LSC

Laboratorio Subterráneo de Canfranc

ANNUAL REPORT | 2015

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

LSC

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DIRECTOR'S STATEMENT

The Laboratorio Subterráneo de Canfranc (LSC) is the second largest deep underground scientific laboratory in Europe. It is run by a Consortium between the Spanish Ministerio de Economía y Competitividad, the Gobierno de Aragón and the Universidad de Zaragoza.

The LSC offers to researchers from all over the world the opportunity to carry out research on fundamental physics and astrophysics as well as on 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, such as dark matter interactions and 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 Expressions of Interests are under examination: one on direct dark matter research with CLYC scintillators and a second on ultra-sensitive force sensor to investigate short-range interactions. In addition, an extension project for the underground site for a nuclear astrophysics facility, CUNA, is under study.

Laboratories, offices and meeting rooms are also available on the surface. The refurbishment of a new building on surface for the Laboratory with an exhibition room and meeting rooms will be completed by spring 2016. 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, ULS)

- 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).
- The conference room for institutional meetings with 98 seats.

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

Lastly, I acknowledge the outstanding work accomplished by the previous Director of LSC, Alessandro Bettini, who ended his mandate in April 2015.

This Report summarizes the science and the experimental activity carried out in 2015. 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 2016

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.

Physicists 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. For this reason 2015 and the following few years are critical for LSC.

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 are the most penetrating (see Fig. 1.1). They reach the surface of the Earth with a flux equal to about ten millions/m2/day.

Deep underground, under the Tobazo Mountain near the Canfranc village, the cosmic ray flux of muons is reduced by a factor of 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 effort.

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

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 this research activity is 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 being put in operation, and a test facility, BiPo, for the SuperNEMO experiment planned in the Modane Laboratory, France, is fully operational.

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.

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.

Fig. 1.2 The Train Tunnel at LSC

Fig. 1.3 Hall A at LSC

In conclusion, LSC is a multidisciplinary world-class science infrastructure with 1600 m^2 surface and a total volume of 10000 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.

2 REPORT ON ACTIVITIES AT LSC IN 2015

The following experiments have been carrying out activities at LSC in 2015: 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 been recommended by the Scientific Committee in November 2015. During 2016 GOLLUM will test the sampling and analysis protocol, which is fundamental to turn this proposal into an international research program. In addition, one Expression of Interest (EoI) has been reported to the LSC Scientific Committee in November about the possibility to search for dark matter with new inorganic scintillators, named CLYC and produced by the Radiation Monitor Devices in the USA (http://rmdinc.com). The basic idea of this proposal is to exploit the high neutron detection efficiency of the CLYC to reject electron recoils background and tag radiogenic neutrons against dark matter particle interactions (WIMP-like interactions). In 2016 a characterization of the CLYC in terms of radio-purity and performances will be carried out in a collaboration effort between LSC and the Gran Sasso Laboratory in Italy. A second EoI has been reported during the Scientific Committee meeting in November about the possibility to install at LSC an ultra-sensitive force sensor, which could study short-range interactions. The environment underground at LSC is expected to be ideal to exploit at best the sensitivity of this equipment. At present a similar equipment is being installed in the CAST magnet at CERN to search for chameleons, which could make the dark energy in the Universe.

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 (see Fig. 2.1).

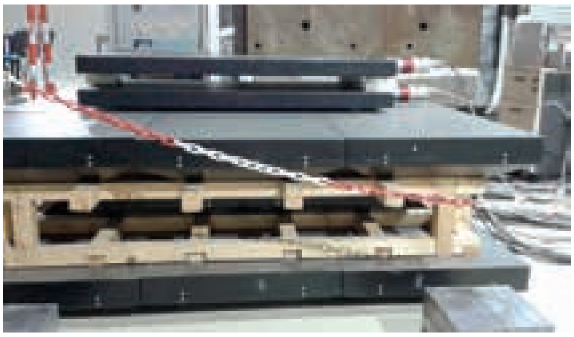


Fig. 2.1 Picture of the cosmic rays muons at LSC.

The muon detector consists of an upper and lower array of 3x3 units. Each unit consists of 4x4 plastic scintillators of 122x122x30mm^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. In October 2015 the detector was moved to LAB2500 (one of the three underground infrastructures at LSC together with LAB780 and LAB2400). Data will be collected in this new location and a full analysis of the measurements carried out. We expect to have a clear understanding of the angular distribution by 2016. This work is done in collaboration with the Moscow Institute of Physics and Technology and the University of Jyvaskyla in Finland.

The ULS Service at LSC has performed a number of measurements within an international project to assist in analyzing the plasma conditions in the KSTAR (Korea Superconducting Tokamak Advanced Research) thermonuclear fusion facility. Samples irradiated inside the KSTAR Tokamak were sent to LSC and other underground laboratories to provide information on charged particles leaking from the plasma. The result will be delivered during the Low-Level Radioactivity Measurement Techniques (LLRMT, 2016) meeting.

The CES Service at LSC is a unique facility among 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. These activities will be developed in 2016. In 2015 with the collaboration of the Gran Sasso Laboratory a measurement of the radio-purity of electro-formed copper was carried out. This work has proved that indeed the electro-formed copper is less radioactive than the original product. Upper limits at the level of ppt in uranium and thorium were determined. In order to improve this result, a collaboration with the Pacific Northwest National Laboratory (PNNL) in USA has started. At PNNL a better sensitivity ICP-MS instrument will be used.

Four electroformed copper pieces were prepared to be part of the PMT encapsulation for the new NaI crystal at ANAIS experiment (Fig. 2.2).

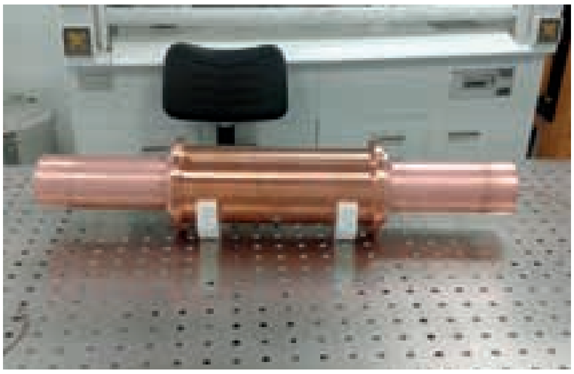


Fig. 2.2 Sample of electro-formed copper made for the ANAIS experiment at LSC.

Environmental measurements (radon, temperature, humidity, atmospheric pressure, water radioactivity contamination) have been carried out in collaboration with the Laboratorio de Bajas Actividades (LABAC) from the University of Zaragoza both underground and on surface at LSC.

A new safety guide for experiments was completed and discussed with the GLIMOS in October 2015. This document includes general regulations on safety for experiments and contractors. The new guidelines are in operation.

In the following we report about new infrastructures installed and upgrades carried out at LSC in 2015.

The infrastructure at LSC has been upgraded with a radon abatement system installed in Hall A in December 2015 as shown in Fig. 2.3.

This system takes air from the environment underground and delivery radon-free air at the level of 1mBq/m^3. The system can produce as much as 220 m^3/h of radon-free air. We recall that on average the air underground at LSC has some 70Bq/m^3 of radon. The air produced will be delivered to Hall C to reduce the radon background in the experimental room, which hosts the high purity germanium detectors for gamma spectroscopy. This improvement should increase the sensitivity of the LSC screening facility. Radon-free air will be also delivered to the NEXT lead shielding castle to reduce the background induced by radon outside the NEXT-NEW pressure vessel. In addition, the radon-free air can be used by any set-up during commissioning and running phase when requested.

The ULS has been upgraded with a SAGe well detector by CANBERRA, and with an alpha spectrometer (Alpha Ensemble 4 by ORTEC).

A new diesel generator has been installed outside the entrance of LAB2400. This equipment can support all experiments and security systems in operation underground in case of power failure. At present LSC is equipped with two UPS diesel generators with power of 63 and 200 kVA, respectively. The minimum autonomy of the system is 12 hours.

Fig. 2.3 Radon abatement system installed at LSC.

An upgrade at 60 Mbps of the internet connection was planned. Unfortunately, this work was not successful for technical reasons not depending on LSC. At present LSC still works with 32 Mbps. We aim to fulfill this upgrade within 2016.

In order to improve the quality of water for underground use at LSC a filtering system was installed. The water going into the $8m^3$ storage vessel goes through a 100µm cartridge. The water delivered from the storage vessel can go through two filters with 50µm and 10µm cartridges. The high filtered water can be used for cleaning activities underground.

Seven new fire-resistance doors were installed in the ventilation system, which delivers about 32000 m^3/h of fresh air to LSC. A fire extinguishing system was installed for the NEXT experiment.

The slow control system of LSC was upgraded: improved quality control of air; power consumption of LAB780; operating conditions of pumps delivering water to Services underground (cooling system for the radon abatement plant, diesel generators).

The fire detection system was upgraded including the NEXT experiment, which has been working on installation and commissioning of new equipment.

A refurbishment of the building named "La Casa de los Abetos" was approved and started. This work will be completed in April 2016. 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 with meeting rooms.

We are very proud to report that in December 2015 the budget to run LSC for the next 6 years has been secured by an agreement between the Spanish Ministry of Economy and Competitiveness, the Aragon Government and the University of Zaragoza.

The total number of users in 2015 has been 254, from 19 countries.

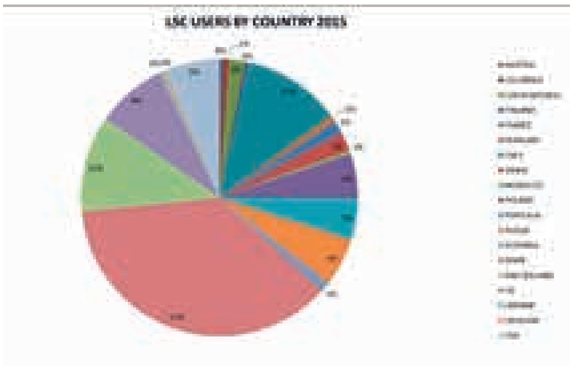


Fig. 2.4. LSC users by Country in 2015

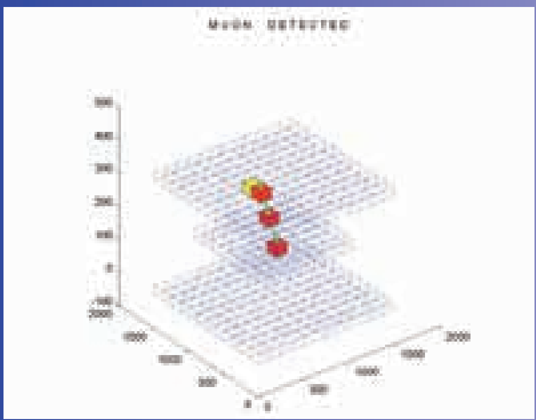
The LSC is running a programme of visits, with nearly 2000 visitors in 2015. In Fig. 2.5 we show the trend of visitors at LSC during the last five years.

