The Canfranc Underground Laboratory: a multidisciplinary underground facility

A Ianni
Canfranc Underground Laboratory, Paseo de los Ayerbe, s/n E-22880, Canfranc Estación (Huesca), Spain
E-mail: aianni@lsc-canfranc.es

Abstract. General characteristics of deep underground laboratories are described. The Canfranc Underground Laboratory is reviewed. Infrastructures and experiments at the Canfranc Underground Laboratory are presented. Future possibilities for the Canfranc Underground Laboratory are discussed.

1. Introduction
Research activities in deep underground sites started in 1965 with the first measurement of horizontal muons induced by atmospheric neutrinos inside mines in India [1] and South Africa [2]. These two locations were very deep, 2700m and 3200m, respectively. In 1966 the Baksan Neutrino Observatory started operating in the Caucasus [3]. This research facility has been the first fully dedicated to underground science with horizontal access. In 1968 the first solar neutrino was detected in the Homestake mine, USA [4]. In the Kamioka mine, Japan, a new underground facility with horizontal access started operating in 1983 with the Kamiokande water Cherenkov detector [5]. In 1987 the Gran Sasso Laboratory, Italy, became the largest underground facility for Astroparticle Physics [6]. Since than a number of other underground sites have been built, the most active ones being: SNOLab in Canada [7], Canfranc Laboratory (LSC) in Spain [8], Modane (LSM) in France [9], Boulby in the UK [10], SURF in USA [11], INO in India [12] and CJPL in China [13]. These so-called Deep Underground Laboratories (DULs) have a number of fundamental features which we briefly review. Access: it can be vertical or horizontal. Horizontal access facilitates operations underground, transport of equipments. Muon flux: it depends on depth and at present, to make an example, roughly changes from $10^{-3}$ m$^{-2}$s$^{-1}$ at LSC and LNGS to $10^{-6}$ m$^{-2}$s$^{-1}$ at SNOLab and CJPG. Radiogenic neutrons flux: it does not depend on depth for DULs but on local geology and material used for lining the underground cavity; the flux is of order $10^{-2}$ m$^{-2}$s$^{-1}$ and the energy spectrum below 10 MeV. Cosmogenic neutrons flux: it depends on depth; the flux is of order ten times or more smaller than for radiogenic neutrons and the energy range is very broad. Gamma background: it does not depend on depth but on local environment; it is of order $10^4$ m$^{-2}$s$^{-1}$. Radon: it depends on local environment, in DULs is of order 50-100 Bq/m$^3$ due to forced ventilation; it can have seasonal variations; in Boulby, a salt mine, it is of order $< 1$ Bq/m$^3$.

The research carried out in DULs is mainly on Astroparticle Physics, namely neutrino physics (atmospheric neutrinos, solar neutrinos, neutrinos from the Earth, neutrinos supernovae, neutrinos from beams, neutrinos from power reactors, neutrinos from artificial sources) and direct dark matter...
observation. Due to the low background environment rare processes are searched for in DULs: neutrinoless double beta decay is the most important one.

In recent years DULs are also used to carry out geophysics research on local and teleseismic scales. In 1990s it became known that life extends deep underground in extreme environments. A large number of microorganisms live in subsurface. The interest in learning about life in underground has grown and DULs are getting involved.

From the above considerations it turns out that DULs, at the present time, are multidisciplinary infrastructures for research.

In this paper we review in details the Canfranc facility (LSC) in Spain. In section 2 we give a general description of the LSC. In sections 3, 4 and 5 we discuss research activities at the LSC. In Section 6 we draw our conclusions.

