LSC

Laboratorio Subterráneo de Canfranc

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EDITING

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COVER PHOTO:

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

LSC

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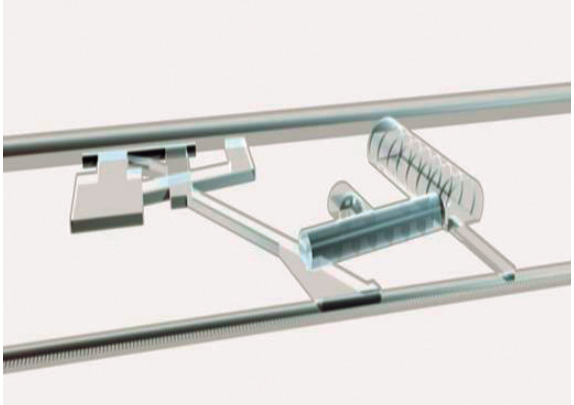


DIRECTOR'S STATEMENT

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 current collaboration and Funding Agreement end in 2015, but the procedures for their renewal are already foreseen.

The LSC offers underground facilities shielded from the natural cosmic rays radiation to fundamental physics and astrophysics and locations of unique characteristics for geology, biology and environment sciences to researchers from all over the world.

Six experimental infrastructures proposed by groups of users from international universities and laboratories are already working or under construction, while more underground space is still available for new proposals. One experiment, ROSEBUD, has been completed. The experiments in underground laboratories are multiannual efforts that evolve through different phases. The progress of the experiments at LSC will be described in the dedicated chapters. We briefly mention here that: a new NaI detector prototype aiming at lower K and 210Po lower than the precedent ones was ordered by the LSC to a specialised Company in November, to be given as a loan to the ANAIS experiment, ArDM transitioned to data taking, in the gas phase, in May and started, in November, the filling of the detector with liquid Ar, for NEXT, the seismically insulated central part of the platform, which will support the detector, its shield and the "castle" hosting the shield, were completed and the stainless steel vessel was delivered at LSC. GEODYN, BiPo and SUPERKGD regularly continued their data taking. A new proposal for deep underground biology, GOLLUM, was advanced in 2014 as is under examination In addition an extension project for a nuclear astrophysics facility, CUNA, is under study.

On the 7th of October 2014, the "Consejo de Política Científica, Tecnológica y de Innovación" approved the update of the "Mapa de Infraestructuras Científicas y Técnicas Singulares (ICTS)". The new Map is integrated by 29 ICTS which sum up a total of 59 infrastructures (56 fully operational and 3 under construction). This action is contemplated in the "Estrategia Española de Ciencia y Tecnología y de Innovación" as a planning and development tool of these infrastructures in coordination with the Comunidades Autónomas. For the update of this Map, the maximum quality scientific, technological and innovation criteria has been taken into account, submitting the candidate infrastructures to an independent rigorous evaluation process procedure. Also, these infrastructures must have their economic sustainability guaranteed. The LSC, having obtained an excellent evaluation, remains in the ICTS Map as an infrastructure of unique location, within the Astronomy and Astrophysics area.

Laboratories, offices and meeting rooms are available on the surface. In addition, the LSC provides the following services to non-scientific users:

- Materials Radiopurity measurements with very low background HPGe detectors (RMS)
- Radiopure copper parts manufacturing service using electroforming techniques (CES).
- Underground clean room class 1.000 (ISO 6) and class 10.000 (ISO 7) (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. We do not fix any deadline for that. Just address to the web site or call. The International Scientific Committee of LSC will analyse the scientific proposals, giving its advice to the management based only on the scientific excellence, while the Access Committee will process the requests for services.

This Report describes to non-specialists the LSC infrastructures, science and the experimental activity of the external users. 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.

Prof. Alessandro Bettini

Canfranc Estación, March 2015

1 INTRODUCTION

Physicists have developed a theoretical description of the elementary building blocks of matter and of the basic forces of Nature, called the standard model. 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, when the new LHC collider had reached the energy necessary to produce it. In 2015 LHC will restart with almost doubled energy. But we already know that it will not be sufficient. Underground laboratories, like LSC, provide scientific information that is complementary to that obtained in laboratories with accelerators, like CERN. Indeed, the first elements of physics beyond the standard model came from underground experiments.

The Universe originated about 14 000 million years ago in an enormous explosion, the Big Bang. The corresponding energy, the Planck energy scale, is fifteen orders of magnitude, meaning a one followed by fifteen zeros, larger than the LHC energy. In addition, we know that the different forces of Nature seem to become equal, to become unified as we say, at energies that only about one hundred time smaller than the Planck scale. We will never be able to reach it with an accelerator. We need another way. Phenomena characterised by a high-energy scale do, in fact, happen naturally even at the lower energies of every day. But the higher is their intrinsic energy scale the more rarely they happen.