Fig. 2.5 Records of visitors at LSC spread over the last five years.

3 RECORDS OF EVENTS IN 2015

2nd "CEMES - INA – LPCNO" TALEM2 Meeting (12-13 February, 2015)

The INA (Instituto Univesitario de Investigación en Nanociencia de Aragón) organized the second TALEM meeting between the CEMES - INA & LPCNO, at the LSC premises on the 12th and 13th of February. Around 26 French and Spanish researchers meet at the LSC meeting room. As part of their activities program a visit to our underground facilities was included.



Workshop on "Investigation of Muon flux in Hall A" (18-20 February, 2015)

Researchers from Russia and Finland met at the LSC premises for a Workshop on the "Investigation of Muon Flux in the LSC underground site". Discussions included simulations of cosmic rays muons flux on the LSC underground site and a visit to the underground laboratory to see the detector.

Presentation of the Refurbishment Project of the "Casa de los Abetos" (26 March, 2015)

The architect in charge of the project, Mr. Basilio Tobías Pintre, presented the refurbishment project of the "Casa de los Abetos", in the surroundings of the LSC surface building, located at the Paseo de los Ayerbe. Such building is located in the area known as "Los Forestales" in Canfranc Estación and in its day it was used as living quarters for the engineers which were involved in the avalanche containment works for the Canfranc Station. The "Casa de los Abetos", which belonged to the Government of Aragon, has been assigned to the Consortium of the Laboratorio Subterraneo de Canfranc to give it use within its activity.

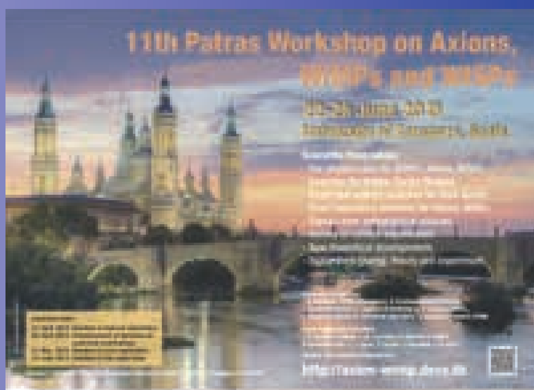
International Workshop MIS3 (Maine in Spain 3) (12-17 June, 2015)

Around 50 researchers from all around the world travelled to Canfranc to participate in some sessions in which they exchanged very specific knowledge and also learnt some aspects about the art, gastronomy and scenery of Canfranc and the Jacetania region. The scientific discussions turned around the molecular prokaryote biology, which refers to the "wonderful and unexpected things" which bacteria do. Amongst the parallel and complementary activities to these sessions it was highlighted the visit to the LSC after holding one of them at its premises.

International Meeting "Challenges for Agencies and Universities" (18-19 June, 2015)

This International Meeting, organized by the quality agencies of Aragon (ACPUA) and the Basque Country (Unibasq), had the aim of exchanging opinions and make a first evaluation by the agencies, universities and experts on the content and outreach of the main novelties, this implying the review of the European Directions and Criteria for the assurance of the quality. A visit to the underground LSC facilities was included in the program.

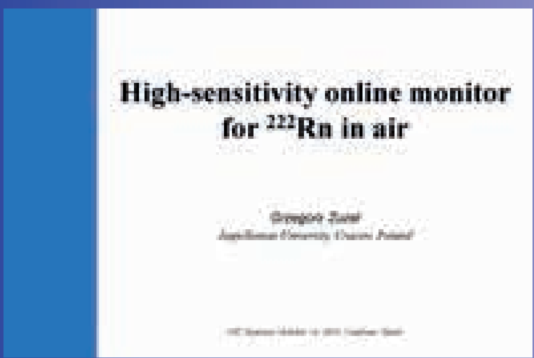
11th Patras Workshop on Axions, WIMPS and WISPs (24 June, 2015)



The 11th Patras Workshop on Axions, WIMPs and WISPs was held in the city of Zaragoza (organized by UNIZAR) from June 22nd to 26th, 2015. One of its sessions was held at the LSC premises and included in the agenda a visit to the underground facilities. The workshop has continued this very rich series, reviewing recent theoretical advances, laboratory experiments and astrophysical and cosmological results regarding axions, WIMPs and WISPs.

DULIA-bio 2015 Workshop on Deep Underground Laboratories Integrated Activities in biology (13-14 October, 2015)

The workshop DULIA-bio (Deep Underground Laboratories Integrated Activities in biology) took place at the LSC premises on Oct 13 and 14, 2015. The aim of the workshop was to establish a common path for European underground laboratories in deep life studies and its application to astrobiology. The workshop goals were to spread interest in this research field, put together a new community working in underground laboratories and be the first of a series of meetings to be held in the four deep underground labs in Europe. Around 30 people attended this event that enjoyed talks from speakers of 15 institutions from 8 different countries.



Workshop on "HIGH SENSITIVITY ONLINE MONITOR FOR Rn-222 in air" (14 October, 2015)

Grzegorz Zuzel, from the M. Smoluchowski Institute of Physics in Poland, gave a workshop to experiments users and members of the LSC staff, informing of the features and operation of an electrostatic detector able to monitor in real time the Rn-222 content in the air at 1 mBq/m^3 sensitivity, in view of the new radon reduction system which will be installed and operating at LSC.

4 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. As a matter of fact, the only experiment that has reported positive evidence so far is DAMA/LIBRA at LNGS. The 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(Tl) scintillating crystals, in extremely low background and low energy threshold conditions.

In March 2015, 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 in the ANAIS-25 shielding. Profiting from an acquisition system designed for a larger number of modules the data taking started only two days after receiving the detector, and after having coupled the two photomultiplier tubes at the LSC clean room. The main goal of this set-up has been the evaluation of the radio-purity of the improved AS powder and crystal growing procedures, in terms of both alpha emitters and ^{40}K content, in order to estimate the background level achievable in the ANAIS experiment. This set-up was referred to as ANAIS-37 (see figure 4.1). The new detector D2 was set in between D0 and D1 in order to better profit from the coincidence efficiency for the potassium content determination.

Fig. 4.1. ANAIS-37 set-up at LSC (March 2015).

D2 module showed similar potassium content to previous detectors but a much lower ^{210}Pb contamination and hence, a much better background at low energies. In figure 4.2 the background is shown in comparison to that of previous D0 module. The improvement is evident, even considering that cosmogenically produced isotopes were still decaying in D2 module.

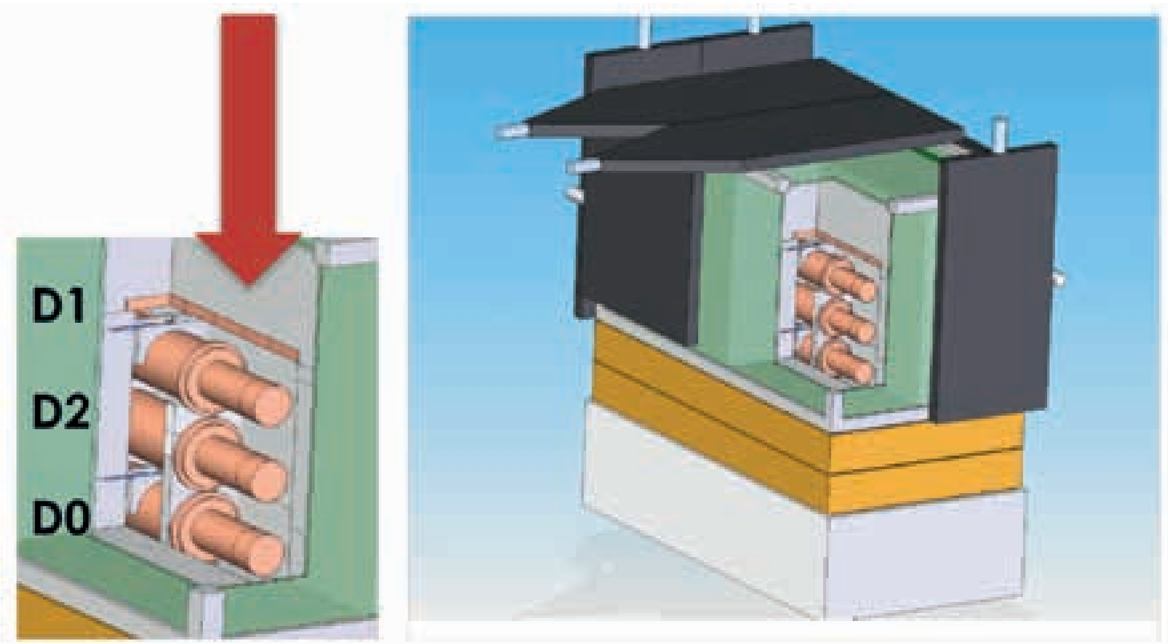


Fig. 4.2. Background improvement observed in module D2 (black) with respect to the background of D0 module (blue). Cosmogenic activated lines are still decaying in D2 module.

Profiting from this background improvement which allowed to reach a high discovery potential for the dark matter annual modulation signal seen by DAMA/LIBRA, and the funding availability, ANAIS research team proposed a new experimental approach for the experiment, to be commissioned along 2016 at the LSC. It consists of a 3x3 matrix of 12.5 kg NaI(Tl) modules, amounting a total mass of 112.5 kg. See figure 4.3 for an artistic view of the proposed experimental set-up. In five years of data taking a large part of the singled-out by DAMA/LIBRA parameter space of dark matter particles could be explored. Moreover, a joint analysis of ANAIS data in collaboration with KIMS and DM-Ice experiments (amounting to 220 kg of NaI(Tl) in total) could allow in two years improving the annual modulation sensitivity significantly.

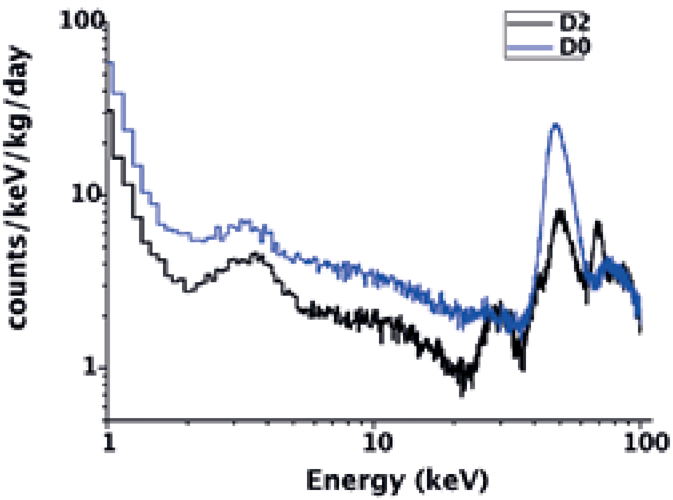


Fig. 4.3. Design chosen for ANAIS experiment: 3x3 matrix of 12.5 kg modules. It will be mounted along 2016 at the LSC.

