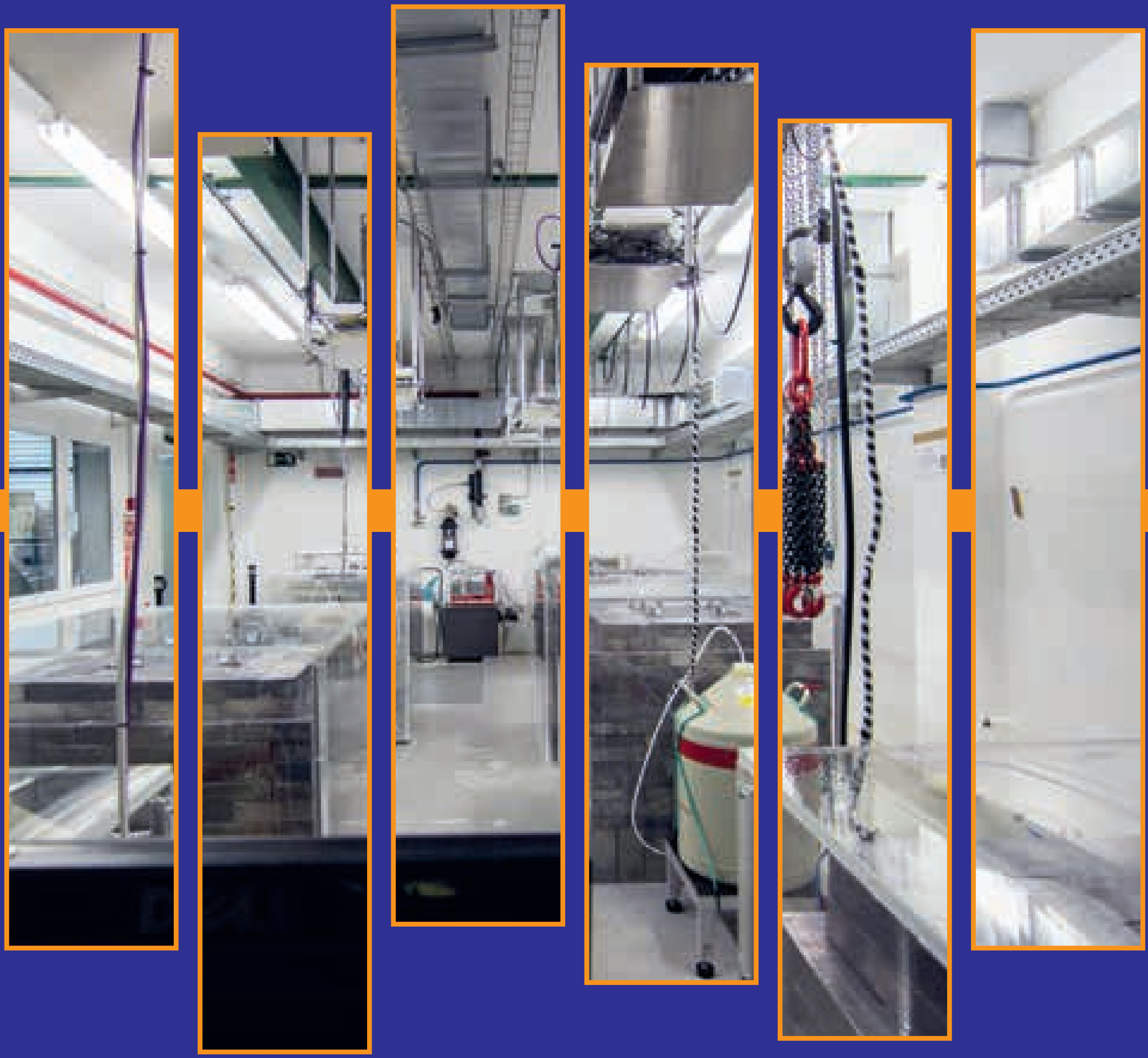
LSC

Laboratorio Subterráneo de Canfranc



ANNUAL REPORT | 2016

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Thanks to all who have helped towards the making of this editorial project

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DIRECTOR'S STATEMENT

The LSC (Laboratorio Subterráneo de Canfranc) is the second largest deep underground scientific laboratory in Europe. It is run by a Consortium between the Spanish Ministerio de Economía Industria y Competitividad, the Gobierno de Aragón and, the Universidad de Zaragoza. LSC belongs to the Spanish network of ICTS "Infraestructura Científica Tecnológica Singular" (Unique Scientific and Technological Facilities).

The LSC offers to researchers from all over the world the opportunity to carry out research on fundamental physics, astrophysics, geology, biology and, environmental science in locations of unique characteristics. In fact, at LSC the underground facilities, shielded from the natural cosmic rays radiation, open the possibility to discover phenomena happening with a very low probability. At present, the main scientific programme at LSC is focussed on direct detection of dark matter and neutrino physics, namely neutrinoless double beta decay.

Seven experimental complex equipment proposed by groups of users from international universities and laboratories are already working or under commissioning, while more underground space is still available for new proposals. Two new projects have been recommended by the Scientific Advisory Committee at the end of 2016: TREX-DM for direct detection of dark matter and, ETSEC for the characterization of newtonian noise in the framework of next generation gravitational wave detectors.

Laboratories, offices and meeting rooms are also available on the surface. A new building, named "*La Casa de los Abetos*", has been refurbished on surface next to the main building. An exhibition room and meeting rooms are available in this new infrastructure. In addition, the LSC provides at present the following services to non-scientific users:

- Material radio-purity measurements with very low background HPGe detectors (Ultra Low Background Service, ULBS)
- Radio-pure copper parts manufacturing service using the electro-forming technique (Copper Electro-forming Service, CES).
- Underground clean room class ISO 6 and class ISO 7 (Clean Room Service, CRS).
- Two Conference rooms for institutional meetings with 98 seats each.

We welcome both new scientific proposals, which can be hosted in the still free underground space and requests for services. The LSC International Scientific Advisory Committee will analyse the scientific proposals, giving its advice to the management based only on the scientific excellence.

The mission of LSC is delivering World-class science and providing international access to a unique research infrastructure.

This Report summarizes the science and the experimental activity carried out in 2016. It is based on the annual reports submitted by each experiment, which have been edited by the LSC. Any inexact element introduced in the editing should be credited to LSC.

Aldo Ianni

Canfranc Estación, March 2017

1 INTRODUCTION

LSC is a World-class deep underground laboratory designed to investigate neutrino physics, dark matter and rare processes in physics. As of today, LSC is the second largest deep underground laboratory in Europe. Strong synergy with other similar infrastructures is underway at LSC to exchange expertise and put forward common interests.

In the framework of sub-atomic physics, researchers have developed a theoretical description of the elementary building blocks of matter and of the basic forces of Nature, called the Standard Model (SM). We have tested with increasing precision all its predictions at the energies that are reachable with the accelerators. A fundamental element that was missing, the Higgs boson, was discovered at CERN in 2012. Underground laboratories, such as LSC, provide scientific information that is complementary to that obtained in laboratories with accelerators. Indeed, the first element of physics beyond the SM came from underground experiments, namely neutrino oscillations. Science carried out in underground laboratories such as LSC is growing in interest worldwide. There is a strong international competition with new proposed underground infrastructures. Yet, this competition might develop in the future in a worldwide collaboration to reach the ultimate sensitivity for extreme rare processes. Therefore, LSC is open to collaborate with other similar infrastructures.

Underground laboratories, in particular the LSC, are dedicated to the search for extremely rare nuclear and sub-nuclear phenomena, such as neutrinoless double beta decay and dark matter interactions. This search requires a very low radioactive background environment. We cannot detect the signals of very rare nuclear decays in presence of the much higher natural radioactivity background, which can be measured on surface. This background noise is due to cosmic rays, originating mainly from cosmic protons hitting nitrogen or oxygen nuclei in the upper layer of the atmosphere. The proton interaction produces a shower of secondary particles. Among these latter the muons, m, and neutrinos, n, are the most penetrating (see Fig. 1.1). Muons reach the surface of the Earth with a flux equal to about ten millions/m^2/day.

The underground area at a depth of 850 meters (about 2400 meters water equivalent) is excavated between the Somport road

Fig. 1.1: Shower of cosmic rays. The most penetrating particles are neutrinos, ν, and muons, μ.

tunnel and an abandon train tunnel about 8 km long at the border between Spain and France. Deep underground, under the Tobazo Mountain near the Canfranc village in Spanish Pyrenees, the cosmic ray flux of muons is reduced by a factor of about sixty thousand. Therefore, the reduced cosmic muons flux allows to search for very low probability processes.

Only about 5% of the matter in the Universe is visible. The rest is of an unknown nature and referred to as dark matter. Understanding the nature of dark matter is a fundamental goal for modern science. LSC is contributing to this international and fundamental effort.

At present, we know that neutrinos have very small masses. A natural explanation for the smallness of the neutrino mass requires them to be Majorana particles. A Majorana particle has the property to be its own antiparticle. If neutrinos are Majorana particles a fundamental parameter, the lepton number, conservation law will be violated. In the SM the lepton number is conserved. Searching for neutrinoless double beta decay can prove that neutrinos are Majorana particles and that the lepton number is not conserved. The lepton number violation may be related to the matter-antimatter asymmetry of the Universe. Again LSC is contributing to this important international research goal.

At LSC these research activities are carried out by a number of different detectors built by international collaborations. In particular, at LSC two experiments on direct detection of dark matter are underway, ANAIS with NaI(Tl) scintillators and ArDM with liquid argon; the demonstrator of an experiment on neutrinoless double beta decay, NEXT-NEW, is in operation, and a test facility, BiPo, for the SuperNEMO experiment planned in the Modane Laboratory, France, is fully operational. A new project on direct detection of dark matter with argon and neon in a high pressure TPC has been recommended by the Scientific Committee at the end of 2016. This project is named TREX-DM.

Other scientific sectors can profit of the unique location of the underground infrastructures at LSC. Geodynamics research can be carried out underground at LSC with the goal to measure and study extremely small changes in the stress of the rock deep inside the mountain due to very small local seismic or teleseismic events. The enhanced sensitivity underground is due to a significant reduction of the human activity and atmospheric phenomena present on the surface. LSC is equipped with a geophysics infrastructure, named GEODYN. GEODYN is an observatory and covers the whole geodynamic spectrum, from near-field seismicity to tectonic deformations, Earth tides or Earth-core nutation. The facility has three components: seismic station, laser strainmeters and external GNSS stations. The seismic station and the laser strainmeters

Fig. 1.2: The Train Tunnel at LSC

Fig 1.3: Surface Samples from the Tunnel

are installed underground. In the framework of geophysics in 2016 a new proposal was submitted to LSC for the installation of six seismic sensors to characterize the Newtonian noise for the next generation of gravitational wave detectors. This proposal, named ETSEC, has been recommended by the Scientific Committee. The sensors will be deployed along the train tunnel (four) and in one by-pass tunnel between the train tunnel and the road tunnel.

In addition, LSC and the long train tunnel (see Fig. 1.2) offer the possibility to carry out studies on subsurface microbiology to understand, as an example, what processes regulate the energy flux for life underground. The GOLLUM project at LSC is interested in the identification and characterization of the microbial communities living in a range of different rocks throughout the length of the train tunnel. GOLLUM has reported preliminary results to the Scientific Committee in December 2016 from samples taken in May 2016 along the train tunnel (see Fig. 1.3).

In conclusion, LSC is a multidisciplinary world-class science infrastructure with 1600 m^2 surface and a total volume of 11000 m^3 in underground equipped with a number of service facilities to support research activities performed by international collaborations. The main underground infrastructure, named LAB2400, is divided in Hall A, the largest experimental area, and Hall B. The other infrastructures are named LAB2500 and LAB780, respectively. At LSC international collaborations are carrying out research at the frontier of particle physics and particle astrophysics. A possible upgrade for LSC in the coming years could come through a new excavation to build an infrastructure for nuclear astrophysics or an instrumented water tank, which works as an active muon veto for a next generation experiment.

Fig. 1.4: Hall A at LSC

2 REPORT ON ACTIVITIES AT LSC IN 2016

The following experiments have been carrying out activities at LSC in 2016: ANAIS and ArDM (a CERN Recognised Experiment) on dark matter, NEXT (a CERN Recognised Experiment) on neutrino physics and GEODYN on geodynamics. Two other projects have been in operation as ancillary set-ups to experiments in other laboratories: BiPo for the SuperNEMO proposal at the LSM laboratory near Modane in France and SUPERKGd for the Super-Kamiokande experiment in Japan. In addition, the CUNA proposal for an underground nuclear astrophysics facility has been under discussion. The GOLLUM project, dedicated to extremophile ecology studies, has collected several 1 m long samples of rock along the train tunnel (see Fig. 2.1) and reported preliminary results to the Scientific Committee in December 2016.

Fig. 2.1: Example of core (5A) fragmented in pieces

In addition, two new proposals have been reported to the LSC Scientific Committee. These proposals are referred to as TREX-DM and ETSEC. TREX-DM is a high pressure TPC in a copper vessel filled with less than 1 kg underground argon (depleted in ^{39}Ar) or neon to search for dark matter interactions. ETSEC aims to deploy six seismic sensors along the train tunnel (four) and in one by-pass tunnel to characterize the newtonian noise for the next generation gravitational wave detectors. Both TREX-DM and ETSEC have been recommended by the Scientific Committee in December 2016.

The GEODYN infrastructure at LSC has three components: seismic station, laser strainmeters and external GNSS stations. The seismic station and the laser strainmeters are installed underground. The seismic station is equipped with a Titan accelerometer and a Trillium 240s seismometer. The laser strainmeters consist of two independent and orthogonally oriented 70 m long tubes under vacuum. The LSC GEODYN observatory has been integrated in the European Plate Observing System (EPOS), which was approved by the ESFRI Roadmap in 2008. In 2016 the strainmeter in LAB780 has been put back in operation. The strainmeter in GAL16 will be put back in operation in 2017.

