the outside of LAB2400 with an evaporator. This system will supply BiPo and all experiments and facilities which need purging nitrogen. This investment is estimated to be about 500€/month + VAT for renting a 3000 liters vessel, evaporator, and liquid nitrogen.

The ULBS should be equipped with a proper purging system. Flowmeters and pressure gauges should be installed to monitor the performance of the system. An investment to upgrade the lead shielding plastic housing of HPGe could be necessary. An investment of the order of 5k€ + VAT is estimated.

The ULBS should be equipped with a XIA alpha counter. An investment of 70k€ + VAT is estimated.

The Clean Room underground should be equipped with a **cleaning system** which consists of an ultrasound bath with capacity of about 150 liters, a baking oven, a catch basin, and a high purity water supply system. This equipment in order to improve the cleaning operations underground and related safety. An investment of 40k€ + VAT is estimated.

The Clean Room underground should be equipped with a copper electro-forming set-up similar to the one in operation on surface.

The NEXT castle should be equipped with a **clean room tent** to facilitate operation on NEXT-100. This equipment avoids to move the NEXT-100 pressure vessel to the main clean room any time opening the same vessel is requested. An investment of 60k€ + VAT is estimated.

A radon emanation detector is being built in collaboration with the Jagiellonian University in Krakow. It is crucial to support the delivery and installation at the LSC of the detector.

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 50% of the investment.

Science program

Double beta decay

It is crucial that the demonstrator of NEXT takes background data with enriched gas. A measurement of the two-neutrino decay mode would be very valuable. Following this

measurement, it is crucial the NEXT-100 detector is put in operation. An investment of about 200k€ is foreseen to support the copper shielding for NEXT-100. The copper is valuable for the LSC and can be re-used for other activities in the long term.
It is crucial LSC gives support to complete the installation and commissioning of CROSS. Engineering work is requested to design and build the cryostat shielding structure. This work is critical and can be estimated of the order of 20k€. In addition, the LSC could support the design and construction of a muon veto for the anechoic chamber, which hosts the CROSS detector. A muon veto for this chamber will be a long term installation for the LSC and for this location is reducing the muon flux and virtually increasing the overburden. An investment of the order of 100k€ is foreseen.
A further and strategic investment for the LSC is to agree with the LNGS about the procurement of 9 tons of lead from the decommissioned OPERA experiment. This lead will be refurbished in Spain to make the shielding for the CROSS cryostat. The investment for this activity is estimated of the order of 10k€.

New interest in developing a selenium-based imaging detector for double beta decay has been submitted to DOE in USA. The LSC agreed to give support to the radio-purity assay related to this experimental effort.

The R&D to make a neutron detector based on CLYC for underground laboratories has started in 2017 in collaboration with CIEMAT and the supplier RMD (MA, USA). It is crucial to keep supporting this work for a low radioactivity neutron detector for underground laboratories is very valuable. Electronics for this R&D could imply an investment of the order of 20k€.

Dark Matter

It is crucial LSC gives support to ANAIS for data taking. LSC should work with the ANAIS collaboration to monitor environmental parameters which could affect the stability of data taking. Some investment could be necessary for this work.

It is crucial LSC gives support to complete the two-phase data taking in ArDM and the construction, commissioning, and running of DART. Some minor costs could be needed to support data taking for ArDM. **It is crucial LSC gives support to the Global Argon Program to keep a high international visibility**.

It is crucial LSC gives support to the completion of TREX which is expected to deliver data in the next four years. In particular, the LSC should monitor the risk assessment and operation procedures.

For both ArDM/DART and TREX the LSC should support an engineer position.

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.

Geophysics

The LSC is supposed to continue giving strong support to the GEODYN facility. In particular, the support is concerned about manpower for maintenance of the instrumentation and data taking.

Besides the involvement of LSC staff, collaborators from the University of Salerno and Barcelona are crucial to be supported in visiting LSC. The investment for this activity is estimated of the order of 4k€ per year. In the framework of the time window considered in the present document the LSC is supposed to delivery results from a continuous data taking from GEODYN. It is strategic the LSC supports this activity successfully.

Apart from some improvement of the electronics, to be made in the next future, and the possible installation of tilt-meters on the end monuments of the LAB780 interferometer, the interferometer setup is well established. However**, it appears that the potentiality of the LSC interferometers is limited by the frequency instability of the laser source**. Since the interferometer reference arm is much shorter than the measurement arm, strain $\Delta l/l$ (fractional change of the interferometer length l) in the measurement arm and fractional changes in wavelength (or frequency, $\Delta f/f$) of the laser light are numerically equivalent, i. e., $\Delta l/l = \Delta f/f$. We know that the strain noise level of the interferometers corresponds to the frequency noise level of their lasers, at least at frequencies higher than 4 mHz; thus, **replacing the present laser sources with better ones might improve the LSC interferometers**, even though we cannot asses how low (or high) the site strain noise actually is.
To our best knowledge, the laser sources we use (MicroG Lacoste ML1) are the best polarization-stabilized He-Ne lasers available on the market. However, a different more expensive class of stabilized lasers performs much better, namely iodine-stabilized lasers.
A possible solution would be using a diode-pumped solid-state laser (e. g., Prometheus by Coherent Inc., USA) with an external iodine-cell system, capable to stabilize the laser frequency with no modulation. Tem-messtechnik, Germany, can provide the stabilization system on request. Since we cannot be sure that the site strain noise is actually much lower than the frequency noise of the polarization-stabilized He-Ne lasers we use, first only the LAB780 laser source should be replaced.
The free-at-destination price of Prometheus laser is 45 k€, VAT not included. The price of the Tem-messtechnik stabilization system is about 40 k€, VAT not included. In addition, about 8 k€ are necessary for the optical isolators and other minor components. Therefore**, an investment of the order of 100 k€ is foreseen to upgrade the laser strainmeter in the next years**.