Data analysis performed using ANAIS-0 and ANAIS-25 detect ors had allowed to progress very significantly in the development of filtering protocols to reject anomalous events in the low energy region, down to 1 keVee. However, in September 2015 a blank module was built and installed in ANAIS-37 set-up in order to better characterize those events surviving the cuts (see figure 4.4).

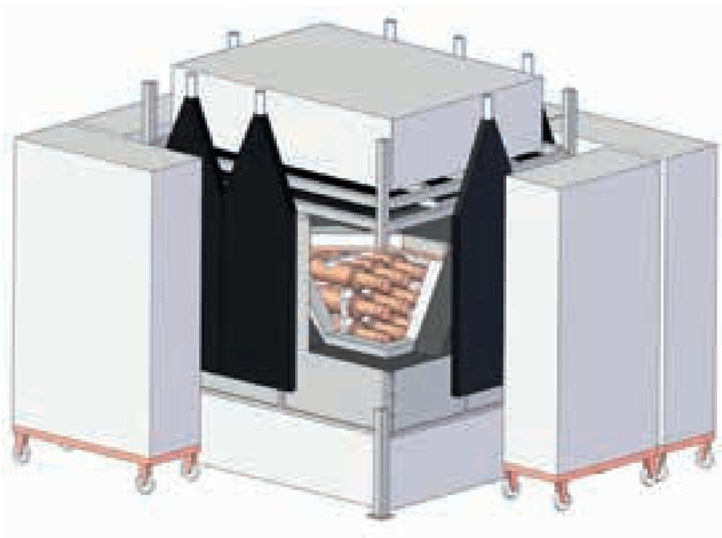
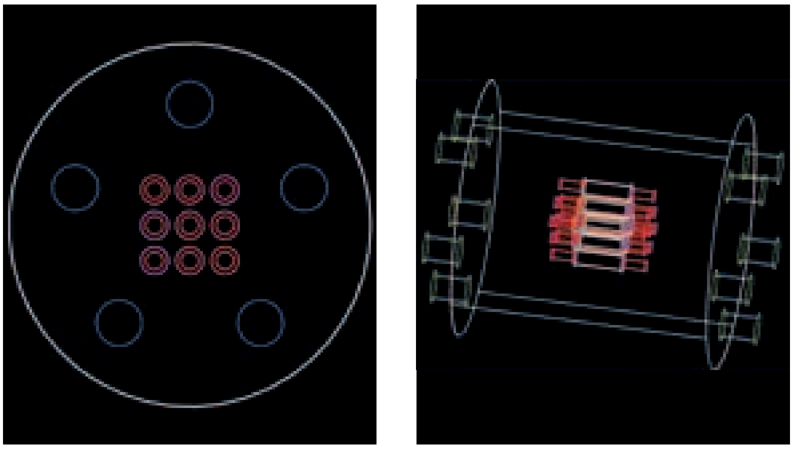


Fig. 4.4. Blank module installed in September 2015 at LSC in order to test the filtering protocols and to evaluate background events having a non-bulk NaI scintillation origin.

Along 2015 it has been simulated the background rejection power of a liquid scintillator veto (LSV) system complementing the ANAIS experimental set-up. This LSV (shown in figure 4.5) would be really effective to reduce the contribution from ^{22}Na and ^{40}K to the ANAIS background at the lowest energies, but not those from other bulk contaminations as ^{210}Pb and tritium, which would become hence as the most dangerous for the experimental goals. Funding for such a LSV system will be requested along 2016.

Fig. 4.5. Design considered for the first Monte Carlo evaluation of the veto effect on ANAIS 3x3 immersed in a liquid scintillator.



Results of the ANAIS activities have been published in international journals and presented in the most important conferences of the dark matter detection and underground physics fields as TAUP conference series (held at Torino, Italy, in September 2015). Moreover, ANAIS has been very recently cited by the prestigious journal Nature as one of the international efforts facing the testing of DAMA/LIBRA controversial claim

http://www.nature.com/news/controversial-dark-matter-claim-faces-ultimate-test-1.19684

5 ARDM

LIQUID ARGON AND DARK MATTER

http://darkmatter.ethz.ch/

The ArDM (Argon Dark Matter) Experiment is the first ton-scale Dark Matter experiment operating at an underground site, having successfully reached all the fundamental milestones in 2015. Following the full construction of the experimental setup for the first phase of the Experiment (Fig. 5.1), ArDM completed its first physics data taking in the single-phase liquid argon (LAr) operational mode (ArDM Run I). A successful commissioning of the detector in February 2015 with ~2 tons of the full LAr target was followed by almost six months of stable data taking until the Experiment was stopped in July according to schedule. An excellent stability of the detector performance was demonstrated throughout the period of the data taking.

More than 3 · 109 triggers were recorded to the local 192-TB data storage system installed underground at LSC during Run I. A first set of this data served as the sample to develop the analysis tools and MC framework for ArDM. Preliminary analysis based on less than 5% of the data confirmed the expected performance of the detector and its environmental installations. In particular the integrity of the light detection system was found to behave according to expectations, including the active, as well as the passive optical components.

A complete Monte Carlo (MC) model was developed, describing the properties of the detector from first principles. It includes a full optical ray tracing, based on modeling of optical processes such as LAr scintillation (emission of 128-nm VUV, vacuum ultraviolet photons), Rayleigh scattering, VUV absorption, conversion to visible blue light with wavelength-shifting TPB (tetraphenylbutadiene), reflections and refractions. The leading parameters used in

Fig. 5.1 Construction of the ArDM setup for the first phase of the Experiment was completed in underground Hall A of LSC. The polyethylene neutron shield (white, in the centre) was fully constructed to enclose entirely the detector vessel. The lower half was covered with fire protection panels consisting of aluminium sheets (outside) and thermal insulators (inside).

the simulation were scanned over large ranges of their values, and results were compared to different data sets. A set of best-tuned parameters was obtained in a global fit. A fully satisfactory description of electron-like background in the LAr target from external (Hall A) and internal (LAr and the detector components) radiogenic sources was found (Fig. 5.2). The dominant background component, the ^{39}Ar decays, could be quantified in agreement with the expected value of ~1 Bq/kg. The second most dominant background is due to external sources. Internal backgrounds from the radioactive contamination of the detector materials account for about 1/20 of the trigger rate. The external (measured in the ArDM detector) and the internal (measured in the material screening campaign using the high-purity germanium detector facility of LSC) gamma fluxes were evaluated based on independent measurements and put in the simulations. This result demonstrated the low background conditions of the ArDM detector and proved the concept of the experiment for WIMP searches. A successful PhD thesis was completed in December 2015 with the results obtained from ArDM Run I as described above, and a second will be completed in early 2016.

Obvious narrowness of the electronic-recoil band seen in the preliminary PSD (pulse-shape discrimination) analysis (Fig. 5.3) has given a first indication of the high background discrimination power of LAr detectors at ton scale. First estimations of electronic-recoil leakage into the nuclear-recoil (signal) region (Fig. 5.4) give promising projections to background suppression by PSD.

While a major part of the recorded data represents physics data taking, nearly 10% was taken employing various calibration sources for detector characterisation. In particular, those data taken with internal ^{83m}Kr and external ^{57}Co sources were used to tune the MC parameters and lead to a satisfactory understanding of the detector response, representing a powerful calibration system of the experiment.

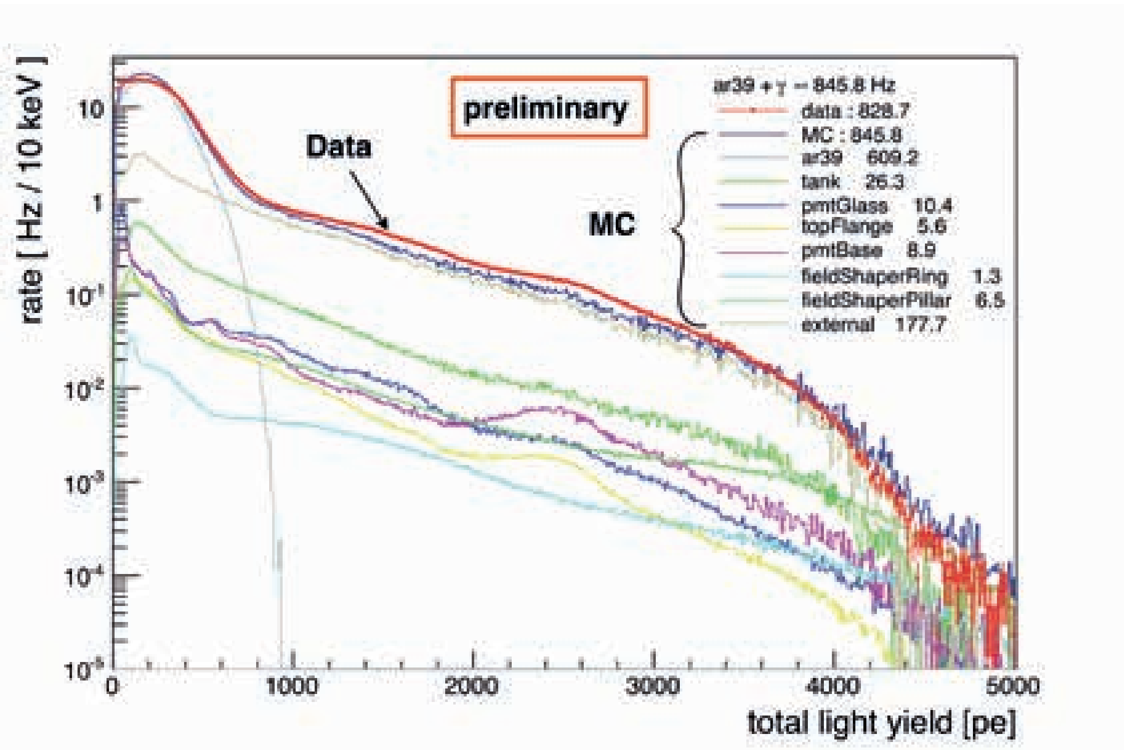


Fig. 5.2. The measured energy spectrum of electron-like backgrounds (red, data) is compared with the Monte Carlo simulation (dark blue, MC). Contributions from different sources (39Ar decay, gammas from external and internal sources), shown in different colors, were simulated separately and scaled according to the results of independent measurements.

The operation of the experiment involving ~2 tons of cryogenic LAr at the underground site was a major challenge. Prior to cryogenic operation a quantitative risk assessment (QRA) of the experimental setup was performed by the Greek scientific research center DEMOKRITOS, specialised in reviewing industrial installations like nuclear power plants. Later on the QRA was reviewed by another external independent company, NIER, Italy, which is particularly experienced in underground installations. Both reviews were done in close collaboration with LSC and with the help of its technical staff. In the first instance the assessment consisted of the simulation of accidents by solving three dimensional transient dispersion problems involving double-phase cryogenic leaks. Accidents were classified into three levels, where only the third one was found to represent considerable risk to personnel at the underground site. However, the frequency for such an event was estimated to be only $4 \cdot 10^{-5}$ per year. A range of additional safety equipment was installed in collaboration with LSC to prevent risks in such events, to be approved for the full cryogenic operation.