Due to the profile of the mountain at LSC the muon flux underground is expected to show an angular distribution. In order to study this, a muon detector was installed and run in Hall A for more than one year. Later the detector was moved to LAB2500, where at present is taking data. (see Fig. 2.2). The muon detector consists of an upper and lower array of 3x3 units. Each unit consists of 4x4 plastic scintillators of $122\times122\times30\text{mm}^3$. In addition, an intermediate array with 2x2 units is used. Each scintillator unit is equipped with an avalanche photodiode and a wavelength-shifting optic fibre. In total there are 352 scintillator units. The three scintillating layers are set in coincidence. The matrix structure of the full detector allows studying the angular distribution of muons from cosmic rays underground. This work is done in collaboration with the Moscow Institute of Physics and Technology and the University of Jyvaskyla in Finland. A meeting was organized in August 2016 to discuss data and make a plan to deliver a paper about the muon angular distribution at LSC. This work is in progress.

Fig. 2.2: Picture of the cosmic rays muons detector at LAB2500

The ULBS Service at LSC has been in operation since 2010 in Hall C in LAB2400. The ULBS is offering a high quality screening facility to experiments. At present it is equipped with seven p-type coaxial High Purity Germanium (HPGe) detectors (Fig. 2.3). Each detector is shielded with 20 cm of lead with a low contamination in ^{210}Pb. An internal OFHC copper layer completes the shielding. In 2016 the inner shielding of one detector, name GeAnayet, was improved from 5 to 10 cm of copper. In addition, a better radon barrier consisting in a box made of methacrylate was installed. Besides screening measurements for existing and proposed experiments more R&D and research activities are carried out with the ULBS. In 2016 the measurements of samples from the KSTAR Tokamak (Korea Superconducting Tokamak Advanced Research) were completed and published in collaboration with other similar infrastructures. The aim of this work was to provide information for plasma diagnostics by measuring activated radio-isotopes in samples exposed to the plasma.

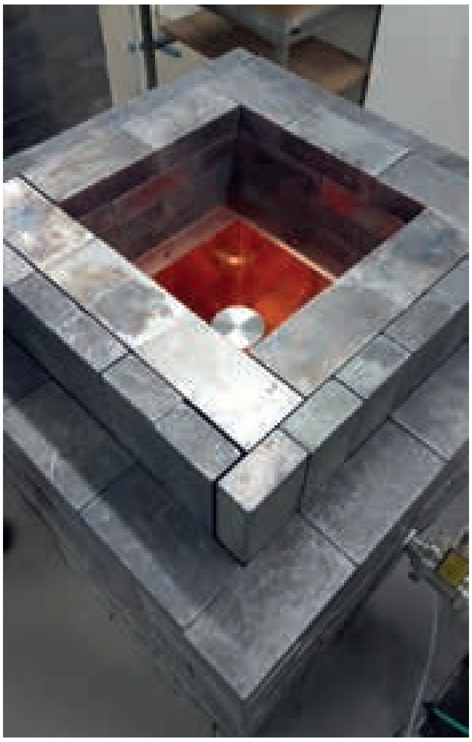

Fig. 2.3: One HPGe detector from the ULS inside the lead and copper shielding

The CES Service at LSC is a unique facility amongst the underground laboratories in Europe. This Service got interest to carry out research to understand the surface contamination due to ^{210}Pb and ^{210}Po, and to characterize the properties of electro-formed copper for low temperature use in bolometers. In 2016 a second set-up to make electro-formed copper has been installed. Both set-ups have been used to produce copper parts for the ANAIS experiment (Fig. 2.4). In particular, the CES has produced the housing for the photomultipliers and the dividers. In collaboration with the Gran Sasso Laboratory, in Italy, the CES has used copper from the OPERA experiment to make electro-formed pieces and later study how the production process is effective in removing radioactive isotopes.

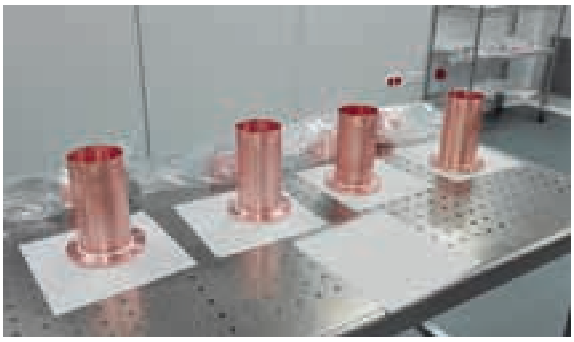

Fig. 2.4: Pieces of electro-formed copper made for the ANAIS experiment at LSC.

Environmental measurements (radon, temperature, humidity, atmospheric pressure, water radioactivity contamination) have been carried out in collaboration with the LABAC (Laboratorio de Bajas Actividades) from the University of Zaragoza both underground and on surface at LSC. In Fig. 2.5 we report the radon and relative humidity measured in Hall A from 2014 to 2016. A clear seasonal correlation between the two quantities is shown.

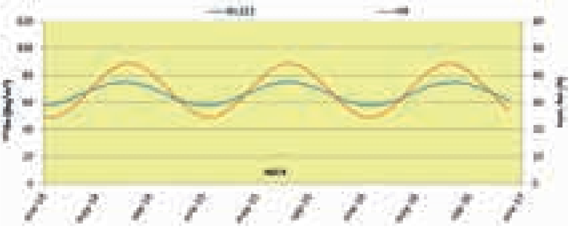

Fig. 2.5: Radon and relative humidity measurements carried out in Hall A from 2014 to 2016

Two meetings with GLIMOS took place in 2016 to review safety procedures and interactions between users and LSC in matter of safety.

At LSC a monitoring system is in operation to study rock deformations underground. A survey of the monitoring measurements was organized in February 2016. Specifically, LAB2400 is equipped with a system of optic fibers to monitor any deformation of the vault, which might occur in the underground site. Optic fibers are deployed in 10 locations: 4 in Hall A, 2 in the corridor, 1 in Hall B and 3 in the area outside the main entrance. In addition, a monitoring of the convergence (distance between fixed points) is carried out every month by means of calibrated rods for a number of specific points.

In the following we report about new infrastructures installed and upgrades carried out at LSC in 2016.

The infrastructure at LSC has been upgraded with a radon detector with sensitivity of order 1 mBq/m^3. This system is installed in Hall A on a new platform built close to the entrance (see Fig. 2.6). The detector is under commissioning. This detector will be used to monitor the radon-free air delivered by the radon abatement system and to monitor radon contamination in sensitive parts for NEXT, ArDM, BiPo and, TREX-DM.

Fig. 2.6: New platform for radon detector

A "Firetrace" fire detection and extinguishing system has been installed in the HV panel for the NEXT experiment. Similar equipment has been installed for the radon abatement system. A platform has been built in Hall A for the radon detector. The installation of the portable fire extinguisher system has been completed in both LAB2400 and LAB780 and also safety signals have been improved in the 3 laboratories. The well pump has been doubled, installing a new one and the corresponding control system for both pumps. Several maintenance tasks and improvement works have been carried out in the laboratory by the LSC staff (installation of new circuits, protection of the equipment, etc.)

An upgrade at 20 Mbps of the internet connection has been carried out. The existing radio-link will be used as backup option. This new connection is made through a dedicated fibre from LSC to ISP, providing a more stable and secure link. This connection also allows the possibility to increase the communication rate in the future.

A new building named "***La Casa de los Abetos***" (see Fig. 2.7) was given to LSC in 2015. The refurbishment of this building has been completed. The building is located just outside the surface building of LSC in Canfranc Estación. It will be equipped with an exhibition room for outreach activities and new meeting rooms.

The total number of users in 2016 has been 279, from 20 different countries.

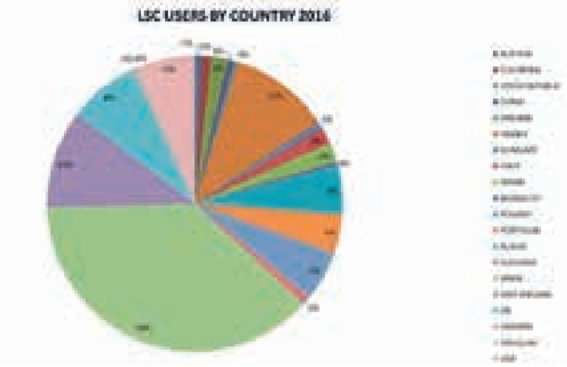

Fig. 2.8: LSC users by Country in 2016

The LSC is running a programme of visits, with nearly 2000 visitors in 2016. In Fig. 2.9 we show the trend of visitors at LSC during the last seven years.

Fig. 2.9: Records of visitors at LSC spread over the last seven years.

Fig. 2.7: The refurbished "Casa de los Abetos"

3 RECORDS OF EVENTS IN 2016

NEXT Collaboration on the platform

NEXT Collaboration Meeting (12-13 January 2016)

On the 12th and 13th of January, around 20 researchers from the NEXT collaboration met at the LSC facilities in Canfranc to carry out one of the annual meetings of this collaboration in order to evaluate the progress and current status of the experiment as well as define the steps to go forward.

NEXT Gas System

Safety Review Meeting for the NEXT-NEW Gas System (08-10 February 2016)

Due to the importance of the gas system and the need to ensure its security for the Laboratory, it was considered necessary to carry out a review by the LSC. A panel of experts from different institutions held a meeting to review the gas system of the NEXT-NEW experiment from the 8th to the 10th of February at the LSC premises. In such a meeting the NEXT collaboration carried out a presentation before the Panel which, after reviewing on site the installed system, will draft a report over it.

Nuclear Astrophysics at the Canfranc Underground Laboratory, 2nd CUNA Workshop

2nd Workshop on Nuclear Astrophysics at LSC – CUNA – (29 February – 1 March 2016)

The 2nd International workshop on Nuclear Astrophysics at the Canfranc Underground Laboratory was held at the laboratory headquarters in Canfranc Estación, from 29 February to 1 March, 2016. The workshop followed the first workshop held in 2012 at the same location, and the previous exploratory meeting that took place in Barcelona in 2009. The aim was to discuss the feasibility, the Physics program and the implementation of the Canfranc Underground Nuclear Astrophysics project at the LSC, in the context of existing and planned facilities worldwide.

18th LSC Scientific Committee Meeting (16-17 May 2016)

The Scientific Advisory Committee is composed of scientist of international reputation. It gives advice on experimental proposals and monitors the progress of the approved experiments. This is the last meeting for two of its members: Ariella Cattai and Concha Gonzalez.

GTFE 2016 Tunnel du Somport Reencounter (9-10 June 2016)

On the 9th and 10th of June the Reencounter of the GTFE (Groupe de travail francophone des exploitants de tunnels routiers) was held in our premises. Directors of the exploitation of different international tunnels attended this meeting. A visit to the underground facilities was part of the program.

Workshop on underground muon measurements (9-11 August 2016)

Muon Detector at LSC

Students and researchers belonging to the MIPT (Moscow Institute for Physics and Technology) travelled to the LSC to join this workshop and participate on discussions over the data analysis and simulation tactics of muon monitoring. Students from other national institutions also attended this workshop.

GLIMOS, Safety Talks (1st September 2016)

Whilst holding the GLIMOS (Group Leader in Matter of Safety) annual meeting for the LSC experiments, the Director invited two experts from the LNGS (Laboratori Nazionali del Gran Sasso) to give a talk in security measures and visit our facilities.

CSFCA & CSIC, Astrology & Cosmology with LSS (3-4 October 2016)

This meeting held at the LSC premises on the 3rd and 4th of October, intended to establish a synergy between two research centers: The CEFCA (Centro de Estudios de Física del Cosmos de Aragón) from Teruel and the CSIC (Consejo Superior de Investigaciones Científicas) from Valencia. There is a connections between the research carried out at LSC and at the CEFCA, which relate to the understanding of the dark matter nature with complementary methods.

Low background measurements and screening at LSC and LNGS (26-27 October 2016)

Aldo Ianni, LSC Director, proposed a workshop on Low background measurements and analysis at LSC and LNGS (Laboratori Nazionali del Gran Sasso). On the first day, three experts on radiopurity services, radioactive sources and low background measurements from both the LNGS and the LABAC (group from Zaragoza University associated to the LSC), gave talks. On Thursday 27, the three LNGS experts participated in a meeting with the LSC's specialized staff to advice on the handling of radioactive sources and discuss over a possible collaboration to develop a very low background Ge radioactive detector.

NEXT Collaboration Meeting (30th of November to 1st of December 2016)

Around 35 researchers from the NEXT collaboration met at the LSC facilities in Canfranc to carry out one of the annual meetings of this collaboration. The first results from the NEXT-NEW detector were presented at this meeting.

19th LSC Scientific Committee Meeting (2-3 December 2016)

The Scientific Advisory Committee is composed of scientist of international reputation. It gives advice on experimental proposals and monitors the progress of the approved experiments. In this last meeting the new three members, whom substitute those who ended up their contribution in May, were presented. They are: Mark Chen - Queen's University, Ontario (Canada), Eligio Lisi - INFN, Bari (Italy) y Paola Tropea - CERN, Geneva (Switzerland).

4 SNAPSHOTS

RECORDING OF THE PROGRAM ÓRBITA LAIKA FOR RTVE
(MAY 2016)

VISIT OF THE PRESIDENT OF THE DIPUTACIÓN GENERAL DE ARAGÓN
(FEB. 2016)

VISIT OF APPEC CHAIRMAN, FRANK LINDE
(NOVEMBER 2016)

VISIT MAYOR OF ZARAGOZA
(DECEMBER 2016)

5 ANAIS

THE JOURNEY OF THE EARTH AND DARK MATTER

http://gifna.unizar.es/anais

ANAIS is a project to search for dark matter looking for the annual modulation of the counting rate expected as a characteristic signature of dark matter. There is only one experiment that has reported positive evidence so far, DAMA/LIBRA at Gran Sasso underground laboratory (LNGS). Such an evidence has never been confirmed by experiments with much larger sensitivity. However, this apparent contradiction cannot be considered definitive, because different techniques and different target nuclei have been employed. A confirmation or confutation of the DAMA/LIBRA positive result can only come in a model independent way by using similar detectors, namely NaI scintillating crystals, in extremely low background and low energy threshold conditions. A few experimental efforts in the world are pursuing the same goal.