2. The Canfranc Underground Laboratory

The Canfranc Laboratory (LSC) is located at about 1100 m above sea level in the Spanish Pyrenees. In 1985, A. Morales and collaborators from the University of Zaragoza started using the abandoned train tunnel at Canfranc to carry out Astroparticle Physics experiments. At that time only old service cavities were used. At present, this space is known with the name LAB780, taking into account the distance to the Spanish entrance to the train tunnel. In 1994, a 8-km road tunnel was excavated to connect Spain and France, the so-called Somport tunnel. During the excavation an experimental hall of 118 m² was built at about 2500 m away from the Spanish entrance on a side of the train tunnel. This cavity is known as LAB2500. In 2006, a larger excavation was started with the idea to make at Canfranc an international underground facility for Astroparticle Physics. This excavation is divided into two halls, named A and B. The new laboratory is known as LAB2400. In figure 1 we show the underground space at Canfranc. The large Hall A 40x15x12(h) m³ was built in the direction to CERN, thinking about the possibility to receive a neutrino beam.

![Figure 1. Layout of underground space at Canfranc Laboratory.](image)
The total underground space available for research activities at Canfranc is about 10000 m$^3$ which corresponds to a total surface of 1600 m$^2$. In the LAB2400, Hall B has dimensions 15x10x8(h) m$^3$. The protocol to access the underground area establishes that users enter from the road tunnel and exit from the train tunnel.

2.1. Service facilities at LSC
LSC is equipped with a number of facilities fundamental for all underground laboratories:

- Screening facility equipped with seven high purity germanium (HpGe) $\gamma$-spectrometers (p-type), one SAGe well, one proportional $\alpha/\beta$-counter, an alpha spectrometer (from 2016), a NaI(Tl) scintillator 3” x 3”, four AlphaGuard detectors for radon monitoring, a Rn detector with mBq/m$^3$ sensitivity (from 2016);
- Underground Clean Room: ISO7 and ISO6 in a sector;
- Radon Abatement system (from 2016): to produce Rn-free air;
- A Chemistry Laboratory on surface;
- A Workshop on surface and underground;
- A computing facility.

In table 1 we report the background rates of some HpGe at LSC in the low energy range.

**Table 1.** Background rate in counts/day of some of the HpGe at LSC in the lower energy bin.

| Detector  | 100-2700 keV |
|-----------|--------------|
| GeOroel   | 148±1        |
| GeTobazo  | 436±2        |
| GeLatuca  | 314±2        |
| GeAspe    | 433±1        |

The chemistry laboratory at LSC can produce electroformed copper which has a lower radioactivity contamination than high quality commercial copper.

2.3. Monitoring
LSC has two monitoring programs: a first one for radon and underground water; a second for convergence measurements. In collaboration with the University of Zaragoza a number of measurements on radon background and water quality parameters are carried out on a regular basis. In addition, a unique feature of LSC, to comply safety requirements for operating tunnels, data are collected to detect signs of instability underground. The conventional method of convergence is implemented together with a set of 18 optic fibers equipped with temperature and humidity sensors. Data has been collected for more than four years on a number of locations underground.

2. The Canfranc Underground Laboratory
The main research program at LSC is the direct detection of dark matter and neutrinoless double beta decay. In addition support activities for projects performed in other laboratories are carried out by means of the facilities reported in the previous Section. In table 2 we summarize all projects which have been done or are in progress at LSC.
Figure 2. Monte Carlo simulation of a double beta decay event in NEXT.

### Table 2. Experiments and experimental activities at LSC.

| Project                      | Status        |
|------------------------------|---------------|
| ROSEBUD (DM$^a$ R&D)         | Stopped       |
| ANAIS(DM$^a$)                | Running       |
| ArDM (DM$^a$)                | Running       |
| NEXT-NEW (DBD$^b$)           | Demonstrator  |
| BiPo (DBD$^b$ R&D)           | Running       |
| BiPo (DBD$^b$ R&D)           | Running       |
| SuperKGd (R&D)               | Running       |

$^a$DM=Dark Matter.

$^b$DBD=Double Beta Decay.

See text for details.

ANAIS [14] will make use in 2016 of 112 kg of high purity NaI(Tl) to search for the annual modulation observed in DAMA/LIBRA. Eventually ANAIS will use 250 kg of NaI(Tl). ArDM [15] makes use of 2 tons of liquid argon in a two-phase TPC to search for WIMPs recoil. At present it has been operated in single phase. The two-phase mode will start in 2016.