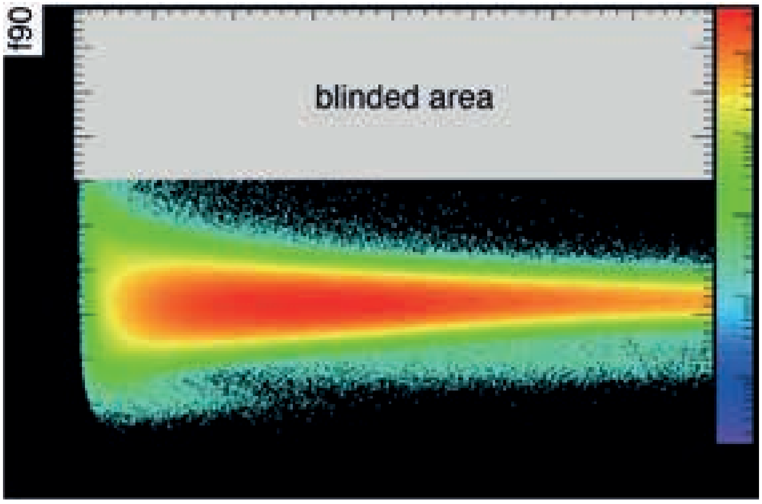


Fig. 5.3. Distribution of measured events (˜30 million events) represented in terms of the PSD (pulse-shape discrimination) parameter f90 as a function of the total number of detected photoelectrons (total LY). The dominant electronic-recoil background (mainly ^{39}Ar decays) is distributed in the band around the mean value of about 0.33 in f90. The obvious narrowness of the band has given a first indication of the high background discrimination power of LAr detectors at ton scale. The nuclear-recoil events, possibly signals induced by WIMPs, are expected in the blinded area with high f90 values.

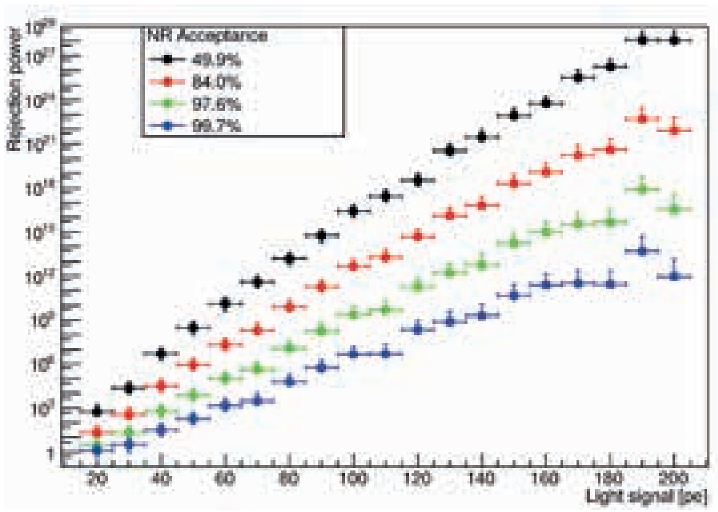


Fig. 5.4. First estimation of the electron-recoil rejection power in ArDM as a function of the number of detected photoelectrons, obtained from the pulse-shape discrimination (PSD) analysis. Neutron-induced nuclear-recoil events were analysed in the data set taken with a 252Cf fission neutron source.

The ArDM cryogenic system showed a high stability and safety during approximately nine months of the cryogenic operation. The full control system of ArDM realised with industrial PLC (Programmable Logic Controller) modules, which automatically regulates the conditions in the system, maintained the pressure of the main LAr volume typically within 10 mbar variations. Its full remote control feature allowed operating the system with minimal local shifters working with remote shifters at the ArDM Control Centre at CERN in Geneva.

Besides the ArDM Run I, one year of continuous data taking was accomplished successfully in the neutron measurement campaign to assess the environmental neutron flux in Hall A, resulting in the total live time of 216 days and >109 recorded events. Detailed analyses are currently being pursued with a special attention put on the observed variations of the detector response and possible corrections for the effect. Measurements will be continued in new detector configurations to provide essential information that will eventually complement our understanding of the neutron backgrounds.

In parallel to the extensive work ongoing on the data analysis as described above, the Collaboration made a great effort to prepare for hardware upgrades, mainly to install the TPC drift cage for the next run. The dual-phase LAr TPC operational mode will enable readout of ionisation charge through secondary scintillation light, produced by electrons drifted in LAr and then extracted into the argon vapour phase. This will allow a full 3D position reconstruction of event vertices, essential for precise fiducialisations, and at the same time, additional discrimination power for electron-like backgrounds from nuclear recoil events. The upgrades will include improvement of the light detection system, employing PMMA (polymethylmethacrylate) windows and newly fabricated inner reflector foils, both coated with TPB. The upgraded detector will be installed underground at LSC in early 2016. After its commissioning, ArDM Run II in the dual-phase LAr TPC operational mode will take place through 2016, where we expect to achieve the highest sensitivity to WIMPs for the experiments based on the LAr technologies. For those hardware upgrades as well as for various R&D programmes towards long-term plans of the ArDM experiment, the status as a CERN Recognised Experiment (RE18) was reconfirmed in March 2015.

6 NEXT

HIGH PRESSURE GAS AND NEUTRINOLESS DOUBLE BETA DECAY

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

The goal of the Neutrino Experiment with a Xenon TPC (NEXT)[1] is the construction, commissioning and operation of the NEXT-100 detector, a high-pressure, xenon (HPXe) Time Projection Chamber using electroluminescent (EL) readout. NEXT-100 will search for neutrinoless double beta decay ($\beta\beta0\nu$) events in ^{136}Xe, deploying 100 kg of xenon enriched at 90% in the isotope ^{136}Xe. The is being installed in Hall A at LSC.

The project is being developed in three phases. The initial R&D extended from 2010 to 2014. The operation of three large (1-kg xenon at 10 bar pressure) prototypes, NEXT-DBDM (LBNL), NEXT-DEMO (IFIC) and NEXT-MM (Zaragoza), has shown the excellent performance (energy resolution, electron reconstruction) of the chosen EL technology.

The second phase of the project is the construction, commissioning and operation of NEW (NEXT-WHITE)[2], a first-stage, radiopure, 10-kg demonstrator intended to exercise the NEXT-100 detector technical solutions and infrastructures (including the gas system and the Slow Controls), as well as to provide essential data for the NEXT background model. The apparatus and the infrastructures have been built during 2015 are currently being commissioned at the LSC. The foreseen operation period is two years (2017 and 2018).

The third stage of the project is the construction (2018), commissioning (2019) and operation (2019 onwards) of the NEXT-100 detector.

In the following we report an overview of the achievements during 2015.

Figure 6.1: The NEXT working platform, showing the Lead Castle and the Gas system. The NEXT-100 pressure vessel (right side of picture) is used as Emergency Recovery Tank.

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

2. The name honours the memory of the late Professor James White, one of the key scientists of the NEXT Collaboration.

Figure 6.2: The compressor chosen for NEXT, manufactured by the SERA company, in Germany. The pump is made with metal-to-metal seals on all the wetted surfaces. The gas is moved through the system by a triple stainless steel diaphragm, ensuring a negligible probability of catastrophic failure (gas liberated to the atmosphere). Between each of the diaphragms there is a sniffer port to monitor for gas leakages. In the event of a leakage, automatic emergency shutdown can be initiated.

The NEXT Infrastructures

Figure 6.1 shows the NEXT working platform. Most of the needed infrastructures to operate NEW have been completed in 2015.

Of particular importance is the gas system, common to the NEW and NEXT-100 detectors, whose role is to purify the xenon, reducing the traces of gases such as O_2, CO_2, CO, H_2, N_2, CH_4 and water vapour to less than one part per billion (ppb). Both NEW and NEXT-100 will operate with natural xenon and enriched xenon. The gas will be maintained at room temperature and 10–15 bar pressure inside the detector(s). The gas system has been designed to avoid significant losses of xenon under all foreseeable circumstances.

The main components of the gas system are:

- Emergency recovery system, which re-uses NEXT-100 pressure vessel.
- Compressor, shown in figure 6.2.
- Purification loop, which includes hot and cold getters to clean the gas.
- Cryo-recovery system, to reclaim the gas in normal conditions.

The gas system components have been completed during 2015 and the first quarter of 2016. The system is now in the final commissioning phase, and ready to pass the tests needed for underground operation and certification. Start of operations is foreseen in May, 2016.

Figure 6.3: The NEW detector being assembled in the LSC clean room in 2015. The picture shows the detector seen from the Energy Plane side. The EP "cross" holds the feedthroughs (each cross side allows the extraction of 4 PMT signals) and also connects to the vacuum pump used to make vacuum in the vacuum side of the detector (in the picture the pump displays the level of vacuum achieved, 4.9 ¨ 10¨5 mbar). The RGA is also clearly visible.

The NEW detector

The NEW detector is the first stage of the NEXT experiment. The NEW pressure vessel and field cage dimensions are roughly 1:2 with respect to those of NEXT-100. It deploys 20 % of the NEXT-100 sensors and the xenon mass is about 10 kg at 15 bar.

Figure 6.3 shows the assembly of NEW at the LSC clean room during 2015. The detector has three main parts called Energy Plane (EP), Tracking Plane (TP) and Field Cage (FC). The EP and TP are already installed in the NEW pressure vessel. The FC will be installed during the first week of May 2016.

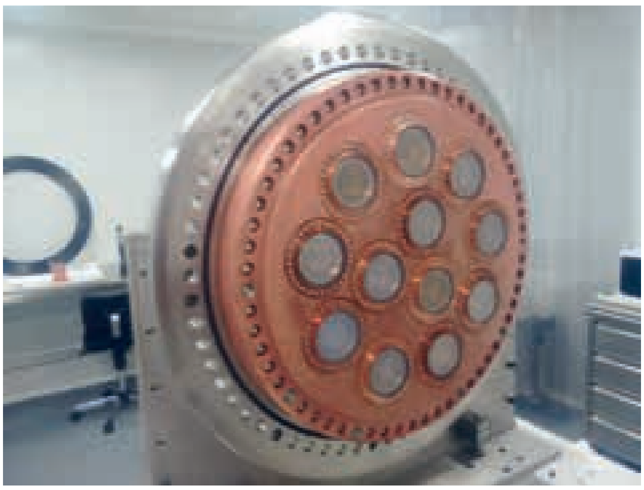


Figure 6.4: Assembly of the Energy Plane at the LSC clean room in 2015. The picture shows the end-cup plate (mother-can) with the sapphire windows already installed.