Underground laboratories, in particular the LSC, are dedicated to the search for these natural, but extremely rare, nuclear and subnuclear phenomena. This search requires very low radioactive background environment. Taking an analogy, we all have observed with astonishment and admiration the innumerable population of stars in the dark heavens of the night. But we don't see stars during the day, even if they are still shining. Starlight is much fainter than that sunlight. To be able to see the weak luminous signal from a star we need darkness, the absence of the strong "background" of the sunlight. Similarly we cannot hear the chirp of a cricket in the noise of a freeway, but we need silence. We cannot detect the signals of very rare nuclear decays in presence of the much higher natural radioactivity background. This background noise is due to cosmic rays, falling on the surface of the earth and to decays of radioactive nuclei present, in traces, in all materials. Deep underground, under the Tobazo Mountain, the cosmic ray flux is reduced by a factor of one hundred thousand.

Other scientific sectors can profit of the unique location of the underground infrastructures. Geodynamics has the possibility to measure extremely small changes in the stress of the rock deep inside the mountain, as those due to the passage of the Moon, and very small accelerations and velocities in the depth, as those due to very small seismic events.

Underground, the experiments are protected by the "noise" due to human activity and atmospheric phenomena present on the surface.

Biologists can look for very peculiar type of microorganisms living in the dark inside the rocks.

2 A BIT OF HISTORY

Canfranc is a village in the central Pyrenees, at 1195 m of altitude in the high Aragón valley at a few kilometres from France, connected to it through the Somport pass. The latter, "el Puerto de Somport", and Canfranc itself are part of the (Aragon's) Camino de Santiago.

In consideration of its position, which is strategic for the connection between Spain and France, important civil works were performed in the first decennia of 1900 for the construction of a railway between the two Countries. At Canfranc Estación large civil and deforestation works were done to host a huge International Station (Fig. 2.1); a tunnel was excavated to reach the French side. It is 7875 m long, 4.75 m wide and 6 m high. The king of Spain, Alfonso XIII, inaugurated the railway in July 1928, between the two World wars. The train operation ended in March 1970, when an accident destroyed a bridge in the French sector, which was never repaired.

In 1985 A. Morales and the Nuclear and High-Energy Physics Department of the Zaragoza University, started a project for the exploitation of underground space in the dismissed train tunnel for possible low background experiments, protected from the cosmic radiation. Their first infrastructure is shown in Fig. 2.2. It consisted in a car, to which the reels had been changed to make it apt to move on rails, and a trailer containing the radiation detectors and the instrumentation to characterise the tunnel along its length.

The first laboratory was lodged in a pair of existing small service cavities on the two sides of the train tunnel at 780 m from the Spanish entrance. Both have been now refurbished and integrated in the new LSC and called Lab

Fig. 2.1. The Canfranc station

780 L and Lab 780 R. Each consists of a small hall (12 m^2) leading, through opposite stairs, to two tunnels, parallel to the main one, of a total length of about 70 m.

At the beginning of the 1990s the Spanish and French governments decided to excavate a road tunnel close and parallel to the dismissed train tunnel. The latter became a safety escape route, having the two tunnels been connected by a series of by-pass.

In 1994, taking advantage of these works, a new experimental hall, 118 m^2, at 2520 m from the Spanish entrance was excavated. The hall hosted in the following years a number of experiments, on dark matter and neutrino physics. Along the years more than fifty scientists from twelve institutions from eight countries have participated in the LSC Scientific Programme. Also this hall has been integrated in the new LSC, after refurbishment works. It is called Lab 2500.

The action of A. Morales continued further. Strong of the success of two decades of research and of his determination, he convinced the Spanish authorities of building between the two tunnels a new, still larger laboratory, with fully international standards and all the necessary underground services. The depth is 850 m under Mount Tobazo. The facility, now called Lab. 2400, was completed in 2006. However, one year later signs of rock instabilities started to appear and the laboratory was closed. The Zaragoza University performed a complete revision of the original project and the rock support structures necessary to completely guarantee the safety of the personnel and of the properties were installed.

The works were completed by Summer 2010. In parallel a service building was designed and built, being completed by January 2011.

Fig. 2.2. The first Zaragoza Laboratory at Canfranc

Figs. 2.3. Excavation works

3 LSC CURRENT STATUS

A Consortium between the Spanish Ministerio de Economía y Competitividad, the Government of Aragón and the University of Zaragoza manage the LSC.

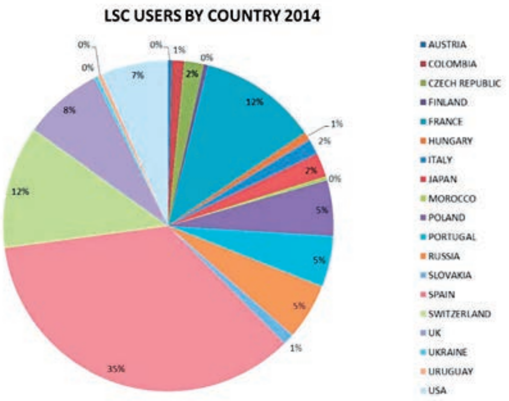
The staff is small, 9 people, to cover the essential services: administration and secretariat, safety, prevention and installations, low background service, chemistry and clean room service, mechanics, electricity, informatics and support to physics.