In February 2016, ANAIS electronics were installed inside a temperature-controlled space besides the ANAIS hut at LSC Hall B (see Fig 5.1). This temperature control should allow decoupling the electronics temperature from the Hall B temperature fluctuations in order to guarantee the stability the annual modulation analysis requires.

Fig. 5.1: ANAIS electronics inside a temperature-controlled space at LSC Hall B.

In March 2016, a new 12.5 kg NaI(Tl) crystal made at Alpha Spectra Inc., CO (US) was received at LSC in order to be set-up and put into operation at the shortest term for radiopurity assessment. This crystal had been grown using a more purified NaI powder (WIMPScint-III quality) and then, it should have a lower potassium content than previous AS crystals. This new detector is named in the following D3. The data taking started only two days after receiving the detector, and after having coupled two photomultiplier tubes at the LSC clean room (Fig 5.2), profiting from the availability of the ANAIS37 set-up. The new detector D3 was set in between D0 and D2 modules in order to better profit from the coincidence efficiency for the potassium content determination of WIMPScint-III powder.

D3 showed a clearly lower potassium content with respect to previous detectors, 19 ± 2 ppb, being the average previous content of about 40 ppb. However, D3 module alpha specific activity was found to be 1.16 mBq/kg, which is a factor of two higher than that observed in D2 module (0.7 mBq/kg), although a factor of

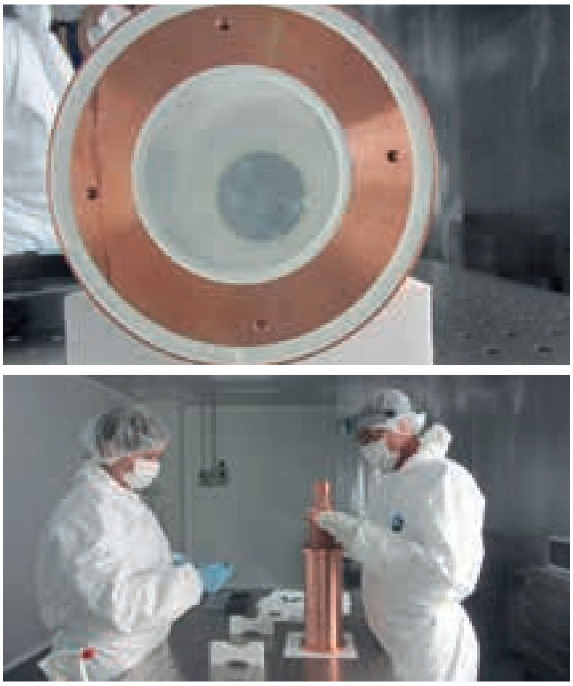

Fig. 5.2: D3 module at LSC clean room and PMT coupling.

two better than that in D0 and D1 (3.15 mBq/kg). This rate is still increasing, as ^{210}Po activity is being built by the decay of the progenitor ^{210}Pb, until equilibrium is reached; a saturation of the alpha rate at 1.8 mBq/kg was foreseen, compatible with the low energy background level produced by ^{210}Pb decay. It is worth to notice that, despite the unexpected high activity in ^{210}Pb found in D3, background in the 2-6 keV region is comparable to that of D2, thanks to the lower potassium content (see Fig 5.3).

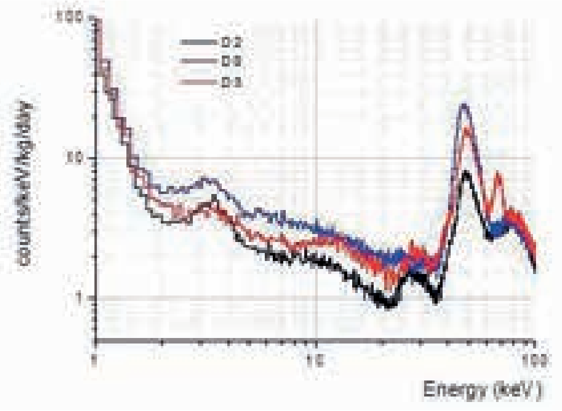

Fig. 5.3: Comparison of background at low energy for D0, D2 and D3 modules.

Because of the high alpha specific activity measured in D3 and after discussing the possible origin of the contamination in ^{210}Pb with AS, several pieces of 1 kg of NaI(Tl) were sent from Colorado to Zaragoza for the measurement of their alpha content. The pieces arrived to Zaragoza from April until August 2016 and were encapsulated at the University of Zaragoza glove box (Fig 5.4) just upon reception and measured in a dedicated facility at the Canfranc Underground Laboratory. One of the samples was also polished on the surface in order to get more information about the contamination origin. As conclusion, all the samples taken from the same ingot D3 showed similar alpha specific activities, pointing at a bulk contamination, whereas samples from a more recently grown ingot showed clearly lower values. Just to confirm these results, two additional modules, one from each ingot, funded by LSC, were ordered to AS in August 2016, D4 and

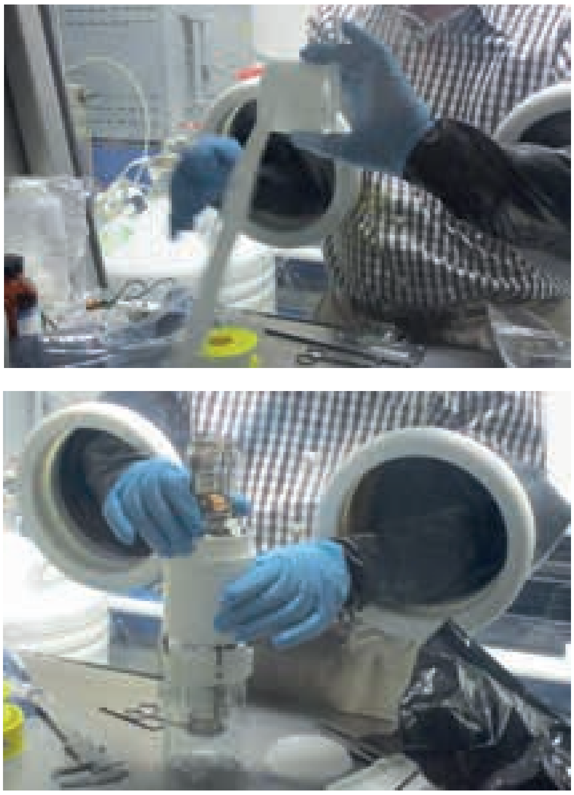

Fig. 5.4: Mounting a 1 kg piece NaI (Tl) in the glove box at the University of Zaragoza.

D5. This R+D work implied a delay on the proposed experiment timeline.

D4 and D5 modules arrived at Canfranc on November 14th and their characterization started immediately after the coupling of the PMTs at the LSC clean room (Fig 5.5) was done. Alpha specific activity in D5 module was below 0.7 mBq/kg, whereas D4 module showed levels compatible with those of D3, as expected because it was grown in the same ingot. With this information, D6, D7 and D8 modules, which should be similar to D5, as they come from the same ingot, were ordered to AS in December 2016. These crystals were purchased with the funding support from the MultiDark project and allow to complete the ANAIS112 experimental design.

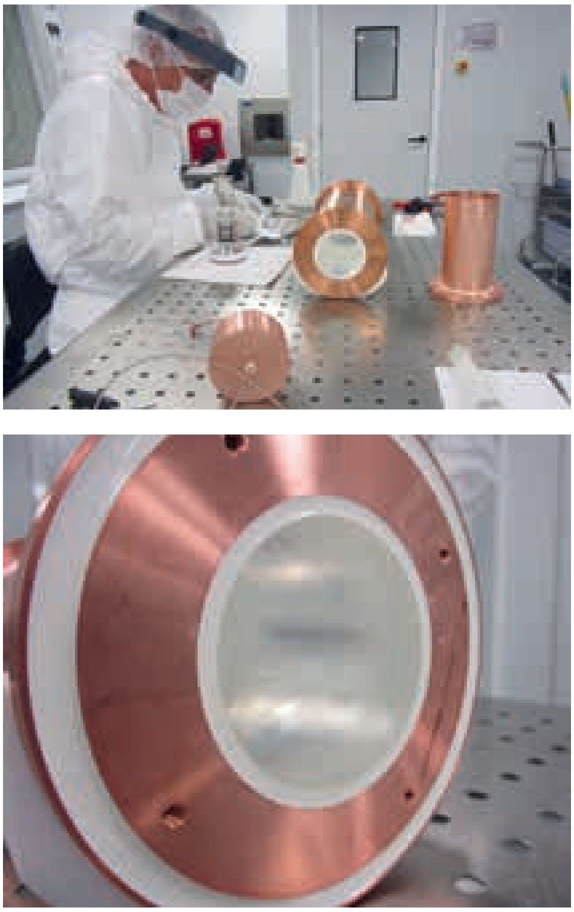

Fig. 5.5: Coupling of the PMTs to D4 and D5 modules at LSC clean room, November 2016.

ANAIS112 will consist of a 3x3 matrix of 12.5 kg NaI(Tl) modules, corresponding to a total mass of 112.5 kg. See Fig 5.6 for an artistic view of the proposed experimental set-up, which will be installed at LSC in the first months of 2017. The expected background for ANAIS112 has been assessed taking into account the background models developed for the already operated modules, based on measurements of the different background components and Monte Carlo simulation. The corresponding sensitivity has been evaluated; in five years of data taking a large part of the DAMA/LIBRA parameters space of dark matter particles could be explored. Moreover, a joint analysis of ANAIS data in collaboration with COSINE experiment (amounting 220 kg of NaI(Tl) the three altogether) could allow in two years improving the annual modulation sensitivity significantly.

Results of the ANAIS activities have been published in international journals and presented in the most important conferences on the dark matter detection and underground physics fields as IDM conference series (held at Sheffield, UK. in July 2016).

Fig. 5.6: ANAIS112 artistic view

6 ArDM

LIQUID ARGON AND DARK MATTER

http://darkmatter.ethz.ch/

The ArDM (Argon Dark Matter) Experiment is the first tonne-scale Dark Matter experiment operating at a deep underground site. The detector is designed as a dual-phase liquid-argon (LAr) time projection chamber (TPC) optimised for the detection of nuclear recoils induced by Weakly Interacting Massive Particles (WIMPs), hypothetical particles that are thought to constitute Dark Matter. The ArDM setup, installed in Hall A of LSC, is rendered in Fig. 6.1 with the inset depicting the schematic of a WIMP detection in the ArDM LAr-TPC. WIMPs elastically scattered off argon nuclei are detected by scintillation light and ionisation charge from the interaction of the recoiling nucleus in the liquid argon.

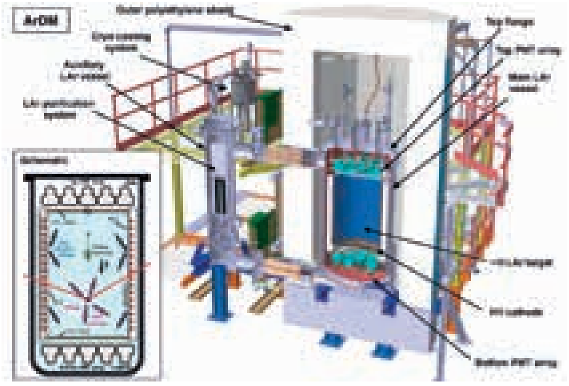

Fig. 6.1: The ArDM setup installed in Hall A of LSC. The inset to the left depicts the schematic of the WIMP detection in the ArDM dual-phase LAr-TPC. WIMPs elastically scattered off argon nuclei are detected by scintillation light and ionisation charge from the interaction of the recoiling nucleus in the liquid argon.

The detector was successfully commissioned in single-phase in 2015 (ArDM Run I). It was operated firstly with a warm (room temperature), then with a cold (87 K) gaseous argon target, and finally with the full LAr target of ~850 kg in stable conditions over six months. More than three billion triggers were recorded, measuring the primary scintillation (S1) signals. Analysis efforts were continued during 2016 to explore the high statistics data. All the raw data files (~200 TB) were transferred to CERN (Geneva), to be analysed exploiting the local computing infrastructure. The efforts lead to a fully satisfactory understanding of the obtained data, in particular the detector response and the observed backgrounds. The results were reported in two papers [1,2] as well as in a successful PhD thesis [3] published in 2016, and will be reported in another paper presently in preparation [4].

The initial experimental setup for Run I is detailed in [1], including the cryogenic system, the light readout, the neutron shield, the data acquisition and trigger system as well as the data reconstruction. The data confirmed the good and stable performance of the detector. The light yield showed a good linearity in a wide energy range, from several tens of keV to several MeV. Its absolute value was found to be around 0.8 and 1 pe/keV, for gaseous and liquid argon, respectively. Fig. 6.2 shows the distribution of 41.5 keV electron events emerging from metastable ^{83m}Kr atoms injected into the vapour phase above the LAr target. The parameter TTR, calculated from a ratio of the signals detected in the top and bottom PMTs, is related to the vertical event position, here plotted as function of the total detected light (number of photoelectrons, pe). The main panel shows a spatially uniform distribution obtained about four hours after injection, while the inset shows the distribution 30–60 minutes after injection, indicating the accumulation of ^{83m}Kr decays near the liquid surface.