The energy plane is shown in figure 6.4. The EP consists of a 11 cm thick copper support plate (called mother-can) with 12 copper window covered with brazed sapphire windows fixed to the front of the plate. The set-up as a whole seals the pressure vessel from the PMT-region, which is held at vacuum levels of $< 10^{-5}$ mbar. Additional copper shielding fixed to the vacuum side of the apertures, offer further shielding against gammas traversing the PMTs and entering in the detector volume. The 12 Hamamatsu R11410 PMTs are optically coupled to the sapphire window using NyoGel OCK-451.

The NEW tracking plane permits the reconstruction of the trajectories of charged particles, (e.g., electrons), in the NEW/NEXT detectors. It consists of a matrix of silicon photomultipliers (SiPMs) which operate as light pixels, providing a 2D picture of the event (the third coordinate is given by the drift time). The SiPMs are radiopure 1mm sensors, manufactured by SENSL. The TP is made of 28 radiopure circuits called Kapton DICE-Boards (KDB). Each KDB has an 8 × 8 SiPM array, where each SiPM is placed at a 1-cm pitch. Each KDB also includes a NTC temperature sensor and one LED for calibration. The KDBs over-cover the fiducial region with 1800 SiPMs, ensuring that there are no dead regions. The connector is located at the end of a long tail, and is screened from the gas, in the fiducial volume, by a 120 mm thick copper shield. The KDBs are covered by reflectors, to increase the amount of light that reaches the energy plane. Figure 6.5 shows the TP with half of the circuits covered with reflectors.

The goal of the FC is to provide a homogeneous and uniform electric field inside the active volume of the NEW detector. The field cage

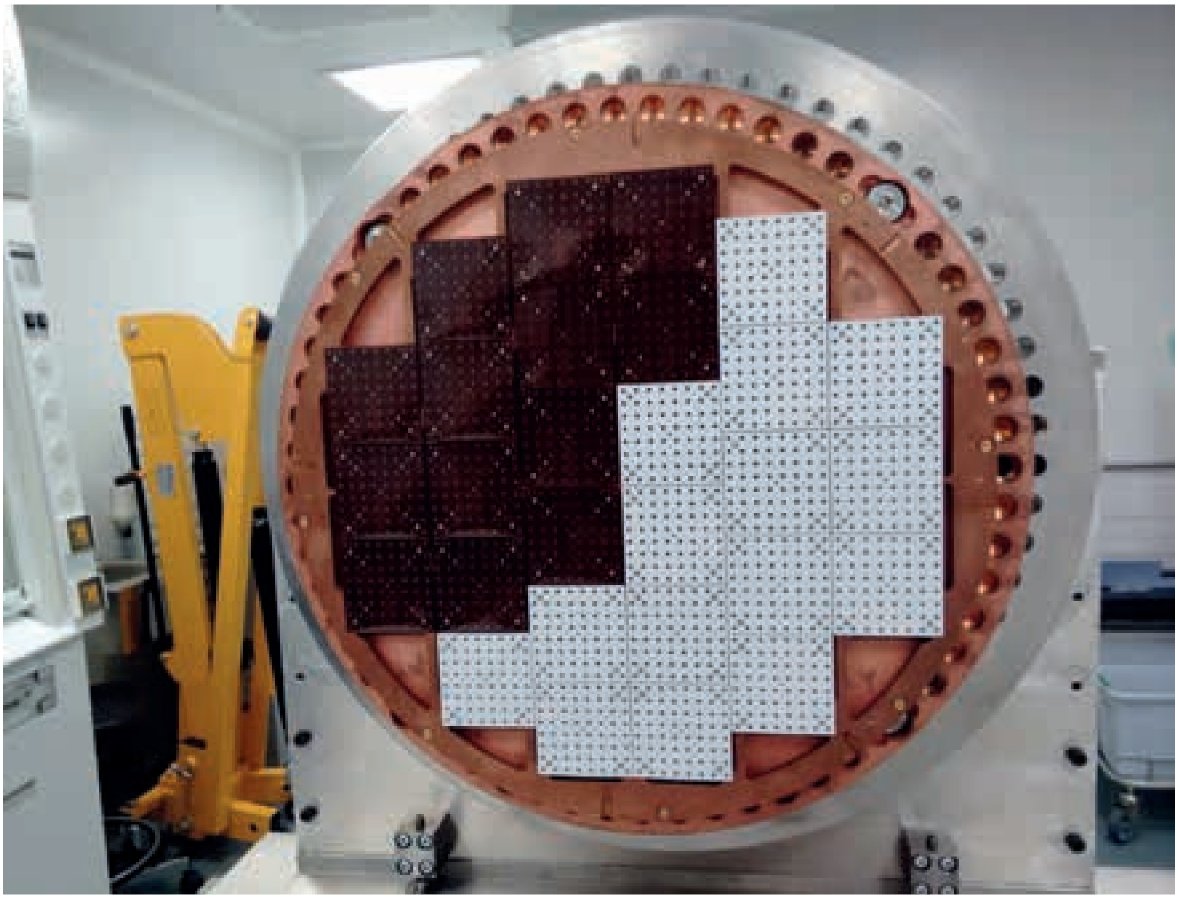


Figure 6.5: The NEW tracking plane being mounted at the LSC clean room during 2015.

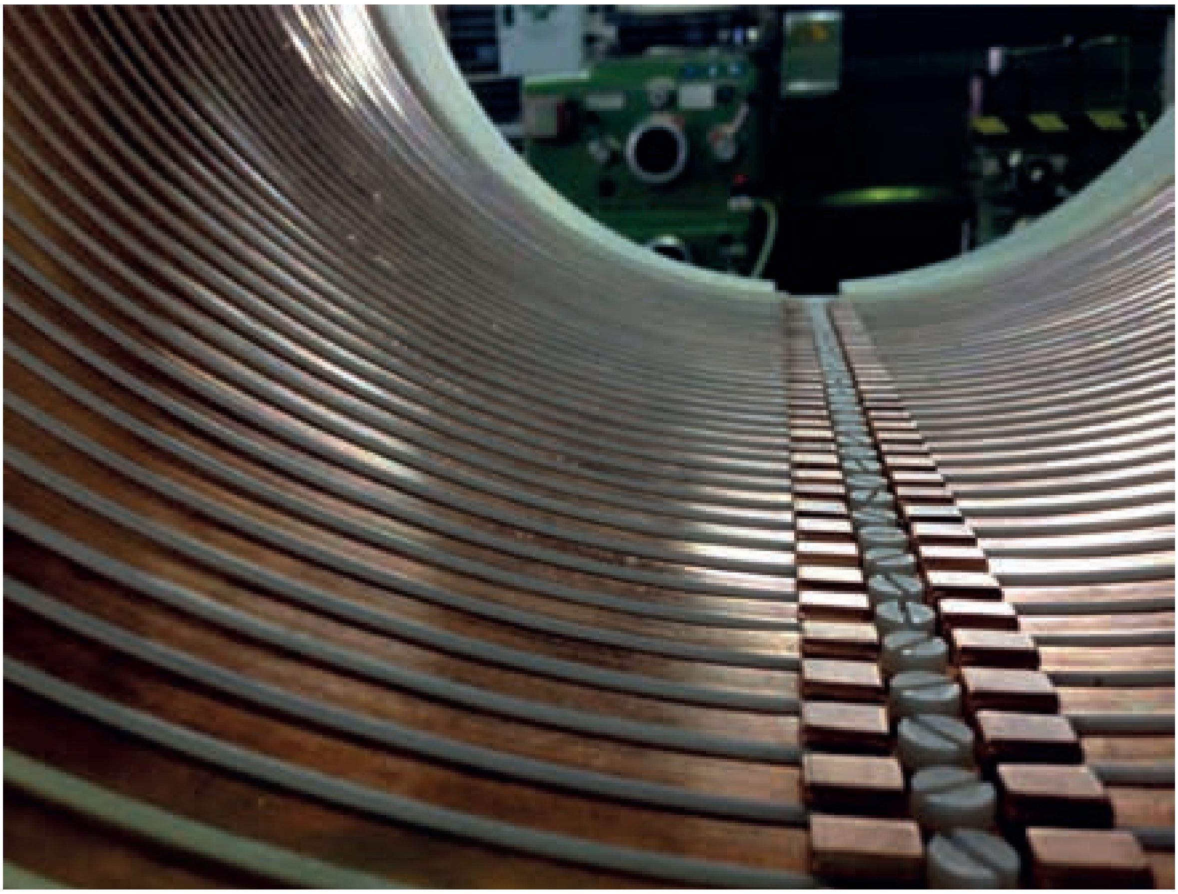


Figure 6.6: Detail of the copper rings in the drift region of the field cage.

has an outer diameter (OD) of 50 cm and a length of 50 cm. Thus, both the longitudinal and radial dimensions are roughly half of those of NEXT-100.

The main body of the field cage is a high-density polyethylene (HDPE) cylindrical shell that provides electric insulation from the vessel. The shell is 2.5 cm thick. Two wire meshes (cathode and anode) define the active volume of NEW. The electroluminescence region is defined by one of these meshes (anode) and a fused silica plate (gate) with an ITO coating to make its surface resistive (gate). Ultra pure copper strips attached to the HDPE and connected with low background 10 GΩ resistors (figure 6.6) grade the high voltage to provide a homogeneous and uniform moderate electric field (300-600 V/cm) inside the active volume of the NEW detector.

Summary

In summary the progress in the construction and commissioning of the experiment infrastructures and detector during 2015 has been:

The working platform, seismic pedestal and lead castle are completed an operational.

The full NEXT gas system, including recirculation, purification, emergency storage and cryo-recovery is ready to be certified for operation (scheduled for May, 2016).

The NEW detector is being assembled at the LSC. The energy plane and tracking plane are already installed and the field cage is scheduled for installation in May, 2016.

7 BiPo

NEUTRINOLESS DOUBLE BETA DECAY: CANFRANC WITH MODANE

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

During 2015, the two results of the BiPo-3 detector are the measurement of eight SuperNemo enriched ^{82}Se foils and the measurement of natural Selenium which has been purified by a new technique developped in JINR, Dubna.

Measurement of the enriched ^{82}Se foils

The available enriched ^{82}Se foils have been produced by ITEP (Russia). The length of the foils is 2705 mm with a width of 135 mm. To produce these enriched ^{82}Se foils, thin and chemically purified ^{82}Se powder is mixed with Polyvinyl alcohol (PVA) glue and then deposited between two Mylar foils. The Mylar foil is 12 mm thick and it has been irradiated at JINR Dubna (Russia) with an ion beam and then etched in a Sodium hydoxide solution. It produces 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 radio-purity 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. This contamination is taken into account in the measurement of the enriched ^{82}Se foils. Besides, two components of the detector background are included in the analysis: the Bismuth (^{212}Bi/^{208}Tl or ^{214}Bi) contaminations on the surface of the scintillators and the random coincidences.

These backgrounds have been measured by long dedicated background runs.