NEXT [16] aims to search for neutrinoless double beta decay with 100 kg of Xe enriched at 90% in $^{136}$Xe. NEXT exploits a TPC in high pressure Xe (15 bars) and two readout planes: the cathode with photomultipliers to detect the energy deposited in the Xe gas; the anode with SiPMs to determine the topology of the event by means of drifting ionization electrons. NEXT will be able to distinguish signals from double electrons (DBD) with respect to signals with single electrons (background). This feature improves the background subtraction for DBD search. At present, NEXT is commissioning a 10 kg demonstrator named NEXT-NEW. The demonstrator has 50 cm drift field, 12 photomultipliers at the cathode and 1800 SiPMs at the anode. The inner TPC vessel surface is coated with TPB. In figure 2 we show a Monte Carlo simulation of a double beta decay event with two blobs at the end of the
tracks. On the contrary, a background event induced by a β or γ will produce just one blob at the end of the track.

BiPo is a set-up to measure $^{214}\text{Bi}$ and $^{208}\text{Tl}$ contamination at μBq/kg level on planar geometry. The method of tagging searches for Bi-Po space and time β−α correlated coincidences in the $^{238}\text{U}$ and $^{232}\text{Th}$ chains. The set-up has an active surface of 3.6 m$^2$ equipped with 24 sectors, each with two photomultipliers and scintillators. At present BiPo is used to determine the contamination of $^{82}\text{Se}$ foils for the SuperNEMO project [17].

SuperKGd is an experimental activity which aims to select a low radioactivity salt with gadolinium, Gd$_2$(SO$_4$)$_3$, for SuperKamiokande. SuperKGd makes uses of the screening facility at LSC.

### 3. Nuclear Astrophysics

At LSC there is interest in developing a facility for nuclear astrophysics. This effort is known as the Canfranc Underground Nuclear Astrophysics (CUNA) project. A feasibility study to make a new excavation has been performed with this purpose. CUNA aims to measure the most relevant cross sections in the s-process, namely:

$$^{22}\text{Ne}(\alpha,n)^{25}\text{Mg} \text{ and } ^{13}\text{C}(\alpha,n)^{16}\text{O}$$

(1)

The measurement is performed by tagging the neutron produced. Therefore, the neutron background is limiting the sensitivity of the project. For this reason the CUNA collaboration has carried out measurements in Hall A at LSC to determine the neutron background from the underground environment at Canfranc. Six large, 60 cm in length and 2.54 cm in diameter, $^3\text{He}$ counters at 20 atm have been used, each with a different thickness polyethylene shielding to measure the energy spectrum of incoming neutrons. The counters exploit the well known reaction: $^3\text{He} + n \rightarrow ^3\text{H} + p$ with Q=764 keV. In figure 2 we show the result of a calibration with a $^{252}\text{Cf}$ neutron source [17]. The peak at 764 keV is clearly visible. The result of the measurement gave: $\phi_n = (3.47 \pm 0.3) \times 10^{-6}$ cm$^2$ s$^{-1}$.

In spite of other projects planned in DULs on nuclear astrophysics as LUNA-MV at LNGS, the physics case of CUNA remains valid. However, the future of CUNA depends on the possibility to make a large international collaboration which can support the cost of the machine and detectors to be installed underground.

![Figure 2](image)

**Figure 2.** Calibration of $^3\text{He}$ counter performed with a $^{252}\text{Cf}$ source.
4. Geophysics
LSC is equipped with a geodynamic facility which aims to study local and teleseismic events. The facility consists of: 1) a broadband seismometer and accelerometer; 2) two 70 m long laser strainmeters; 3) two GPS stations on surface in the surrounding of the underground site. The two lasers are installed in LAB780 and in one by-pass gallery (gal 16) between the road and train tunnels, respectively. They are aligned at $90^\circ$ one with respect to the other. The instrument has a nominal sensitivity of $\Delta L/L < 10^{-12}$ and a bandwidth ranging from zero to 200 Hz. A displacement of $\Delta L/L=10^{-9}$ corresponds to $\Delta L=0.07\mu m$. The LSC site is exceptionally low noise and the strainmeters has studied non-linear ocean load tides at 120 km distance in the Gulf of Biscay. The observed amplitude and phase are well in agreement with predictions. Hydrological signatures due to the load of rain water and from discharge of the close by river Aragon have been studied with the strainmeters.