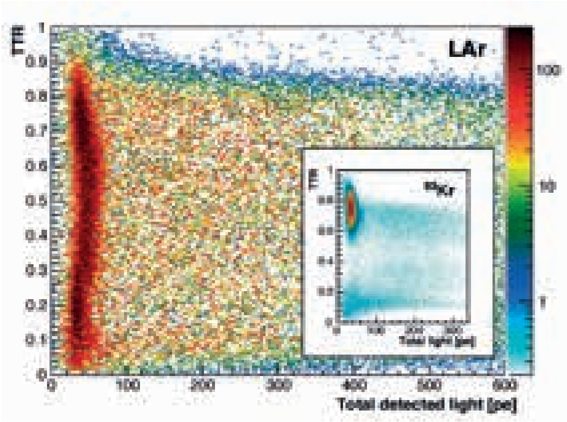

Fig. 6.2: Distribution of ^{83m}Kr events (41.5 keV electrons) obtained four hours after their injection into the ArDM detector. The vertical axis (TTR) represents the vertical position of the event. The inset shows their initial distribution, 30–60 minutes after injection, indicating the accumulation of the events near the liquid surface.

The ability to detect, trigger and reconstruct signals down to ~10 keV range demonstrates the capability of ArDM to perform searches for Dark Matter. These achievements also represent an important milestone towards sensitive WIMP searches with liquid argon targets and open the path towards next-generation 10 tons or larger scale detectors with nuclear-recoil sensitivity.

Extensive efforts were undertaken to develop a complete Monte Carlo (MC) model of the detector, based on the Geant4 simulation framework, describing the properties of the detector from first principles. It includes a full optical ray tracing, based on the modeling of optical processes such as LAr scintillation of 127 nm vacuum ultraviolet (VUV) photons, Rayleigh scattering, VUV absorption, conversion to visible blue light with wavelength-shifting TPB (tetraphenylbutadiene), reflections and refractions. The optical processes include some parameters that are not known very precisely and hence need to be determined experimentally. In this context the reflection coefficient and the VUV attenuation length were scanned over large ranges in the simulation, and results were compared to the data. A set of best-tuned parameters was obtained in a global fit, using a Bayesian variation technique. A fully satisfactory understanding of the observed data was obtained e.g. in the energy spectra as shown in Fig. 6.3.

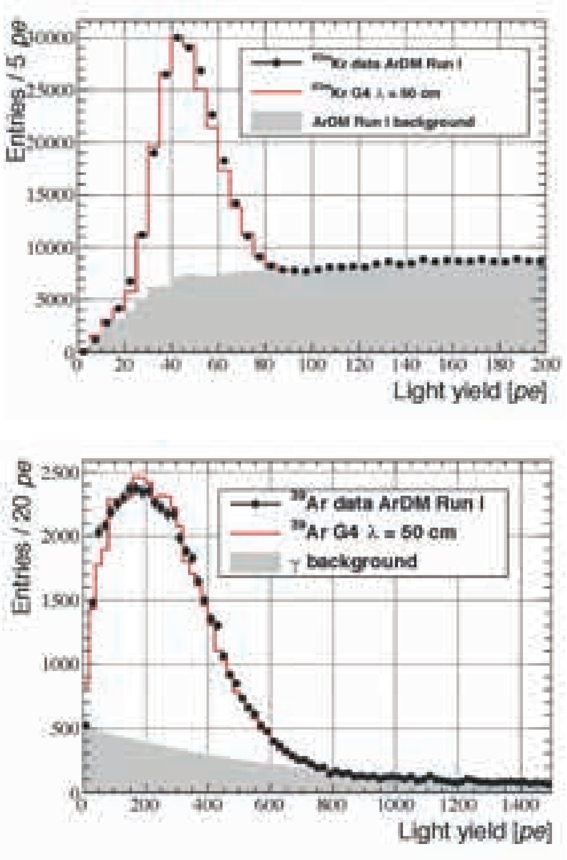

Fig. 6.3: Data (black dots) superimposed to Geant4 spectra of ^{83m}Kr (left) and ^{39}Ar (right) events using the best-tuned parameter set. The gray areas show the backgrounds for the two data sets.

This MC study resulted in a value of 0.5 m for the attenuation length of the LAr bulk to its own scintillation light, which is lower than the expected value. We interpret this with the presence of optically active trace impurities in the LAr, not filtered by the installed purification systems primarily designed to target O_2 molecules. To investigate possible impurities a combined analysis was conducted with respect to the involved photo-absorption cross sections, the measured lifetime of the slow scintillation component, as well as the mass spectra taken on argon gas samples. Full details of the analysis and the results are reported in [2]. A variety of impurity candidates could be excluded by this analysis, e.g. O_2, H_2O, N_2, CO_2, as well as the heavier elements, Xe and Kr. Elements such as hydrocarbons, which could not be excluded, are believed to be removable with an upgraded purification system. A cold charcoal trap, known to reduce impurity levels of elements with condensation points above the filter temperature by several orders of magnitude, is being added to the purification circuit of ArDM for the upcoming Run II. An increase of the VUV attenuation length, and consequently of the light yield, can be expected with the upgraded system.

Furthermore, analyses of the observed electronic-recoil backgrounds are being finalised with the best-tuned MC parameters and the high statistics data. A detailed understanding of the measured background has been obtained, confirming the expected low-background condition of the Experiment. The analysis of the calibration data taken with a ^{252}Cf fission neutron source allowed first estimates of the statistical rejection power for the electronic-recoil background by the pulse-shape discrimination (PSD) method in a tonne-scale LAr detector. These results are encouraging for large LAr projects and will be published soon [4].

In parallel to the analysis work as described above, hardware efforts resulted in the upgrade of the ArDM detector in 2016 with the newly built drift cage for dual-phase operation. The TPC drift cage basically is of cylindrical shape consisting of 27 vertically aligned field-shaper rings made of copper, transparent cathode and anode windows closing the bottom and the top, respectively. The structure is constructed inside a 10-cm-thick shell of Borotron, borated high-density polyethylene, serving as internal neutron shield. The cathode and anode windows are made of a PMMA (polymethyl methacrylate) plate, both faces coated with a conductive and transparent ITO (indium tin oxide) layer. A custom-made 100-kV high-voltage (HV) feedthrough is installed to supply the cathode voltage and the linearly decreasing voltages to the field shapers interconnected via resistor chains. A uniform vertical electric drift field is created in this way. Ionisation electrons drift upwards and are extracted into the vapour phase by a strong electric field (~3 kV/cm) between the anode window and the extraction grid immersed 5 mm below the liquid surface, producing the secondary scintillation (S2) signal. The assembly of the anode window and the extraction grid is shown in Fig.6.4.

Fig. 6.4: Assembly of the extraction grid and the ITO-TPB-coated PMMA anode window in a clean tent built in Hall A of LSC (July 2016).

The prompt scintillation (S1) in LAr and the delayed S2 light in the vapour phase are emitted in a narrow band around 127 nm in wavelength. These VUV photons are converted to visible blue light by the wavelength-shifting TPB, which is deposited on the inner surfaces of the drift cage, containing multi-layer plastic-film reflectors on the sides, as well as the anode and cathode windows. The S1 and S2 signals are recorded by 24 8" cryogenic PMTs arranged in top and bottom arrays. The assembly of the top PMT array is shown in the left picture of Fig. 6.5. The TPC drift cage mounted under the top PMT array with the 100-kV HV feedthrough can be seen on the right. The TPB coating of the PMT windows, which was used for Run I, could be removed thanks to the ITO-TPB-coated anode and cathode windows. This new design will improve largely the fiducialisation capabilities of ArDM; only events inside the active volume can deliver scintillation and charge signals.

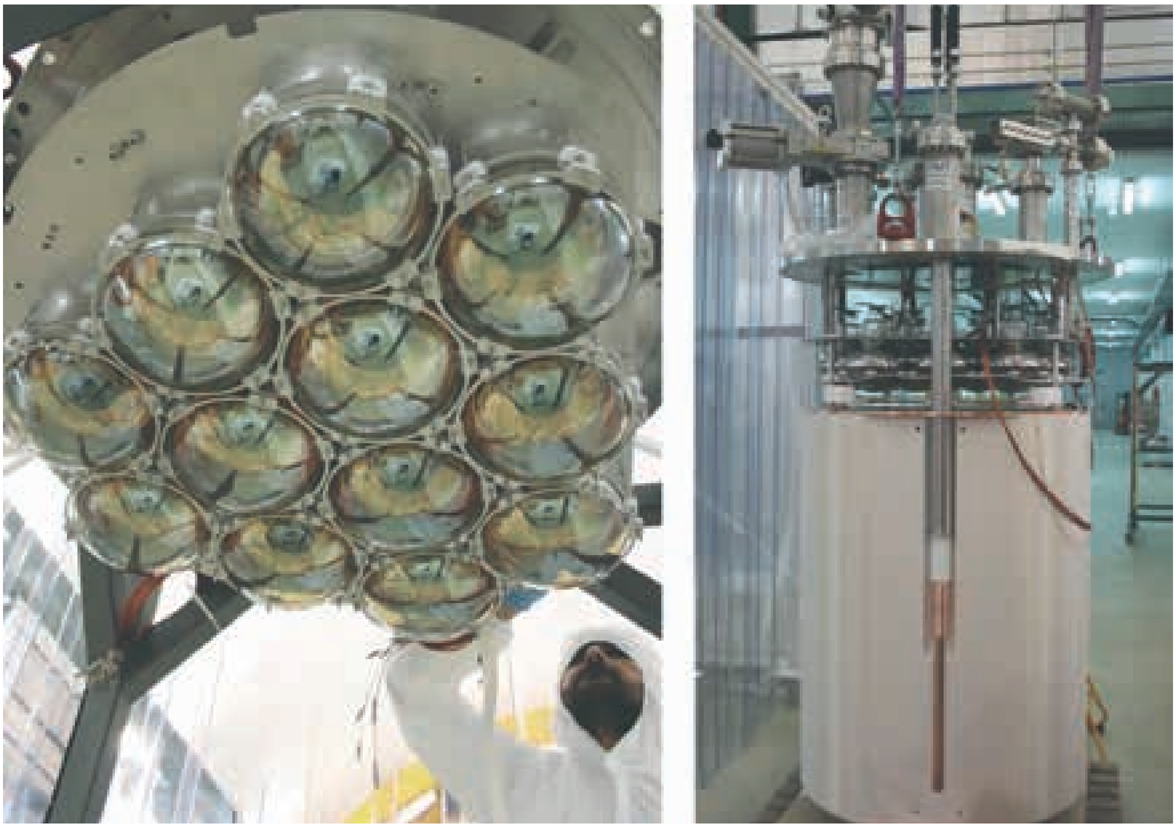

Fig. 6.5: Experimental upgrade of the ArDM detector in 2016. Left: Assembly of the top PMT array. Right: The TPC drift cage mounted under the top PMT array. The custom-made 100 kV HV feedthrough for the electric drift field is visible.

Commissioning of the upgraded detector has been undertaken recently with a warm gaseous argon target. Currently, the Collaboration is preparing for the dual-phase Run II. The new purification system including the cold charcoal trap as described above is under construction. Together with the upgraded light collection system an improvement of the light yield is expected. The dual-phase Run II is planned to start in mid-2017.

With an improved light yield in the order of 2 pe/keV$_{ee}$ ArDM is expected to achieve a significant sensitivity for WIMP searches with a LAr target. Due to the large target mass, a relatively short period is estimated to reach the sensitivities presented in Fig. , calculated for a 90% confidence level, 50% nuclear-recoil (NR) acceptance and an energy range of 60–160 keV$_{nr}$. Assuming a 500 kg fiducial mass the exposures of 4000, 8000 and 12000 kg·day correspond to 8, 16 and 24 ArDM live days, respectively. The background from single scatter neutrons emitted from internal detector components is estimated to amount to 1 event in about 20 days. The blue line in Fig. 6.6

shows the sensitivity of ArDM for a light yield of 1 pe/keV and 120–160 keV$_{nr}$ energy range as a comparison. The red line corresponds to the latest limit recently set by the DarkSide-50 experiment (1422 ± 67 kg·day). The allowed spaces for a popular theoretical calculation of WIMP parameters (CMSSM) from Bayesian 1σ and 2σ predictions are depicted in light and dark grey.

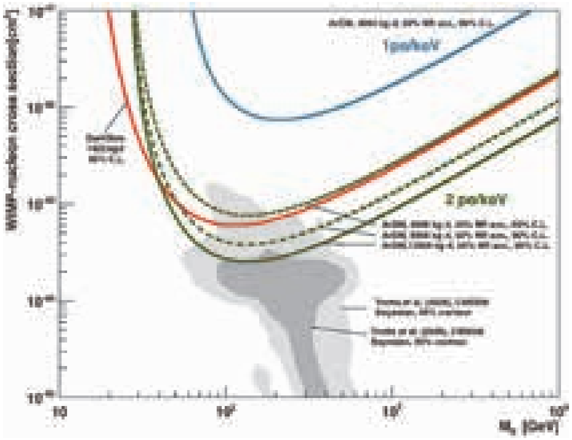

Fig. 6.6: Projected sensitivity at 90% C.L. for exposures of 4000, 8000 and 12000 kg˙day (green lines), assuming 50% NR acceptance and an energy range of 60–160 keV$_{nr}$. A light yield of 2 pe/keV is assumed. The blue line shows the sensitivity for a light yield of 1 pe/keV and 120–160 keV$_{nr}$ energy range. The red line corresponds to the latest limit set by DarkSide-50 (1422 ¨ 67 kg˙day. The CMSSM preferred parameter regions from Bayesian theoretical predictions are depicted in grey.

Objectives of Run II for the ArDM project include the study of multiple-scatter neutron events, the improved electronic-recoil rejection power (based on PSD and the S1/S2 ratio), as well as the study of the VUV attenuation length in effect of the upgraded purification system. All of these items are regarded to represent fundamental milestones towards large LAr Dark Matter detectors of the next generation.