The first four enriched ^{82}Se foils (labelled foils 1,2,3 & 4) have been measured from August 2014 untill June 2015. Two first SuperNEMO ^{82}Se strips have been measured from August 2014 to December 2014, using half of the available surface area of the BiPo-3 Module 1. The second half has been kept empty and has been used to control the background. In

December 2014, two additionnal strips have been installed besides the two first strips in the second half of the BiPo-3 Module 1. Then the four strips have been measured from December 2014 to June 2015.

The total duration of two periods of measurement is 262 days for the ^{212}BiPo measurement (after rejecting the three first days to suppress the background induced by the Thoron deposition) and 241.1 days for the ^{214}BiPo measurement (after rejecting the fifteen first days to suppress the background induced by the Radon deposition).

For the ^{212}BiPo measurement, 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) = [6.3 - 34.2] mBq/kg at 90 % C.L.

For the ^{214}Bi measurement, a preliminary analisis showed that the number of events in the data is compatble 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) < 300 mBq/kg at 90 % C.L.

The second four enriched ^{82}Se foils (labelled foils 5,6,7 & 8) started to be measured in June 2015. The measurement is on-going and the partial result for the ^{212}BiPo measurement is in agreement with a ^{212}Bi contamination inside the ^{82}Se+PVA mixture at the level of A(^{208}Tl) = [14 - 79] mBq/kg at 90 % C.L.

Fig. 7.1: Installation of a sample in one of the BiPo-3 modules.

Measurement of the purified ^{nat}Se pads

A novel purification technique has been developped in JINR, Dubna. The BiPo-3 detector has un unprecented sensitivity to asses the radiopurity levels achieved for ^{212}Bi and ^{214}Bi in the Se and this result will prove the strenght of the new purification technique.

The available ^{nat}Se pads have been produced by LAPP (Anncey, France) with a total length of 2700 mm and a width of 135 mm. To produce these pads, the purified ^{nat}Se powder is mixed with Polyvinyl alcohol (PVA) glue and then deposited between two Mylar foils. Since a contamination in ^{208}Tl has been observed inside the Mylar after irradiation, the pads have been produced with Mylar without irradiation. A new production method therefore have to be developed, as the Mylar without irradiation, without tiny holes as the irradiated Mylar, does not ensure a good bond with the PVA glue and does not allow the water evaporation.

The measurement of the purified ^{nat}Se pads showed a relatively large surface contamination was observed pointing to the fact that the production method needed to be improved. Efforts have been on-going to improve the radiopurity of the final sources with the new production method.

Final remarks

Today eight SuperNemo enriched ^{82}Se foils have been measured or are under measurement in BiPo. Other enriched ^{82}Se foils are under development, with a different purification method and a different production technology. Part of these foils will be also measured in the BiPo-3 detector in the year 2016.

There is a growing interest from dark matter or double-beta decay experiments in measurements with the BiPo-3 set-up to asses the radiopurity of thin materials since the material selection is a key ingredient to reach the targetted sensitivities. Samples of CUORE and LUMINEU double-beta experiments have already been measured with the BiPo-3 detector. Several samples of micromegas produced with different technologies from the University of Zaragoza have also been measured. The group in CEA/Saclay from the IAXO project for axions search (CAST follow-up) is interested in measurements with BiPo-3 of micromegas and the alternative technologies of MMCs and TES. The dark matter experiment DarkSide is also interested in measurements with BiPo-3.

The BiPo-3 detector has become a generic detector and will be available in 2017 to measure samples from several experiments.

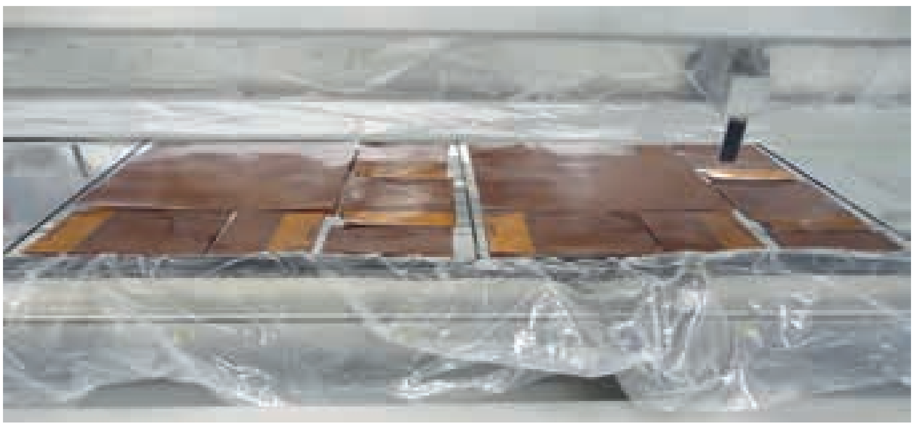


Fig. 7.2 : Micromegas installed for measurement in the BiPo-3 detector.

8 SUPERKGD

SEARCHING FOR RADIO-PURITY: CANFRANC WITH KAMIOKA

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

SuperKGd in 2015

A very important milestone occurred during 2015 is that the Gd project has been officially endorsed by the Super-Kamiokande Collaboration on its Council meeting of June 27th 2015. The official statement follows:

In June 27, 2015, the Super-Kamiokande collaboration approved the SuperK-Gd project, which will enhance anti-neutrino detectability by dissolving gadolinium to the Super-K water. The actual schedule of the project including refurbishment of the tank and Gd-loading time will be determined soon taking into account the T2K schedule.

Activities. Several radio-purity measurements mostly on samples of Gd salts have been carried out during the year 2015. They are listed below, along some explanation to put them in context.

1. A new sample $Gd_2(SO_4)_3$ from ***Stanford Materials Co.*** (CA, USA) [Gd-201412]. Even though the contamination is still large, it is steadily improving at every new batch delivered. It is certainly good news that ***Stanford Materials Co.***, up to now the only realistic provider candidate for mass production, is improving their levels of contamination.
2. A sample of $Gd_2(SO_4)_3$, [Gd-201508] from the Japanese supplier ***Kojundo Chemical Laboratories Co. Ltd.***. It is the cleanest $Gd_2(SO_4)_3$ sample measured so far (see summary table below). Interestingly we do see significant amounts of ^{134}Cs and ^{137}Cs in this sample.
3. We have re-measured the sample of the $Gd_2(SO_4)_3$ batch that it is currently dissolved at the EGADS test tank in the Kamioka Observatory. It is [Gd-201308] from ***Stanford Materials Co.*** (CA, USA). The initial reason for this was to understand ICP-MS results of samples taken in situ, however the main outcome is the noticing of major changes in the non-equilibrium of the ^{232}Th and ^{235}U chains after the 2-year gap between both measurements.
4. A sample of SiO_2 powder, glue candidate for the sealing material of the leak in Super-Kamiokande, also manufactured by ***Kojundo Chemical Labs. Co. Ltd.*** As the sample of Gd from ***Kojundo*** was so clean, we had good expectations for the cleanness of this SiO_2, which did not fulfilled.
5. A sample of Gd_2O_3 from ***Molycorp, Inc.*** (CO, USA) [Gd2O3-201510]. This company is a world leading mining and processing of rare earth and rare metal products. It has shown interest in our project and, particularly, in pursuing its own R&D program to produce clean $Gd_2(SO_4)_3$. In order to have a first, order 0, iteration they have provided us with this off-the-shelf Gd_2O_3 sample.

The results for the 3 radioactive chains and

Chain	Main sub-chain isotope	Gd-201412	Gd-201508	Gd-201308 measured 201508	SiO_2 Kojundo	Gd2O3 -201510
^{238}U	^{238}U	< 76	< 34	14 ± 7	777 ± 207	1673 ± 122
	^{226}Ra	< 1.4	< 0.8	1.0 ± 0.4	449 ± 8	< 3
^{232}Th	^{228}Ra	2 ± 1	< 1.1	12 ± 1	40 ± 6	258 ± 6
	^{228}Th	29 ± 2	2.0 ± 0.5	63 ± 2	43 ± 5	124 ± 3
^{235}U	^{235}U	< 1.8	< 0.6	< 2.5	<	25 ± 8
	$^{227}Ac/^{227}Th$	190 ± 6	11 ± 4	196 ± 5	<	< 15
	^{40}K	< 5	< 3	3 ± 1	875 ± 36	21 ± 6
	^{138}La	23 ± 1	< 0.6	3.2 ± 0.3		< 3.2
	^{176}Lu	2.5 ± 0.6	2.9 ± 0.2	24 ± 1		5.9 ± 0.4
	^{134}Cs		0.5 ± 0.1			< 0.8
	^{137}Cs		2.6 ± 0.3			< 1.1

relevant radioactive isotope are summarized in the following table (units are mBq/Kg):

Respecting the expected impact of the measured contaminations on the SuperK-Gd physics program, we estimate that contaminations as measured in the delivered batch [Gd-201508] (***Kojundo Chemical Labs. Co. Ltd.***), 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 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 10 and 100 is still needed in order to maintain the current solar capabilities of SK. Even though we still aim for such a clean $Gd_2(SO_4)_3$ sample at delivery, a Th/Ra removal system is being developed in the Kamioka Observatory for that purpose.

Near future plans.

We have established successful relationship with two new company providers of $Gd_2(SO_4)_3$: the Japanese ***Kojundo Chemical Labs. Co. Ltd.,*** from which we have got the cleanest sample received so far, and ***Molycorp Inc.*** (CO, USA), a world leading mining and processing of rare earth and rare metal products company that has shown interest in pursuing, with our help, its own R&D program to produce clean $Gd_2(SO_4)_3$. Adding to them ***Stanford Materials Co.*** (CA, USA) that, on the other hand, is improving steadily and significantly the cleanliness of their product, they make three very serious candidates for the production and delivery of the 100 ton of $Gd_2(SO_4)_3$ needed at SuperK-Gd.

At some point in the medium term future, thorough negotiations with the final candidates for full production will be started in order 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. SuperKGd will be important for its success.

The current SuperK-Gd Gd-loading scenario agreed upon with T2K, contemplates the largest activity to occur during 2018. As we originally foresaw in SuperKGd, we plan to measure at the LSC at least one sample of every batch 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 start of related activities in SUPERKGD by the end of 2016, increasing steadily during 2017 and lasting for, maybe, one year more. The detailed requests of support to the LSC by SUPERKGD will depend very much on how the production and delivery is planned.

9 GEODYN

GEOPHYSICS FROM UNDERGROUND

In October 2015 the EPOS IP project (Earth Plate Observing System, Implementation Phase) started with 46 partners from 23 countries across Europe. The project is funded under the European Commission's Horizon 2020 programme and aims at creating a pan-European infrastructure for solid Earth science. Geodyn is listed as one of the research infrastructures in the RIDE (Research Infrastructure Database for EPOS) catalogue, thus enhancing its international visibility and ensuring widespread scientific access to the recorded data.

Seismic component

The two sensors (Broad Band seismometer and accelerometer) and the data-logger installed on the Lab780 have been fully operational during 2015, providing accurate seismic recordings. The seismic data remain open through the EIDA node hosted in the Orfeus Datacenter, which receives the seismic data in near-real time and makes them available to the seismological community.