5. Life in extreme environments
Since 1990s it has been known that life extends in the subsurface and in extreme environments. Several questions need to be answered about this finding [19]: what is the extent and diversity of deep life? What are the limiting factors for life in underground? How does the deep biosphere interact with geosphere and atmosphere? What are the types of energy sources in subsurface environments? DULs offer an opportunity to carry out this research. At present scientists are trying to identify a network of sites where perform sampling according to a standard protocol [19]. LSC offers the train tunnel and other underground locations for this purpose. In this context, at present, the GOLLUM project has been proposed to the LSC Scientific Committee. GOLLUM aims to characterize microbial communities underground by extraction of DNA in rock samples (metagenomics). For a review on this subject see [20].

6. Conclusions
In conclusion LSC is the second larger underground laboratory in Europe after LNGS. It is a multidisciplinary facility equipped with a number of Services to support scientists and underground installations. At present, the research activity at LSC goes from dark matter and neutrinoless double beta decay, to geophysics and biology in the subsurface. At LSC new space is available to carry out research. The infrastructure used by ROSEBUD [21], a hut 3x3x4.8m$^3$ inside a Faraday cage and acoustically isolated, is open for new projects. This hut is suitable for rare events searches such as dark matter, chameleons underground, small set-ups for double beta decay. In Hall A about 100 m$^2$ are at disposal for new research activities.

Acknowledgments
The author wishes to acknowledge the organizers of the International Conference on Particle Physics and Astrophysics for the invitation to report about the Canfranc Underground Laboratory.

References
[1] Achar I C V et al. 1965 Phys. Lett. 18 196
[2] Reines F et al. 1965 Phys. Lett. 15 429
[3] Kuzminov V V 2012 Eurp. Phys. J. 127 114
[4] Davis R et al. 1964 Phys. Rev. Lett. 12 302
[5] Suzuki Y 2012 Eurp. Phys. J. 127 111
[6] Votano L 2012 Eurp. Phys. J. 127 109
[7] Smith N J T 2012 Eurp. Phys. J. 127 108
[8] Bettini A 2012 Eurp. Phys. J. 127 112
[9] Piquemal F 2012 Eurp. Phys. J. 127 110
[10] URL http://www.boulby.stfc.ac.uk/Boulby/
[11] Lesko K T 2012 Eurp. Phys. J. 127 107
[12] Mondal N K 2012 Eurp. Phys. J. 127 106
[13] Chen H 2012 *Eurp. Phys. J.* **127** 105
[14] Cuesta C (ANAIS collaboration) 2015 Background analysis and status of the ANAIS dark matter project *Low Radiation Techniques workshop, 18-20 March 2015*
Amaré J et al. (ANAIS collaboration) Production and relevance of cosmogenic radionuclides in NaI(Tl) crystals *arXiv*:1505.06102
[15] ArDM collaboration 2015 *arXiv*:1505.02443
[16] NEXT collaboration 2014 *Adv. High Energy Phys.* 907067
[17] Arnold R et al. (SuperNEMO collaboration) 2010 *Eur. Phys. J. C* **70** 927
[18] Jordan D et al. 2013 *Astroparticle Physics* **42** 1
[19] Kieft T L et al. 2015 Workshop to develop deep-life continental scientific drilling projects *Sci. Dri.* **19** 43
[20] 2015 *DULIA-bio Workshop, LCS, 13-14 October 2015*
[21] Coron N et al. (ROSEBUD collaboration) 2013 *Astropart. Phys.* **47** 31