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7 NEXT

HIGH PRESSURE GAS AND NEUTRINOLESS DOUBLE BETA DECAY

http://next.ific.uv.es/next/

The NEXT experiment aims to detect neutrinoless double beta decay ($0\nu\beta\beta$) in gaseous xenon enriched in the isotope ^{136}Xe. The signal observed when this reaction occurs is a peak in the distribution of energy deposited by the two electrons emitted in the decay, which must occur at a constant energy, as no neutrinos are emitted to carry away part of the energy. Therefore, a good $0\nu\beta\beta$ experiment must measure the deposited energy with excellent resolution and be capable of rejecting background events that fall into the energy range of interest given the achieved resolution. Neutrinoless double beta decay, if it exists, would be an extremely rare event with a half-life greater than 10^{25} years. To be able to measure such an event, in addition to accumulating a large quantity of the candidate isotope, an experiment must protect the detector from the various types of radiation that could produce a signal similar to that of the two product electrons. For this reason, such experiments are placed underground, where the Earth itself shields the experiment from the majority of radiation present at the surface. In addition, the materials used in constructing the detector must be extremely radiopure, so as to not introduce additional radiation that could produce signals similar to those of neutrinoless double beta decay.

NEXT consists of a high pressure xenon Time Projection Chamber (TPC), constructed as a steel cylindrical pressure vessel filled with 100 kg of xenon at a pressure of 15 bar. Electric fields are produced between high-voltage planes inside the vessel, and two distinct planes of photosensors are employed, one to measure energy and the other to take a "picture" of the event. The NEXT detection principles are described graphically in Fig 7.1. When a charged particle enters the gas, it deposits its energy by interacting in two key ways with the gas. In one such way, the gas molecules are excited and quickly return to their initial state by emitting light in the UV range. The sensors behind the detector cathode record this light (called primary scintillation), thereby marking the initial time of the event. These sensors are called photomultiplier tubes (PMTs), and are devices which convert light into electrical current. The other key channel of energy deposition is ionization, in which the charged particle removes electrons from the xenon atoms in the gas.

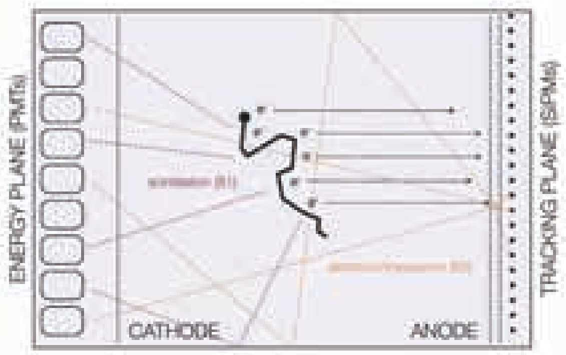


Fig. 7.1: The NEXT detection principles

The ionized electrons drift under the influence of an electric field towards a region of more intense field in which they are accelerated such that more scintillation (but not ionization) is produced. This process produces an amplification of the signal which grows linearly with the magnitude of the applied electric field. The PMTs detect this light, called secondary scintillation, and thereby record a precise measurement of the energy of the event. In the opposite extreme of the detector, the distribution of light detected by a denser plane of silicon photomultipliers (SiPMs) gives, at each moment, a 2D image of the event at a specific position in the direction of the applied electric field. Knowing the initial time of the event, one can reconstruct its absolute position.

This novel detection concept fulfills the main requirements of a $0\nu\beta\beta$ experiment previously described. In terms of energy resolution, the fluctuations in the number of ionization electrons and resulting secondary scintillation produced are very low. Furthermore, in xenon at 15 bar, it is possible to exploit the topological signal of the event: the two electrons of $0\nu\beta\beta$ leave a track of relatively constant ionization density with two large "blobs" of energy at its ends, due to the more tortuous path traced by the electrons once most of their energy has been expended. This signal provides a powerful tool for rejecting background events.

THE NEW DETECTOR

The detector NEXT-White (NEW) is an asymmetric high-pressure xenon gas TPC constructed with radiopure materials. It employs electroluminescence (EL) at pressures between 10 and 15 bar and is installed in the Laboratorio Subterráneo de Canfranc (LSC).

The detector is equipped with 12 Hamamatsu R11410 PMTs (Fig 7.2), placed 10 cm behind the cathode, which permit the detection of the primary scintillation signal (S1) used to determine the initial event time and thereby it's z-coordinate. The PMTs are also responsible for determining the event energy by measuring the secondary scintillation signal (S2) at high pressure. Given that the PMTs are not capable of operating at high pressure, they are separated from the active volume by a 12 cm copper plate and operate in vacuum. They visualize the active volume through sapphire windows coated with Tetraphenyl Butadiene (TPB), an organic material that shifts the wavelength of UV photons to blue.

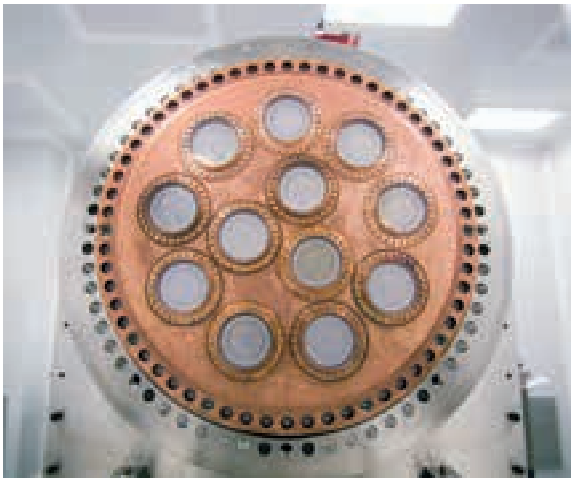


Fig. 7.2: The NEW PMT plane

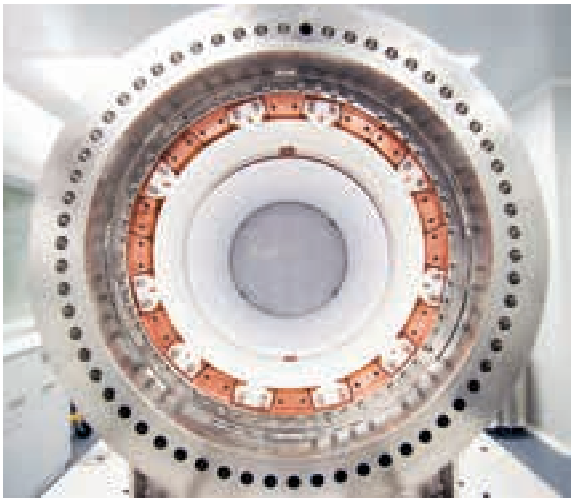


Fig. 7.3: The NEW field cage

At the opposite extreme of the detector, just behind the amplification region, a plane of 1792 SensL series C SiPMs is placed, over which the SiPMs are distributed in a matrix with a 1 cm pitch. The space between SiPMs is covered with a thin (2 mm) layer of teflon which increases the total reflectivity and therefore the light collection efficiency of the PMTs. The SiPMs collect the signal that allows for a topological reconstruction of the events.

The NEW field cage (Fig 7.3) creates a homogeneous electric field of 300 V/cm in the active volume, and a field of 2-3 kV/cm/bar in the EL region. It is fabricated using high-density polyethylene (HDPE) to support copper rings which create the drift field in the active volume. The grooves in which the rings are placed were machined from a single compact piece of HDPE. The copper rings are connected by resistors of 10 GΩ. The buffer region (the space between the cathode and the PMT windows), which serves to degrade the high-voltage at the cathode, consists of a series of grooves to prevent the movement of charge across the surface. The EL region consists of a stainless steel mesh (at the higher-voltage plane) with a transparency of nearly 100% to electrons and ~95% to photons, and the anode. The anode is a quartz plate coated with Indium Tin Oxide (ITO) on one side to allow for well-defined electrostatic boundary conditions and TPB on the other side to shift the VUV light emitted by the xenon to blue light, which the sensors detect with much greater efficiency. The high voltage feedthroughs employed, which must support up to 20 kV in the EL region and 50 kV in the cathode, were based on a design by H. Wang (UCLA) which avoids field lines perpendicular to all dielectric surfaces. Finally, a light tube is installed inside the field cage. This is a tube of teflon 10 mm thick and coated with TPB to shift VUV light to blue and increase the reflectivity of the teflon.

NEW OPERATION AND DATA ACQUISITION

The gas system and photodetector systems of NEW formally began their operations throughout 2016. Data acquisition was performed in two phases: test acquisition with argon and first xenon data.

The first phase took place from May until the end of September and resulted in the approval of the gas system as well as the definition and testing of the sensor calibration methods and improvements in isolating the electronics from possible sparks originating in the field cage of the TPC.

SENSOR CALIBRATION

In event reconstruction, NEW makes use of information from two types of photosensors. The 12 PMTs in the energy plane have high sensitivity to the photons emitted by the TPB and a low electronic noise. For a proper PMT calibration, this noise must be quantified, as well as the average number of digital counts produced by the absorption of a photon in the photocathode (the conversion gain) and the variation on this value (the charge resolution). The SiPMs in the reconstruction plane have a more complex noise profile than the PMTs because they also exhibit much greater dark current (the production frequency of thermal charge). Thus, for the SiPMs, both the noise and dark current must be quantified in addition to the gain. Various ways of determining these parameters exist, though in NEXT we choose to determine the gain in a way similar to that which is used for the PMTs, that is, by using the position of the first peak in the response to the absorption of blue photons. Instead of extracting parameters to quantify the noise and the dark current for NEW, we construct spectra of the charge observed in the absence of external light, from which much more pertinent information can be extracted.

Fig. 7.4 shows a low-light charge spectrum for a single PMT in which the peaks correspond to the absorption of one or several photons. SiPM spectra with and without external light are shown in Fig 7.5.

FIRST XENON DATA

The first NEW data were taken using radioactive sources with the aim of calibrating the detector. Calibration with radioactive sources is a procedure that will be carried out regularly throughout NEXT physics runs in order to monitor the variations in sensor responses throughout time and correctly reconstruct events. The first source used was 82-krypton, a noble gas that decays emitting electrons with a total energy of 41 keV, which deposit their energy in a very small region of the gas (several millimeters in extent). The krypton is produced by the decay of 83-rubidium, which is inserted in the gas system and rapidly diffuses, distributing itself uniformly throughout the chamber. Krypton is very useful for characterizing the detector, in particular for measuring the drift velocity and mean lifetime of the electrons in the gas, both of which are affected by the level of impurities. In addition, by producing an energy deposition in a very small region, one can precisely measure the geometric dependence of the light detection with the photomultipliers and thereby achieve an excellent energy resolution.

Several different data acquisition runs have been analyzed to perform a stable characterization of the detector, obtaining a drift velocity of 0.9 millimeters per microsecond and a mean electron lifetime of 4 milliseconds (increasing with time thanks to the continuous recirculation of the gas). Fig 7.6 shows how, due to the attachment of electrons to impurities in the gas, the charge detected in the PMT plane decreases with increasing event distance from the anode. The electron lifetime is calculated by fitting an exponential function to the data,

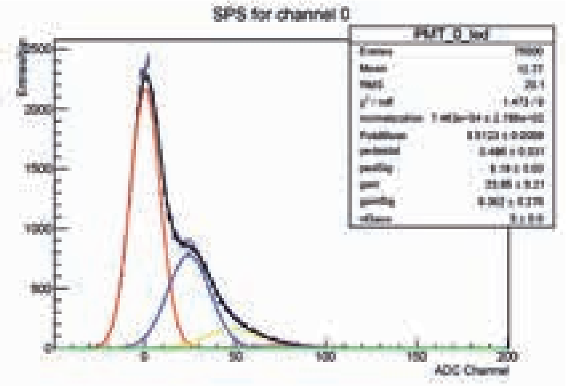


Fig. 7.4: Calibration spectrum for a PMT.

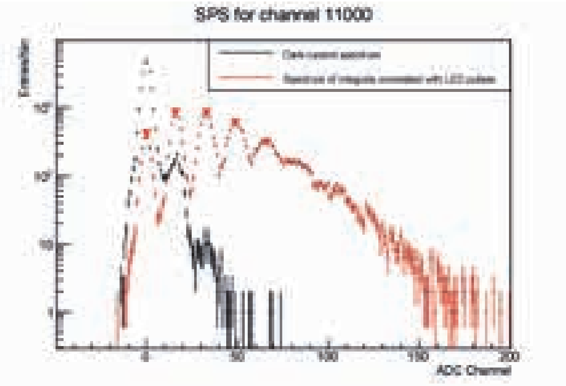


Fig. 7.5: SiPM calibration spectra.

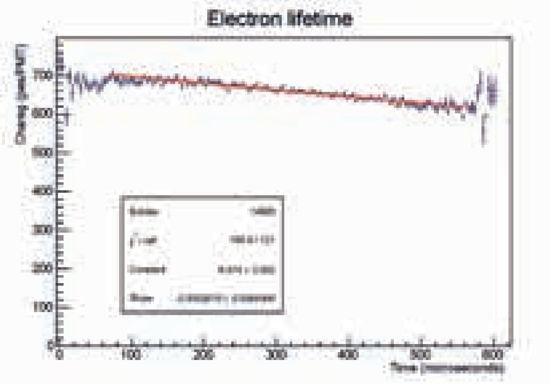


Fig. 7.6: Example of detected charge as a function of drift time. The charge decreases due to the capture of electrons by impurities in the gas.

and knowing this allows one to correct the detected charge for the attachment effect.

Fig. 7.7 shows the energy distribution of krypton events after all corrections (geometrical and attachment) have been applied: in the central part of the Gaussian one finds a resolution of 8% FWHM, which extrapolates to 1% at the $0\nu\beta\beta$ energy.

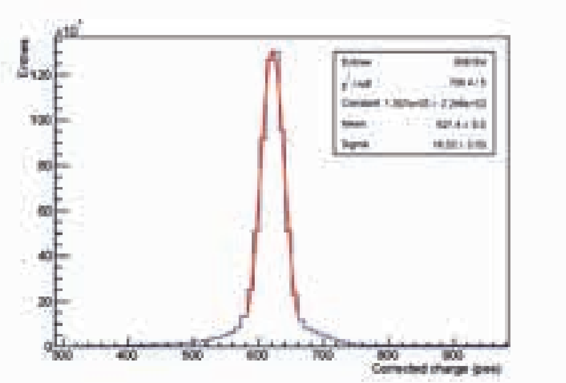


Fig. 7.7: Energy distribution of krypton events after the application of all corrections.