We have continued the record and identification of local/regional and teleseismic events in both the accelerometer and the broad-band seismometer. The local seismicity has been rather scarce during 2015, without any local event reaching magnitude 4. Regarding regional activity, we can highlight the recording of the 23/02/2015 event with epicenter in Montilla (Albacete), at about 600 km south of LSC and magnitude 5.2 (Figure 9.1).

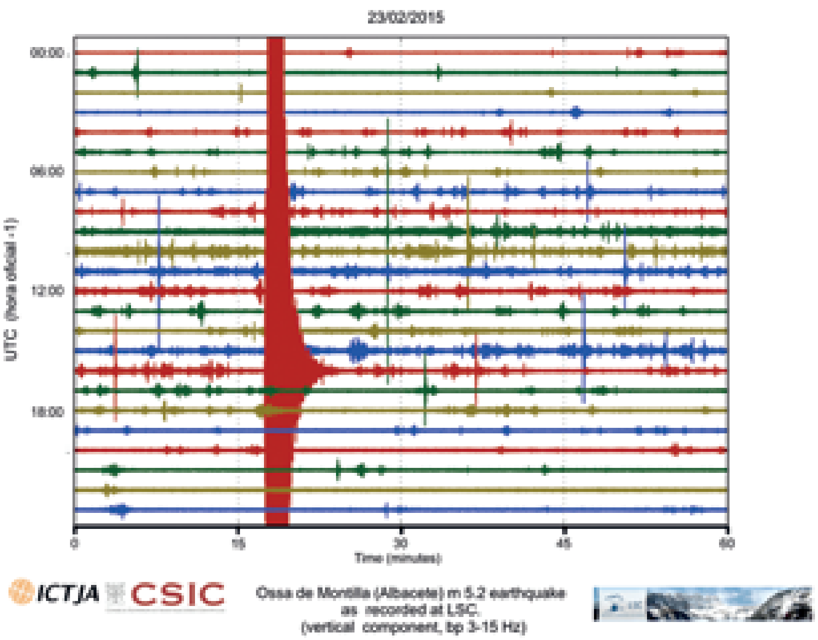


Figure 9.1: Seismic record of the of the Montilla event (each line is for 1 hour)

The most significant distant earthquake recorded at Geodyn during this year has been the 16th September 2015 magnitude 8.3 Mw event with epicenter near Illapel (Central Chile) (Figure 9.2).

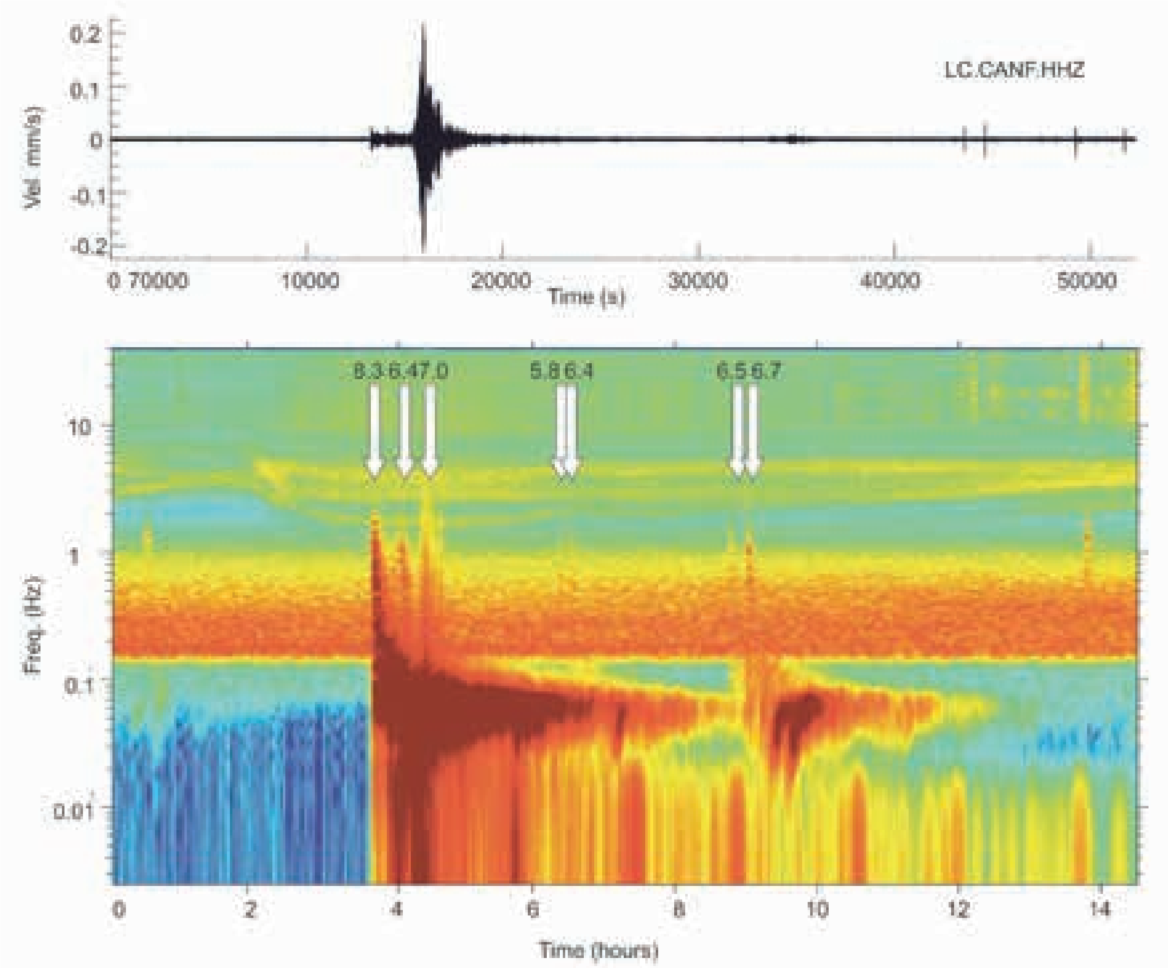


Figure 9.2: Seismic record of the 16/09/2015 8.3 mW in Central Chile. White arrows show the arrivals of the main aftershocks.

During 2015 we have retaken the investigations on the use of seismic data to monitor hydrological features. A manuscript has been submitted to "Physics of the Earth and Planetary Interiors".

Strain component

Failures of the vacuum pumps and the acquisition computers of both interferometers, already detected in 2014, have resulted in severe disruptions in the laser interferometers during 2015. In January the vacuum pumps of both interferometers and the acquisition Pc for Gal16 have been replaced. Data acquisition was restarted on March, but Gal16 stopped again in July, after one of the several blackouts which affected the interferometers. Lab780 interferometer stopped in early June 2015 because of the Pc breakdown and was restarted in late July using the Pc moved from Gal16

The typical operating lifetime of a HeNe laser tube is about 25,000 to 30,000 hours, and depends on operating conditions. The two lasers at LSC have been working for about 3.5 years without any tube replacement resulting in intensity instabilities, indicating that the tubes were close to failure. Therefore, the laser tube of both interferometers have been removed on August 18th and send to manufacturer for maintenance. The refurbished lasers were delivered at LSC in March 2016. Data acquisition is expected to restart in June 2016.

The Scientific activity concerning deformation data has been centered in the investigation of hydrological signals. During the heavy rain episode on November 2013, the two interferometers provided the data displayed in the figure 9.3, which have been interpreted and integrated in the paper on hydrological events submitted to PEPI.

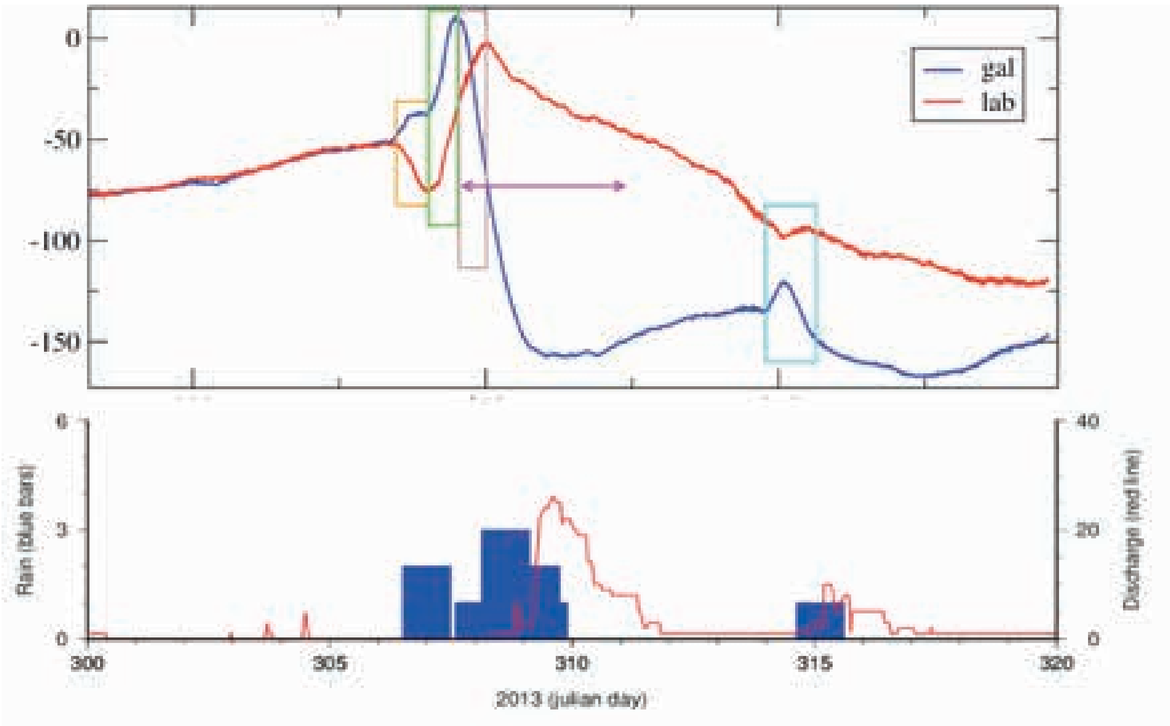


Figure 9.3: Deformation data during the November 2013 episode. Lower panel show rainfall (blue bars) and river discharge as measures in the gauge station. Time scale in Julian days

GNSS component

In March 2015 Fuerte de Rapitán station (CGPS1) was equipped with all the necessary equipment (antenna, receiver, solar panels). The station is located about 18 km south of the LSC, close to the Fuerte de Rapitán, on the outskirts of Jaca.

CGPS2 site, installed in Candanchú within the grounds of the military base (Escuela Militar de Montaña), has been equipped in May 2015. The monument consists of a 2 m tall concrete pillar anchored to the ground using iron rebars, while the instrument box and a solar panel will be located approximately 2-3 meters away from the monument within the installed fence.