The LSC is supposed to give support through its staff to ETSEC data taking. ETSEC is supposed to delivery long term data in the time window considered in the present document.

The LSC is supposed to encourage collaboration between GEODYN and ETSEC.

Biology

The LSC can host the Life in Waves (LIW) platform, with small investment and open the installation to a new community which plans to perform experiments with high economical and social impact. The small investment will be dedicated to acquire equipment necessary to replicate the biology experiments underground. Therefore**, an investment of the order of 100 k€ is foreseen to host biology experiments and monitor radiation conditions underground** of interest for the designed experiments.

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. No safety issue is underlined, however more data are requested. Therefore, an investment of the order of 10k€ per year is estimated.

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. In 2019 the Low Radioactivity Technique international meeting will be hosted at the LSC.

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

1) LSC must have on a permanent basis a qualified safety manager; 2) LSC must assure funding for the three positions emphasized above, hopefully turn them into permanent positions.

Risk assessment

1) 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 connection; 2) a movable clean tent is crucial to be designed and built to accomplish the installation of NEXT-100 and other set-ups of similar size; 3) The LSC will design and build a purging system for the ULBS; 4) The LSC will upgrade the clean room with cleaning equipment as underlined above; 5) The LSC will build a copper electroforming system underground inside the clean room and maintain collaboration with the LNGS and Jagiellonian University on the use of electroforming copper.

Science program

Double beta decay

1) LSC must obtain and delivery results from the NEXT demonstrator (10 kg scale) with enriched gas; 2) LSC must boost the installation of NEXT-100; 3) LSC must accomplish the installation, commissioning, and running of CROSS.

Dark Matter

1) LSC must obtain and delivery results from TREX demonstrator (0.5 kg scale) with neon and depleted argon; 2) LSC must allow ANAIS to take data regularly and smoothly; 3) LSC must accomplish the installation of DART.

Geophysics

1) LSC must assure GEODYN and ETSEC take data regularly and smoothly for a long term period and delivery results; 2) LSC must encourage data exchange and collaboration between GEODYN and ETSEC.

Biology

LSC must host the underground activities of the platform Life in Waves to test response of lite to different types of radiation; 2) LSC must assure the platform Life in Waves could operate underground making use of existing infrastructures and with the required equipment needed to replicate the ground based experiments.

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 complete 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

	2017	2018	2019	2020
Delivery science				
NEXT enriched xenon results	background and 2-neutrino mode			
NEXT-100		Installation, risk assessment, commissioning		
CROSS detector			Installation and commissioning	
CROSS data				Data taking
ANAIS	Data taking and results			
TREX	Data taking and results			
ArDM		Data taking		
DART		installation	Data taking	Data taking
GEODYN	Data taking and results			
LIW			Installation and data taking	Installation and data taking
Facilities				
Radioprotection		Installation		
Copper e-forming			Installation	
Radon-free clean room			Installation	
CROSS support structure		Installation		
Clean tent		Installation		
Nitrogen purging for HPGe		Installation		
Liquid nitrogen plant			Installation	
New R&D for DAMIC			Installation	
Equipment				
Copper shielding		procurement		
Lead shielding		procurement		
XIA alpha counter				Installation
Cloud chamber		Installation		
Electronics for CLYC			procurement	

Follow-up of science program is managed by the LSC Director in collaboration with the SAC. Two meetings per year are organized to review the status and accomplishments of experiments in data taking and in installation/commissioning phase.

Follow-up indicators. As follow-up indicators the applied strategy follows:

- for new equipment and facilities the LSC management will follow the proposed timeline
- for the science program the LSC management will follow the recommendations proposed by the IAC (two meetings per year) in order to accomplish the program reported in the timeline.

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. In particular, in the Third Clause of the Second Addenda to the Agreement approved on the 18th of December 2015 and published in the BOE on the 28th of January 2016, the amounts which each member of the Consortium have compromised to contribute with for the funding of the LSC are established, these being between 2017 and 2020 as follows:

	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 dedicated to running expenses are considered to be sufficient to be able 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**
Nitrogen supply system based on liquid nitrogen	30k€	High
XIA alpha counter	70k€	High
Purging system for HPGe detectors	10k€	High
Cleaning system for the underground clean room	40k€	High
Clean tent	70k€	Very high
Network connection	1.5M€	Very high

	(EDFR 50% contribution)	
Science program		
Copper shielding	200k€	Very High
CROSS cryostat support structure	20k€	Very high
Muon veto for ROSEBUD hut	100k€	High
Lead shielding	10k€	Very high
Support new R&D proposals	100k€	High
Equipment for radioprotection and source handling	20k€	Very high
New copper electroforming set-up	15k€	Medium
Water purification system	50k€	High
Computing	30k€	High
Electronics for CLYC	20k€	HIgh
Biology lab	100k€	High
Divulgation, outreach and broader impact of research at LSC		
Cloud chamber	27k€	Medium
Long term plan		
New excavation	3M€	Long term
Argon distillation tower	5M€ (goal: 50% EDFR contribution)	Long term
Radon-free clean room for ULBS	420k€	Medium
Future generation HPGe detector	400k€	Medium/long term
Upgrade laser strainmeters	100k€	Medium
CUNA accelerator	3M€	Medium/long term

Remarks on long term investments

As underlined above the dismissed train tunnel offer a unique opportunity to the LSC to enlarge the underground infrastructure with more space for research. The following remarks are in order:

- a new excavation for hosting the CUNA accelerator and/or a next generation project will give to the LSC a stronger international visibility and offer an important and long term research program;
- an argon purification plant, if supported by the international community, will allow the LSC to play a fundamental role in the Global Argon Program.