After completing data-taking with the krypton source, a 22-sodium source was employed. This isotope decays emitting a positron which then annihilates with an electron from its surroundings to produce two 511 keV photons emitted in opposite directions. At the same time, the de-excitation of the neon daughter nucleus produces a photon of much higher energy (1275 keV). The measurement of photoelectric interactions of photons of different energies allows for the calibration of the detector response. A track produced by a 511 keV electron in the chamber is shown in Fig 7.8, where the color indicates density of energy deposition. The "blob" of high energy deposition density is clearly visible at the end of the track.

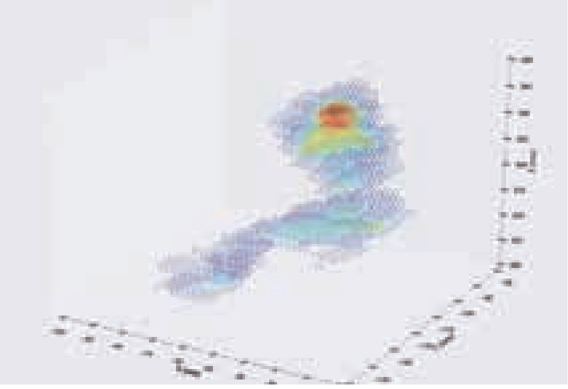


Fig. 7.8: The track of a 511 keV electron produced in a calibration event with a sodium source

8 BiPo

NEUTRINOLESS DOUBLE BETA DECAY: CANFRANC WITH MODANE

http://nemo.in2p3.fr/nemow3/

The BiPo-3 detector is a low-radioactivity detector dedicated to measuring ultra-low natural radionuclide contaminations of ^{208}Tl (^{232}Th chain) and ^{214}Bi(^{238}U chain) in thin materials.

The detector has been developed to measure the radiopurity of the double-beta decay source foils of the SuperNEMO experiment. SuperNEMO aims at a bb0n half-life sensitivity of $T_{1/2} > 10^{26}$years. One of the main sources of background for SuperNEMO is a possible contamination of ^{208}Tl and ^{214}Bi produced inside the source foils. The required radiopurities are ^{208}Tl < 2 mBq/kg and ^{214}Bi< 10 mBq/kg in order to achieve the targeted SuperNEMO sensitivity.

The main results during the year 2016 of the BiPo-3 detector are the final measurement of the first eight SuperNEMO enriched ^{82}Se foils, the measurement of foils produced by a new technique and the measurement of microbulk micromegas.

The first module of SuperNEMO, called demonstrator, will contain 7 kg of ^{82}Se in the form of foils. The SuperNEMO foils are strips, 270 cm long, 13.5 cm wide and ~200 mm thick. A total of 36 foils will accommodate the required mass. The first 11 foils have been produced with the same technique as in NEMO-3 by ITEP in Russia. However, the first measurements of these foils resulted in a ^{208}Tl activity about 20 mBq/kg too high for the SuperNEMO requirements. Thus, a new technique for the source production has been developed by LAPP in France and a novel purification technique has been developed in JINR, Russia. Test foils using ^{nat}Se have been measured by BiPo-3 during 2016.

This report presents 1) the final results of the first 8 foils produced by ITEP, 2) the results of the tests foils produced by LAPP and 3) results of the radiopurity measurement of microbulk micromegas for the University of Zaragoza.

FINAL RESULT OF THE MEASUREMENT OF THE FIRST ENRICHED ^{82}SE FOILS

To produce the foils, ^{82}Se powder is mixed with Polyvinyl alcohol (PVA) glue and then deposited between two Mylar sheets. The Mylar sheet is 12 mm thick and it has been irradiated with an ion beam to produce a large number of microscopic holes in order to ensure a good bond with the PVA glue and to allow the water evaporation during the drying of the glue.

We remind that the radiopurity of the Mylar and the PVA glue have been measured separately with the BiPo-3 detector.The Mylar before irradiation and the PVA are very pure. However contamination in ^{208}Tl has been observed inside the Mylar after irradiation at a level of A(^{208}Tl) = [47 - 171] mBq/kg.

Four first SuperNEMO ^{82}Se strips with thickness 40 mg/cm^2 have been measured from August 2014 to June 2015. The total duration of this measurement is 262 days for the BiPo^{212} measurement and 241 days for the BiPo^{214} measurement. A second set of four strips with thickness 55 mg/cm^2 have been measured from November 2015 to July 2016. The total duration of this measurement is 161 days for the BiPo^{212} measurement and 109 days for the BiPo^{214} measurement. Combining the data of the two set of measurements, we obtain the final result for the contamination of the first eight enriched ^{82}Se foils.

A significant excess of ^{212}BiPo events above the expected background is observed for the data and it is in agreement with a ^{212}Bi contamination inside the ^{82}Se+PVA mixture. It corresponds to a ^{208}Tl activity of A(^{208}Tl) = (21 ± 11) mBq/kg at 90 % C.L. For the ^{214}Bi measurement, the analysis showed that the number of events in the data is compatible with the expected background fluctuation and allowed to set an upper limit to the ^{214}Bi contamination inside the ^{82}Se+PVA mixture of A(^{214}Bi) < 290 mBq/kg at 90 % C.L. Fig 8.1 shows the alpha energy spectra of the data together with the expected contributions from the intrinsic detector surface background, irradiated mylar and random coincidences.

Two other foils produced by ITEP are in measurement since August 2016 and show contaminations very well compatible with the values obtained for the first eight foils.

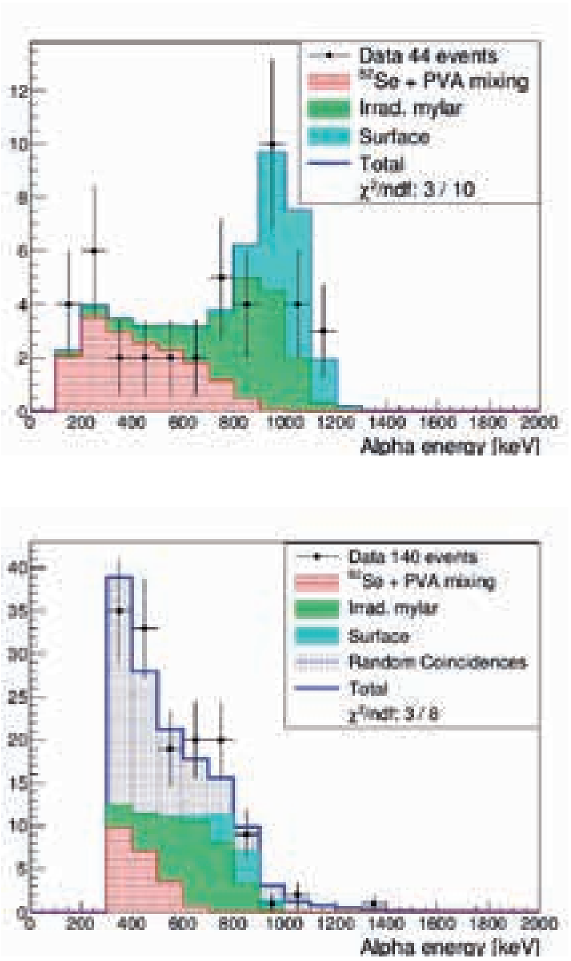


Fig 8.1: Alpha energy distributions, for the BiPo^{212} (left) and BiPo^{214} (right) measurement of the eight first enriched ^{82}Se SuperNEMO foils, with a total of 423.3 days and 350.8 days of data collection respectively. The data is compared to the expected background from the contamination on the surface of the scintillators (light blue histogram), the irradiated Mylar (green histogram) and random coincidences (dark blue histogram). The excess above the expected background is shown in red and it corresponds to the contamination inside the ^{82}Se+PVA mixture.

MEASUREMENT OF THE ^{NAT}SE TEST FOILS

As mentioned above, the LAPP in France has developed a new production technique for the SuperNEMO double beta decay source foils. Since a contamination in ^{208}Tl has been observed inside the Mylar after irradiation, the foils in the new technique have been produced with Mylar without irradiation.

A first measurement of the ^{nat}Se lasted from March 2015 to March 2016. A relatively large surface contamination was observed pointing to the fact that the production method needed to be improved. The measurement of a second strip, started in August 2016, shows no surface contamination thanks to modifications in the production method. For the bulk contamination in the ^{nat}Se+PVA mixture, the analysis gives A(^{208}Tl) = (114 ± 67) mBq/kg and A(^{214}Bi) < 970 mBq/kg at 90 % C.L. A new measurement of strips produced with enriched Se and with the new method has started in December 2016 and is on-going.

Fig 8.2: Installation of LAPP foils in one of the BiPo-3 modules.

MEASUREMENT OF MICROBULK MICROMEGAS

Samples of microbulk micromegas from the University of Zaragoza have been measured with the BiPo-3 detector from March 2016 to December 2016. The surface activities, at 90 % CL, resulting from a first analysis of part of the data gives: A(^{208}Tl) < 50 mBq/m^2 and A(^{214Bi}) < 450 mBq/m^{2}., which are the lowest limits ever obtained for micromegas surface contamination. These micromegas will be used in the TREX-DM and PandaX-III experiments.

9 SUPERKGD

SEARCHING FOR RADIO-PURITY: CANFRANC WITH KAMIOKA

The radio-purity works that we are carrying out at the LSC for the upgrade of the Super-Kamiokande experiment (SuperK-Gd), by dissolving a Gadolinium (Gd) salt in its water, and the SuperK-Gd project itself, have entered a phase characterized by a) the presence of several major companies interested in our project remarkably the Japanese ***Nippon Yttrium Co. Ltd.***, ***Shinetsu Chemicals*** and ***Kanto Chemicals***, as well as the North America's ***Molycorp Inc.***, b) the opening of those companies to their production and purification processes and their interest in our Project, and c) their real knowledge about how to produce radio-pure Gd salts. In order to keep the confidentiality necessary at this stage of the program, we will refer those Companies as Companies A, B, C and D. Notice that the ordering is different.

Correspondingly our measurements are reaching higher and higher precisions to cope with the very high purities of the most recent salts. Below the measurements are detailed and their implications discussed.

On the other side, in the Kamioka Observatory, host of the Super-Kamiokande experiment and of SuperK-Gd, the preparations for the first phase of the project, the refurbishment of the Super-Kamiokande tank, are well under schedule. Even though not yet finally decided, the start of this phase is expected in spring 2018.

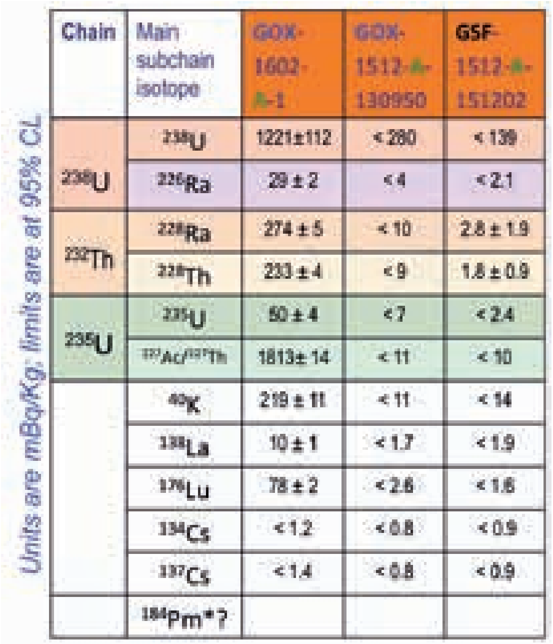
http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html

ACTIVITIES:

The radio-purity measurements on samples of Gd salts carried out during the year 2016 are listed below, along with some explanation to put them in the general context.

1-, 2- Two Gd samples, ~0.6 kg each, from the new provider Company A. The company advertised high purity rare earth production. These samples were considered a first contact with Company A. One is $Gd_2(SO_4)_3$ [GSF-1512-A-151202], measured with the detector GeOroel, the other is Gd_2O_3 [GOX-1512-A-130950] measured with the detectors GeAspe at the LSC ULBS. Even though the statistics is limited, the two samples were found already rather clean. See columns 5 and 6 in Table 1.

3- A 3rd Gd sample by company A, 1.44 Kg of Gd2O3 [GOX-1602-A-1], was measured with GeAspe. This sample was of the same batch as [GOX-1512-A-130950] above, but before any cleaning procedure. It was found extremely dirty, with the ^{238}U chain in an amazingly large non-equilibrium and the presence of a large amount of the lower part of the ^{235}U chain. See column 3 in Table 9.1.



Units are mBq/Kg; limits are at 95% CL

Chain	Main subchain isotope	GOX-1602-A-1	GOX-1512-A-130950	GSF-1512-A-151202
^{238}U	^{238}U	1221±112	< 280	< 139
	^{226}Ra	29 ± 2	< 4	< 2.1
^{232}Th	^{228}Ra	274 ± 5	< 10	2.8 ± 1.9
	^{228}Th	233 ± 4	< 9	1.8 ± 0.9
^{235}U	^{235}U	50 ± 4	< 7	< 2.4
	$^{227}Ac/^{227}Th$	1813± 14	< 11	< 10
	^{40}K	219 ± 11	< 11	< 14
	^{138}La	10 ± 1	< 1.7	< 1.9
	^{176}Lu	78 ± 2	< 2.6	< 1.6
	^{134}Cs	< 1.2	< 0.8	< 0.9
	^{137}Cs	< 1.4	< 0.8	< 0.9
	^{184}Pm*?			

Table 1: Measured contaminations in the samples from process 1 by Company A.

4-, 5-, 6- Three Gd_2O_3 samples from Company B: [GOX-1603-B-237] measured at detector geAspe, [GOX-1603-B-239] at geLatuca, and [GOX-1603-B-236] at geOroel. They were very clean, probably the cleanest ones measured by SuperKGd-LSC at that time. However a couple of new gamma lines were observed consistent with coming from the decay of cosmogenicaly produced 148Pm* (41 days lifetime). Even though there is no firm conclusion yet, we do believe that this contamination is not relevant for the experiment. See columns 3, 4 and 5 of Table 2.