Both stations (see figure 9.4) have been put on operation during the second semester and are now acquiring data on regular basis. Data from CGPS1 station can be accessed remotely using the web address: http://95.124.250.98. Candanchú station is acquiring data but remote access has not been possible during 2015 due to technical issues.

Figure 9.4: Final aspect of the CGPS-1 monuments near Jaca (left) an the CGPS-2 one near Candanchú.

Currently the group from University of Barcelona is processing the data from the RAPI station using the GAMIT/GOBK software from MIT. Next improvement will be augmenting the external memory of the receivers in order to allow high frequency acquisition (1 Hz for example).

10 CUNA

NUCLEAR ASTROPHYSICS FROM UNDERGROUND

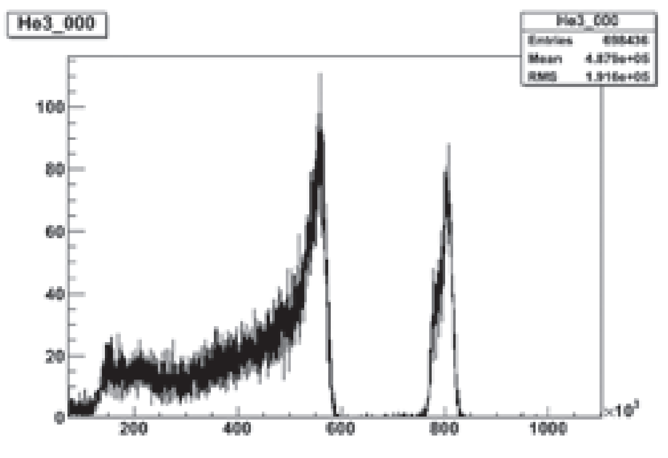
The slow neutron capture process (s-process), taking place in red giant stars on the Asymptotic Giant Branch (main component) or in massive stars (weak component) is thought to be responsible for the synthesis of about half of the species above iron. An outstanding question is how the flux of neutrons capable to produce the neutron captures is created, the most likely candidates being (α,n) processes, specifically the $^{22}Ne(\alpha,n)^{25}Mg$ and $^{13}C(\alpha,n)^{16}O$ reactions, depending on the precise scenario.

Precise cross section measurements are required to evaluate both the expected neutron flux and the s-process efficiency. But the measurements needed to understand the astrophysical processes cannot be done at surface laboratories due to the cosmic rays that produce background interactions at very large rates, and therefore they need to be performed in an underground laboratory. The LSC overburden provides the required low-background environment allowing measurements to be extended to very low energies, where counting rates would be of the order of 1 event/hour or even lower. An "Expression of Interest" entitled "A Nuclear Astrophysics facility for LSC: The sources of neutrons in the stars and other reactions of astrophysical interest" was submitted to the LSC in 2009 by Spanish groups and international partners. The idea was to install a state-of-the-art high-current accelerator operating at low energies, to measure the reactions of interest. A full "Letter of Intent" was submitted in October 2012, endorsed by more than 50 international support letters. .

The extremely low cross sections of the nuclear reactions to be studied at CUNA makes the case for a high efficiency detector set-up, with high discrimination capability for the reaction channel of interest. Since the core of the experimental programme proposed at CUNA is the (α,n) reactions, the use of a neutron counter based on ^{3}He proportional tubes embedded in a polyethylene matrix acting as a neutron energy moderator is the best suited detector candidate, because it combines detection efficiencies of the order of 50%, a very clean signature of neutron events and insensitivity to other types of radiation. A detector of this kind, consisting of 20 tubes arranged in two rings around a central longitudinal hole of radius 5.5 cm, has been recently built by a Spanish collaboration for the measurement of β-delayed neutrons, and could be easily adapted to the measurements at CUNA. A full characterization of individual ^{3}He tubes embedded in polyethylene blocks is ongoing in order to fully understand the detector response. An experiment where the matrices were shot with neutron beams of fixed energies at the Physikalisch-Technische Bundesanstalt (PTB) near Brunswick, Germany, is currently under analysis. The results will complement the measurements of the LSC underground neutron background (work published in [1]), where the detectors were calibrated with a ^{252}Cf source, and eventually will help reduce the systematic uncertainty on the measured neutron flux in Hall A of LSC. In addition, the full detector BELEN-48 was calibrated in the same experiment using several reactions that produced a broad spectrum of neutron energies in the relevant range.

The neutron background that could mask the rare real signals from the reactions needs to be fully characterized. Following the work performed at the LSC in the last years, a comparative neutron background measurement has been performed in 2015 at the low background laboratory in Felsenkeller (Germany). The measurement will allow the comparison of the background in a shallow laboratory (Felsenkeller) and a deep underground laboratory (LSC) and thus a better understanding of the conditions for a successful (α,n) measurement. The experiment has been carried out in collaboration with the Nuclear Physics group at the Helmholtz-Zentrum Dresden-Rossendorf using eight polyethylene neutron moderated ^{3}He counters from the BELEN collaboration (Spain-Germany) and ^{3}He proportional tubes with reduced pressure to 10 atm. The six high-density polyethylene matrices already used at the LSC have been employed, with the addition of an extra new PE-Pb-PE matrix with enhanced efficiency at high energy (E_n > 10 MeV), plus a bare counter.

A second aspect to reduce the background that hinders real measurements is the one arising from the detectors themselves. In 2015 we have investigated the intrinsic background of the ^{3}He tubes, with the aim of understanding the unwanted signals that have been previously identified [2] in the spectra, in the region where there is an overlap with the neutron-induced signals (200-800 keV). The development of a dedicated neutron detector for measurements at the LSC is required, with a low sensitivity limit defined by the key (α,n) cross section measurements. A comparative measurement with two twin small ^{3}He tubes has been performed at LSC in 2015. One of the tubes is internally covered by a thin carbon layer, preventing alpha-radioactivity from the walls entering the gas volume, whereas the other one is a standard counter. The measurement will allow to assess the origin of the intrinsic background and to devise ways to reduce it.



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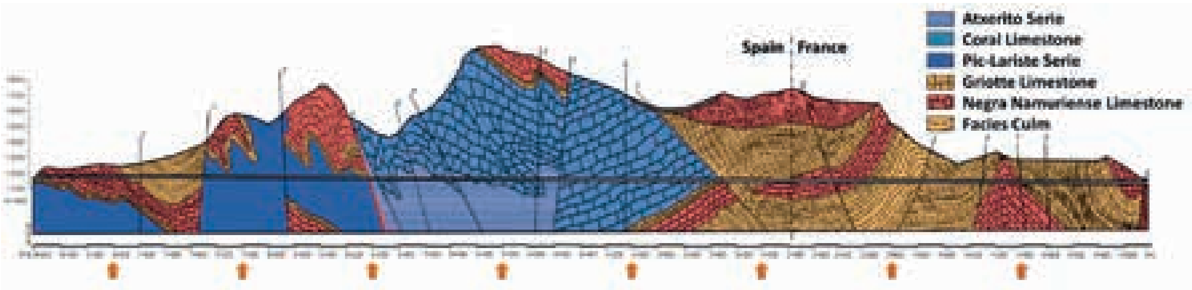
11 GOLLUM

LIFE IN EXTREME ENVIRONMENTS



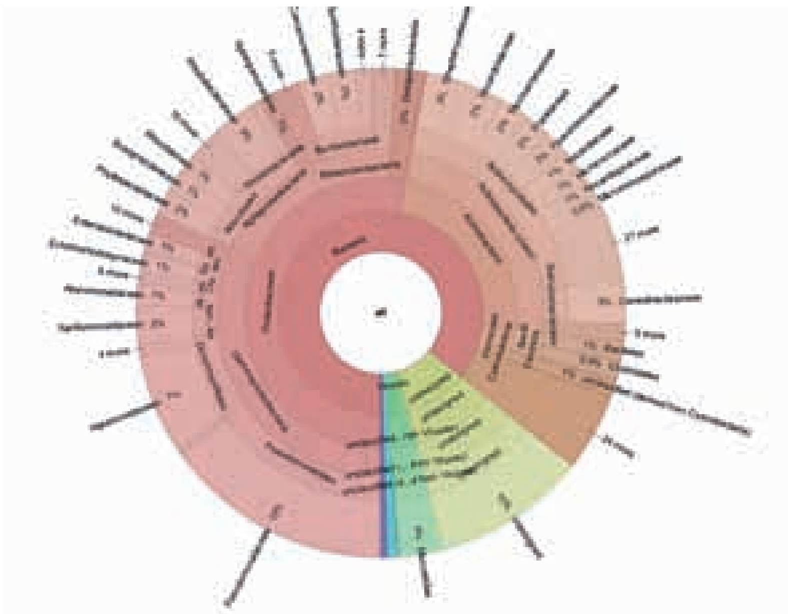
The Somport tunnel crosses different rocks from the late Paleozoic ages, and includes several Facies. Its length, depth and diverse ecology make it a perfect site for extremophile ecology studies. In extreme environments, bacteria –and archaea- tend to be the main living organisms. Subterranean microorganisms have been described to sum detail, but almost all reports refer to samples taken centimeters 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, though, 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.

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. We are improving our protocols for DNA extraction of the scarce genetic material sampled. Recent progress in high throughput next generation sequencing leads to discovery of numerous new species of bacteria and archaea, non-cultured by standard methods.

Modern computational methods support scalable metagenomic classification and show accurate classification in the presence of novel organisms on samples that include viruses, prokariotes, fungi and protists. The new code Livermore Metagenomics Analysis Toolkit (LMAT) is capable to taxonomically classify metagenomic shotgun data with high precision and low level of dismissed reads (smaller than 0.1%). This method has provided new insights in the metagenomic content of important historic samples. Krona visualization of the taxonomic composition of a control sample analyzed by our lab team can be seen in the figure. The interactive taxonomic classification can be found on http://som1.ific.uv.es/krona/kwashiorkor_ALL.html .

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 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.

GOLLUM collaboration has identified the best protocol for drilling and sampling with the cleanliness requirements for useful DNA extraction and genome characterization. This protocol has been verified with shallow rocks taken from the tunnel walls next to the underground laboratory. The microbiome composition is shown in the figure below, pointing to a very distinct composition compared to other soils, with abundance of Actinobacteria, Pseudomona and Halomona species.



The timeline for the experiment has been approved. About 20 cores (10 cm diameter, 1 meter long) will be collected in May 2016, packed in sterile aluminum cylinder boxes and transported and stored at low temperatures (-20 ºC). Sterile Water used for drilling will be doped with KBr for contamination verification. Core sampling will be done in Valencia University, small rocks will be pulverized in a sterile steel cylinder and pest with a high pressure press and DNA will be extracted with standard kits and sent to high throughput whole genome shotgun metagenomics sequencing to Sistemas Genomicos. Samples will be shared with GOLLUM associated research groups in Sevilla, Alicante and Bucharest for complementary studies (pH studies, single cell and viruses, diamond anvil cells). Sequencing and data analysis will be worked out in the second half of 2016 and first half of 2017.

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Background model of NaI(Tl) detectors for the ANAIS Dark Matter Project

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