7- One sample of Gd2(SO4)3 from Company A [GSF-1604-A-160311] with the detector Asterix. See column 3 of Table 3.

Units are mBq/Kg; limits are at 95% CL

Chain	Main subchain isotope	GOX-1603-B-237	GOX-1603-B-239	GOX-1603-B-236	GSF-1604-B-1	GSF-1604-B-1	GSF-1512-B-003
^{238}U	^{238}U	< 98	< 130	< 38	< 180	< 25	< 13
	^{226}Ra	< 0.9	< 1.0	< 1.4	< 1.2	< 0.8	< 0.3
^{232}Th	^{228}Ra	< 2.7	< 2.3	< 1.4	< 2.9	< 0.7	< 0.3
	^{228}Th	< 2.5	< 1.4	< 0.8	< 2.5	0.9 ± 0.3	< 0.4
^{235}U	^{235}U	< 1.6	< 0.8	< 1.0	< 0.8	< 3.1	< 0.8
	$^{227}Ac/^{227}Th$	< 4.3	-	-	< 3.8	< 6.1	< 1.9
	^{40}K	< 4.6	< 5.3	< 3.4	< 3.3	< 2.1	< 1.8
	^{138}La	< 0.6	< 0.7	< 0.7	< 0.5	< 0.5	< 0.3
	^{176}Lu	< 0.8	< 0.7	< 1.0	1.2 ± 0.3	0.4 ± 0.3	0.4 ± 0.1
	^{134}Cs	< 0.24	< 0.4	< 0.23	< 0.24	< 0.24	< 0.09
	^{137}Cs	< 0.3	< 0.34	< 0.30	< 0.3	< 0.24	< 0.16
	^{148}Pm*?	0.3 ± 0.1	0.3 ± 0.1	< 0.35	-	-	[illegible]

Table 9.2: Measured contaminations in the samples from processes 1 and 1+ by Company B.

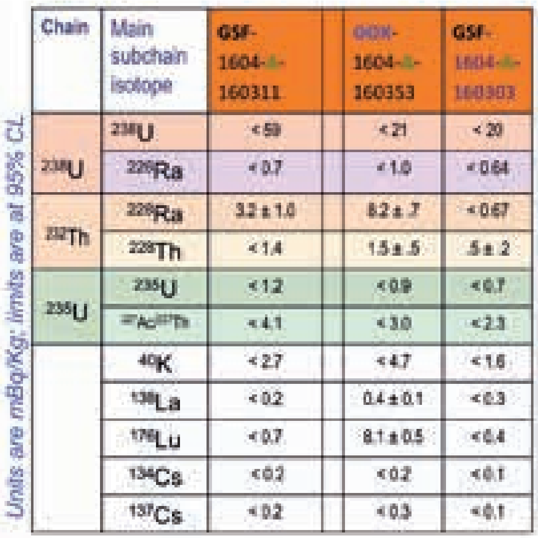
8- One sample of Gd2(SO4)3 from Company A [GSF-1604-A-160303] with the detector Obelix. It was processed from the same Gd_2O_3 batch from where the sample [GOX-1604-A-160353], that is measured afterwards, was taken. That sample became the cleanest sample measured until that moment within SuperKGd-LSC. See last column of Table 9.3.

9- The mentioned Gd_2O_3 sample by Company A, GOX-1604-A-160353 with the detector Asterix. See column 4 of Table 9.3.

10- Another sample of $Gd_2(SO_4)_3$ from Company A [GSF-1604-A-160311]. It came from the same raw material as [GOX-1604-A-160353] and [GSF-1604-A-160303]; but underwent a different production process than the latter.

11-, 12- A sample of $Gd_2(SO_4)_3$ from Company B [GSF-1604-B-001] was measured first with the geLatuca detector. This sample was produced from a Gd_2O_3 from the same batch as the sample [GOX-1603-B-236] previously measured. The batch of [GSF-1604-B-001] was the final product of a process for which high purity was expected. As the precision obtained was not enough, the measurement was repeated in the Obelix detector. The results from both measurements along those performed previously in the "mother" Gd_2O_3 salts are shown in columns 6, 7 and 5, respectively, of Table 9.2.

13- One sample of $Gd_2(SO_4)_3$ from a new production batch by Company B. This batch featured the use of a more radio pure H_2SO_4 at the last stage of production in an attempt to further reduce the impurities currently achieved. See Table 2, last column. This sample is the cleanest of the whole SuperK-Gd-LSC project so far.



Units are mBq/Kg; limits are at 95% CL

Chain	Main subchain isotope	GSF-1604-A-160311	GOX-1604-A-160353	GSF-1604-A-160303
^{238}U	^{238}U	< 59	< 21	< 20
	^{226}Ra	< 0.7	< 1.0	< 0.64
^{232}Th	^{228}Ra	3.2 ± 1.0	8.2 ± .7	< 0.67
	^{228}Th	< 1.4	1.5 ± .5	.5 ± .2
^{235}U	^{235}U	< 1.2	< 0.9	< 0.7
	$^{227}Ac/^{227}Th$	< 4.1	< 3.0	< 2.3
	^{40}K	< 2.7	< 4.7	< 1.6
	^{138}La	< 0.2	0.4 ± 0.1	< 0.3
	^{176}Lu	< 0.7	8.1 ± 0.5	< 0.4
	^{134}Cs	< 0.2	< 0.2	< 0.1
	^{137}Cs	< 0.2	< 0.3	< 0.1

Table 3: Measured contaminations in the samples from processes 2.1 and 2.2 by Company A.

Respecting the expected impact of the measured contaminations on the SuperK-Gd physics program, we estimate that those as in the latest batches will basically have no impact on key measurements as Supernova Relic Neutrino background and Early Supernova Warning from Si burning in pre-supernova candidates. In contrast they would still jeopardize the current superb sensitivity of Super-Kamiokande to low energy solar neutrinos (3.5 MeV recoil electron kinetic energy), because of the electron and gammas produced at β decays of Ra daughters, mainly ^{208}Th and, to a less extent, ^{214}Bi. A reduction of the Ra contamination by a factor between 5 and 10 is still needed in order to maintain the current solar capabilities of SK. Notice that during this year radio-purities have been already improved by more of one order of magnitude.

Negotiations, of a more commercial character, with those Companies candidates for full production have also been started. They intend to settle a reasonable set of requirements for low radioactivity, reproducibility, delivery capabilities, price, others, that will be included in the mandatory bidding process for the main contract.

The current SuperK-Gd preparation scenario under negotiation with T2K, contemplates the largest activity to occur during 2018-2019. As we originally foresaw in SuperK-Gd-LSC, we plan to measure at least one sample of every batch (typically 500 kg) of the 100 ton, full production of $Gd_2(SO_4)_3$. Even though there are currently large timing uncertainties in the project, we find rather probable a steady increase of related activities during 2017 and lasting for almost two years more. The detailed requests of support to the LSC by SuperK-Gd-LSC will depend very much on how the production and delivery are planned.

10 GEODYN

GEOPHYSICS FROM UNDERGROUND

Geodyn is a geodynamical facility aimed 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, as detailed in previous reports.

SEISMIC COMPONENT

During the first months of 2016 intermittent anomalies in the broad-band signal were detected. Following discussions with the manufacturer of the instrument, the problems were related to the broad-band seismometer / datalogger cable, a new cable has been on duty since the 4th of April. Unfortunately, the new cable did not solve the problem, so we decided to remove the instrument and send it to Nanometrics for revision. The 7th September 2016 a Trillium120 seismometer provided by ICTJA was installed to assure the continuity of the data recording during reparation.

The most significant local event during this year was an earthquake located near the Lacq gas field (Aquitaine basin) occurred the 25th April and magnitude 4.0 (Renass catalogue). This event was probably induced by the gas extraction activities in the Aquitanean Basin.

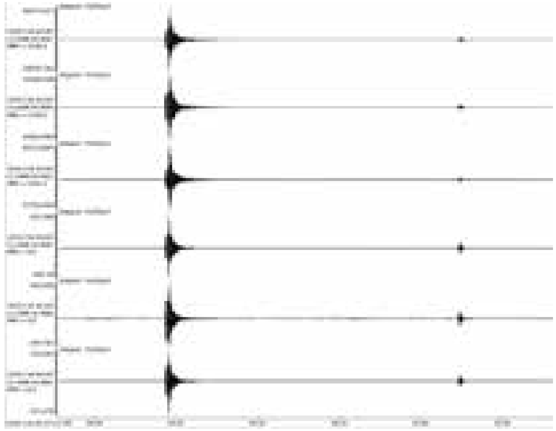


Fig. 10.1: 25/4/2016 event near Lacq (ML 4.0) and one of its aftershocks (ML 1.5) recorded at the 6 seismic channels (upper 3 lines: accelerometer, Lower lines: Broad-Band) Epicentral distance: 75 km.

At regional scale, we can highlight the seismic crisis at the southern Alboran Sea following a 6.3 Mw event occurred the 25th January 2016 and the seismic crisis in Central Italy, including a 6.2 Mw event the 24th of August, a 6.1 Mw event the 26th of October and a 6.6 Mw earthquake four days later. The main events of both crisis and many of their aftershocks were recorded at Geodyn.

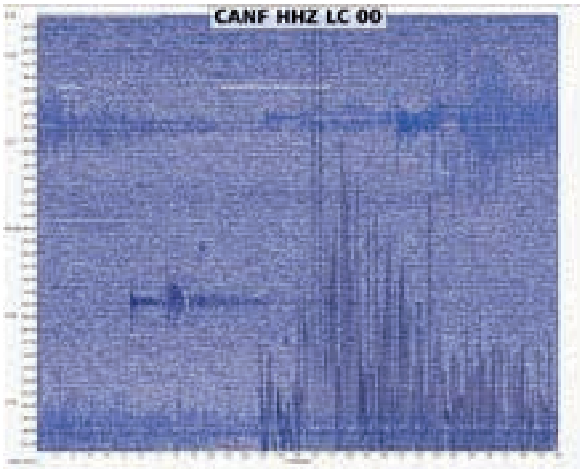


Fig. 10.2: Helicorder image (30 minutes per line) showing the October events with epicentre in Central Italy

Regarding teleseismic activity, around 20 events with magnitude above 6.5 have been recorded by the USGS catalogue, 3 of them exceeding magnitude 7. We can highlight the event (13/11/2016) in New Zealand, reaching Mw 7.8 and resulting in large affectations in the landscape.

A remarkable milestone in this period is the publication in the highly ranked "Earth-Science Reviews" journal of a paper illustrating the different processes, from tides to distant and local earthquakes, microseismic signals, anthropogenic noise and hydrological signals that can be observed in the seismic recordings at Geodyn. (Earth-Science Reviews has a journal impact factor of 6.991 and is ranked 5 of 184 in the "Geosciences, Multidisciplinary" category of JCR-2015.

STRAIN COMPONENT

The two laser interferometers were sent to the manufacturing Company (MicroGLacoste) in July 2015 for maintenance. They returned to the Geodyn facility in March 2016. As planned, last June the lasers have been re-installed and both interferometers realigned. Additionally, the mechanical setup of the remote cat's eyes has been modified to improve their stability.

Unfortunately, we experienced problems with one of the two lasers and both data acquisition systems. As regards the laser, it came back from the manufacturer (MicroGLacoste, USA) with a malfunctioning thermostating circuit, which is necessary for proper laser frequency stabilization. In order to save time and money, we have replaced the broken chip by ourselves, but the chip became broken again soon after our departure because of a blackout, and we could not come back to LSC till now. With regards to the data acquisition, one of the two PCs was replaced before our maintenance visit last June, but it has been impossible to make the National Instruments acquisition card working with the new PC. We have tried to solve the problem by ourselves and contacting National Instruments: the customer support service, after a long time and several tests, got to the conclusion that our cards are not compatible with new PCs. Last but not least, the acquisition system of the other interferometer ceased to work at the end of August. Considering that usual PCs are not the best choice for a dusty environment like GAL16 and that our National Instruments cards are not compatible with new PCs, we decided to replace the acquisition system of both interferometers, using fan-less industrial PCs and different acquisition cards.

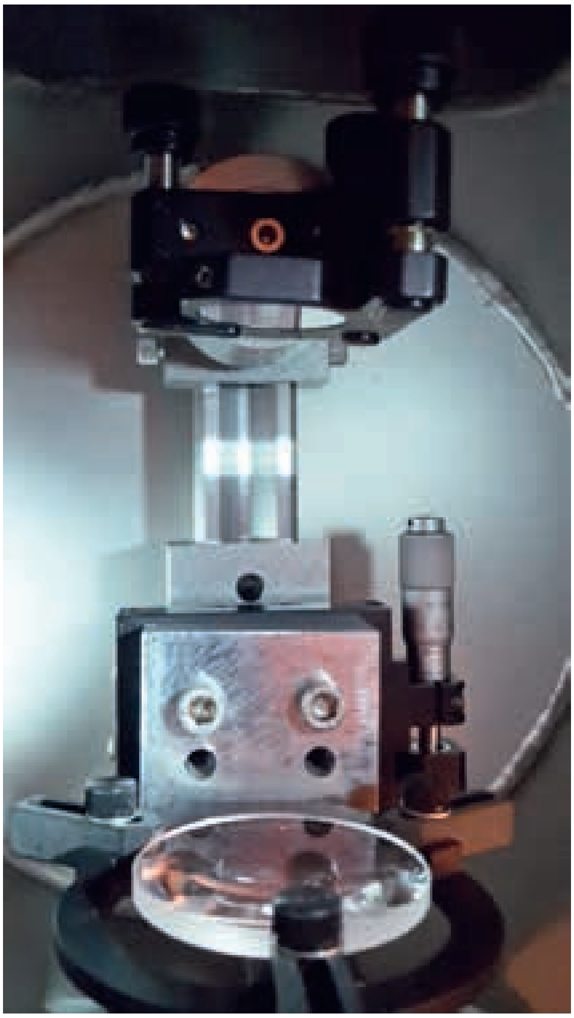


Fig. 10.3: Modified mechanical setup of the remote cat's eyes

From a scientific standpoint, during this period we have completed the analysis of recorded strain data in the tidal bands. Because of the excellent signal-to-noise ratio, we could study nonlinear and minor ocean tides in the Bay of Biscay through load strain tides. This has led to the publication of a new paper in a top-rank geophysical journal (A. Amoruso and L. Crescentini, Nonlinear and minor ocean tides in the Bay of Biscay from the strain tides observed by two geodetic laser strainmeters at Canfranc (Spain), J. Geophys. Res.: Oceans).

GNSS COMPONENT

Giorgi Khazaradze at the Universitat de Barcelona (UB) has been downloading the data from the two CGPS stations at Fuerte de Rapitán near Jaca and at Candanchú on a weekly basis and processing the 30 sec sampling 24 hour data to obtain the daily positions for the both stations.

Judging by the WRMS values, both of the GNSS stations exhibit good quality day-to-day scatter and within 1.5 years of observations will be capable of resolving deformations below 1 mm/yr. Due to the modem related problems, in mid May, 2016 CAND stations stopped communicating and approximately 4 months' data was lost (See Fig 9.5). Fortunately, no earthquake has been recorded during this period in the vicinity of the Candanchú, and thus, no valuable scientific data has been lost. For determining the long-term deformation of the Pyreneans the lack of 4 month data is not too crucial. Data from the RAPI CGPS station has been obtained without any interruption.

In the second half of 2016 we were successfully equipped the receivers with additional 8 Gb capacity USB memory devices, which enabled the acquisition of 1 Hz data, useful for comparison with the data acquired from the seismometers located within the underground laboratory..

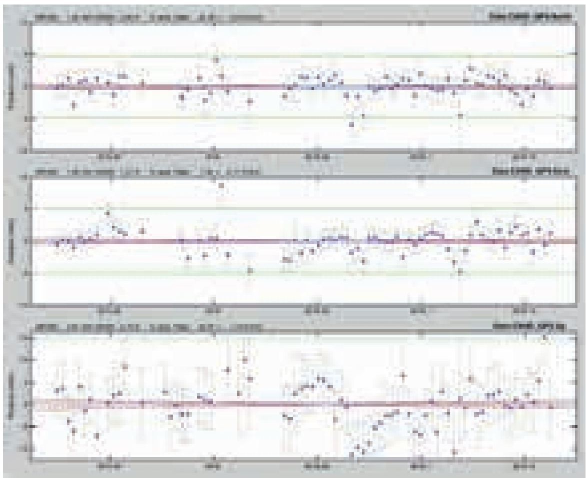


Fig. 10.4: Residual position time-series of the CAND GNSS station for the N-S, E-W and Up components with 1¨ uncertainties in ITRF2008 reference frame. Time frame includes: 01/12/2015 to 01/3/2016

11 CUNA

NUCLEAR ASTROPHYSICS FROM UNDERGROUND

The CUNA experiment is aimed at the measurement in the laboratory of reaction cross sections with a strong impact in nuclear astrophysics. Neutron capture reactions are responsible for the production of most of the elements in the Universe, starting from the building blocks formed during the Big Bang nucleosynthesis and by complex nuclear processes taking place in stars. The slow neutron capture process (the s-process) is thought to produce about half of the isotopes above iron and to occur in red giant stars on the Asymptotic Giant Branch phase (the main component) and in massive stars (the weak component). For the s-process to occur a source of stellar neutrons is required, and the most likely scenario is the production via the ^{22}Ne(α,n)^{25}Mg and ^{13}C(α,n)^{16}O reactions, depending on the specific s-process.

This is the reason why the cross sections must be accurately known at the temperature where reactions take place, which defines the kinetic energies of the atomic nuclei in stars (the Gamow peak), and turn out to be too small to be measured in surface laboratories due to the background arising from the interaction of cosmic rays. Thus, measurements in an underground environment are absolutely needed. The LSC overburden provides the needed low-background environment, and allows to perform measurements at very low energies, where the counting rates would be of the order of 1 event/hour or even lower. The Letter of Intent "A Nuclear Astrophysics facility for LSC: The sources of neutrons in the stars and other reactions of astrophysical interest" has been submitted to LSC and proposes an underground nuclear astrophysics laboratory based on state-of-the-art high-current low-energy accelerator.

In the last years, the CUNA collaboration has undertaken several tasks towards the implementation of the facility. These include Monte Carlo simulations of accelerator-induced background and its effect on neighbouring experiments, the simulation of the shielding requirements, the characterization of the neutron background and the neutron spectra at LSC and other laboratories, sensitivity studies for experimental detection of the proposed reactions, the comparison of gamma background at several underground laboratories and the characterization of realistic detection systems with special emphasis on neutron detection.

In 2016 an international workshop on Nuclear Astrophysics at the Canfranc Underground Laboratory was organized at the LSC headquarter in Canfranc Estación (29 February to 1 March 2016). The workshop followed the first one held in 2012 at the same location, and the previous exploratory meeting that took place in Barcelona in 2009. The aim was to discuss the feasibility, the physics and the implementation of the CUNA project at the LSC in the context of existing and planned facilities worldwide. The idea was to prepare a proposal for the LSC Scientific Committee, including the physics case, the infrastructure, the accelerator and beam lines, the detection techniques and the instrumentation.

The main conclusion of the meeting was that there is a compelling case for underground Physics, with examples presented by various speakers, and with a very strong impact, based on remarkable success of the existing LUNA 400 kV accelerator. The European nuclear astrophysics community strongly supports that at least one new MV scale underground accelerator be installed in Europe. Given the time needed for the measurement of a single reaction, as well as the number of important reactions for which measurements are needed, the construction of another facility would be highly beneficial. At present the LUNA-MV project at Gran Sasso has been funded and will be realised in a few years.

It was underlined that a high-current and fully equipped accelerator installed at the LSC is the key element to efficiently measure the desired reactions and assure the success of the project. During the past years, and in 2016 particularly, a large effort has been devoted to exploring possible options to furnish the project with a suitable accelerator, including used machines, with no success up to now. In addition, a robust organizational structure to manage the scientific and practical needs of the CUNA proposal is a must to continue the project. Clearly an improved European networking would strengthen the community of researchers interested in underground accelerator science. In conclusion, an excellent opportunity for an underground Nuclear Astrophysics laboratory, complementary to other projects, exists at Canfranc.

12 GOLLUM

LIFE IN EXTREME ENVIRONMENTS

The Somport tunnel crosses different sedimentary rocks built by accumulation of sediments in the Mesozoic and Cenozoic ages (see Fig. 12.1). Its length, depth and diverse ecology make it a perfect site for extremophile ecology studies. In extreme environments, bacteria –and archaea- tend to be the main living organisms. Subterranean microorganisms have been described to sum detail, but almost all reports refer to samples taken centimetres to few meters below the surface. In fact, many of those have a photoautotrophic metabolism. By contrast, the literature describing microorganism inhabiting the very inside of rocks are scarce. The few reports, analysing the microbial diversity of rock inhabitants evidence, a rather high diversity of microbial taxa and metabolism pathways, including bacterial groups such as green non-sulfur, sulfur or iron reducing, and also methan producers, amongst others.

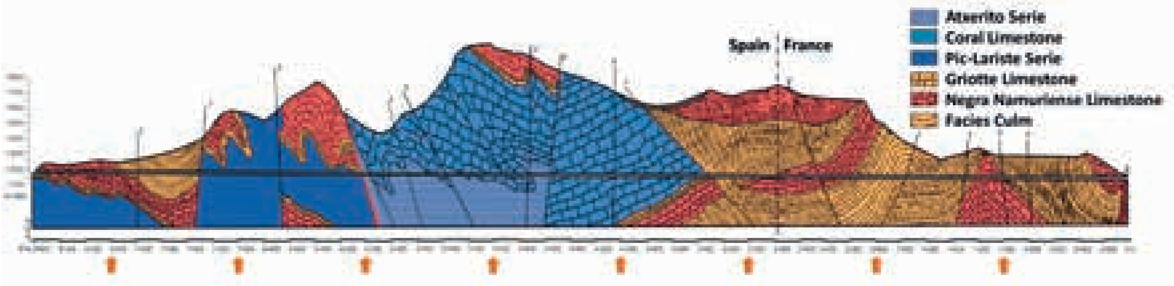


Fig. 12.1 Morphology of rocks around the Canfranc railway tunnel.

GOLLUM goal is the identification and characterization of the microbial communities living in a range of different rocks throughout the length of the Somport tunnel, from the surface to the maximum depth. This will be accomplished through 16S amplicon and shotgun high throughput sequencing of the combined genomes in a given sample (metagenomics). Taken together, these procedures will allow determining with high precision the microbial composition of the Somport tunnel at different depths and on different mineral substrates. Sampling different depths and rocks will be achieved by collecting one-meter length cylinders of rock drilled along the tunnel, minimizing external contamination. Improved protocols are needed for desoxyribonucleic acid (DNA) extraction of the scarce genetic material sampled. Recent progress in high throughput next generation sequencing is leading to the discovery of numerous new species of bacteria and archaea, non-cultured by standard methods.

GOLLUM collaboration drilled 14 cores in locations placed along the train tunnel in May 2016, in sterile conditions required for DNA extraction and genomic studies of low DNA samples (see Fig. 12.2). We have developed techniques to obtain rock powder with grain sizes in the range 10 -100 microns and extraction protocols of low DNA content in carbonated samples (with sensitivity of one in 10 billion in DNA grams per gram). Genomic sequencing was performed in Sistemas Genomicos laboratories. The archaea content in one of our samples is shown in the figure. The interactive visualization of the taxonomic classification of the DNA in this sample can be found on: http://som1.ific.uv.es/krona/gollum.2B2.V4_coff5.mothur_summary.html.

In Fig. 12.3, we show the 6% of the DNA content, which corresponds to archaea genera. Most of the genera cannot be identified by comparing to the existing databases, with closest taxa identified in submarine samples.

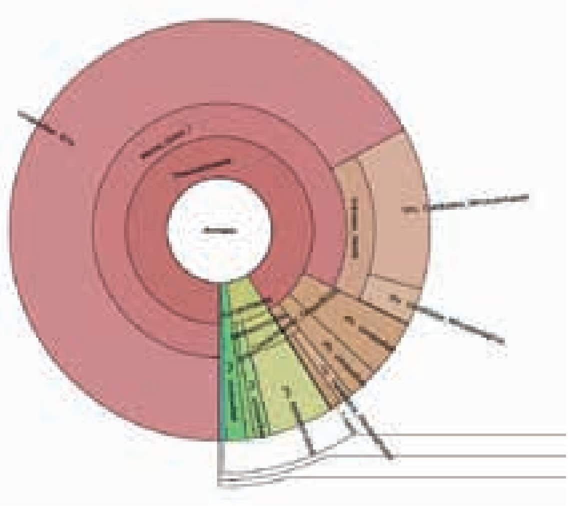


Fig. 12.3: DNA content

Chemical studies of the sampled rocks using, among other techniques, X-ray fluorescence, show a correlation of the DNA content in archaea with the presence of some metals, particularly Molybdenum (Mo), a metal identified in proteins associate to metanogenesis. The figure shown below (Fig. 12.4) is the X-ray fluorescence spectrum of samples with positive (negative) DNA presence in green (red). When comparing the spectra, we can see a significant variability in metal abundances and particularly the presence/absence of the Mo peak.

Fig. 12.2: Picture of a fragmented core

Our proposal will shed light on a barely explored extreme environment, characterized by poor nutrients, diverse physicochemical substrates, moderate radiation levels (in some cases), and very narrow temperature fluctuations. The presence of native DNA is already a first success of the experiment and opens many questions, starting by asking whether the biological material corresponds to relic DNA or living cells. The originality of the Somport tunnel as a "highway to depths", its geological diversity and the potency of the methods we plan to use may yield an unprecedented complex matrix of data on the microbial biocenoses of subterranean habitats, with both fundamental (i.e. origin of life, astrobiology) and applied (bioprospection, discovery of new species with useful properties) important consequences.

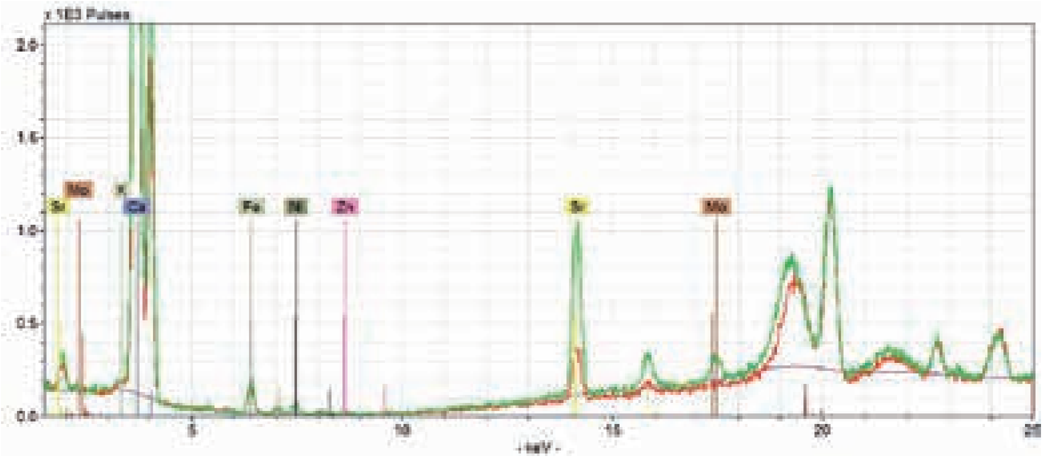


Fig. 12.4 X-ray fluorescence spectrum of samples with positive (negative) DNA presence in green (red)

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J.Phys.Conf.Ser. 718 (2016) no.4, 042030

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Sensitivity of NEXT-100 to neutrinoless double beta decay

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During 2016, 15 presentations to International Scientific Conferences have been made by users of the LSC.

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