The protocol of access with the Tunnel de Somport (Ministerio de Fomento) foresees the access to the LSC via the road tunnel, to which a bypass connects with dedicated entrance leading to gallery 12, and the exit through the safety tunnel. Both actions are communicated via radio to the tunnel control.

The "experiments" in an underground laboratory are complex and sizeable structures, which are designed and built by "Collaborations" of scientists, all external in the case of LSC, belonging to Universities and scientific laboratories. Typically, several years of R&D are necessary, followed by a few years for construction and finally many years to collect the data.

A fully international Scientific Committee of nine renowned scientists, which meets twice a year, helps the management in the processing of the proposals and in the monitoring the development of the experiments. The following experiments have been approved to date: ANAIS and ArDM on dark matter, NEXT on neutrino physics and GEODYN on geodynamics. Two other projects are ancillary to experiments in other laboratories: BiPo for the SuperNEMO proposal at the LSM laboratory near Modane in France and SUPERKGd for the SuperKamiokande experiment in Japan. In addition, the CUNA proposal for an underground nuclear astrophysics facility is under discussion. The GOLLUM proposal is dedicated to extremophile ecology studies.

The total number of users in 2014 was 258 from 19 different countries.



A total of 258 users from 19 different countries

Fig. 3.1. LSC users by Country in 2014

LSC is presently run purely as a service to external users. As such up to now, and differently from similar scientific institutions, it does not have an internal scientific staff neither a programme of doctorate or post-doctorate fellowships. However, several PhD students belonging to the users groups work at their experiments not only in their sites but also at LSC.

The main underground general services (Radiopurity Service and Clean Room Service) and their development in 2014 will be described in the next chapter. Other important investments in the year have been devoted to:

- The order of a new NaI detector prototype with enhanced radio-purity characteristics to the Alpha Spectra Company in November by LSC, which will be given as a loan to the ANAIS experiment. This order came after in depth discussions with the Company, building on the work of the ANAIS Collaboration on two prototypes produced by the Alpha Spectra in 2012, which had not reached the highly demanding purity levels necessary for the experiment.
- The construction of the seismic platform and the "castle" for the Pb shielding it supports for NEXT, the procurement of the Pb, as a loan by the Italian INFN, and the production of the Pb "bricks" for the shielding
- The installation of the infrastructures stemming from the risk analysis of the ArDM experiment (limitation of the flash evaporation of liquid Ar, Ar gas extraction system, temperature and oxygen monitoring system, etc.)
- The completion of the design and installation of the slow control system for monitoring the parameters relevant to maintain the integrity of the infrastructures
- The acquisition of a portable sodium iodine gamma detector
- The renewal of the pumping system of the GEODYN interferometers

Underground experiments often require in different phases of their evolution to be developed in a "Radon free" atmosphere. To cope with this request, LSC developed a project for a "Radon reduction system" that was submitted, and the funding of which was approved in the frame of a FEDER funding.

The LSC is one of the four deep underground laboratories in the European Union, together with the Laboratorio Nazionale del Gran Sasso in Italy, the Laboratoire Subterraine de Modane in France and the Boulby Underground Laboratory in the UK. Co-ordination activities have been continued in 2014, with the aim to optimise the use of the resources existing in the four labs. In the frame of Horizon 2020, the "DULIA" project for the integration of the laboratories, under the INFRAIA action, and the "Multi-Deep Multidisciplinary and Innovative Training in Deep Underground Labs", under the Marie Skłodowska Curie Actions, were developed and submitted In addition, LSC represents Spain in the APPEC (AstroParticle European Consortium), the European Consortium coordinating the research in astroparticle physics and has the specific responsibility of its web-site.

Since Summer 2014 the GEODY seiemic station is fully integrated in the EIDA module hosted in the data centre ORFEUS (Observatories and Research Facilities for European Seismology) providing open access of siesmic data in quasi-real time to the seiemic community. (http://www.orfeus-eu.org/eida)

The historical building named "Casa forestal de los abetos", property of the Aragon Government, is situated close to the external building of the LSC. In April 2014 the house was made available by the Aragon Government to the LSC for its complementary activities, including scientific meetings and conferences,

"Fig.3.2 Artist view of the restored casa de los abetos" outreach activities and the like. To this aim, taking into account also the bad status of conservation of the building, a rehabilitation project was developed. The rehabilitation works are foreseen for 2015. Fig. 3.2 is an artist view of the restored casa de los abetos.

Workshops and Conferences are organised at LSC. In 2014 LSC organised or hosted:

- 1st Meeting on Axion Dark Matter including the projection of the documentary: "Neutrino, measuring the unexpected" featuring the LSC director.
- RENATA annual meeting: "Astroparticle Physics in Spain in view of Horizon 2020".
- VII Course on infections and support treatment for oncohematologist patients.

Fig. 3.3. Posters of Events at LSC in 2014

The LSC is running a programme of visits, with 1090 visitors in 2014.

Fig. 3.4. Visitas al LSC

Overall, nearly 4000 people have visited the laboratory since visits started in 2010.

Fig. 3.5. Numbers of visits at LSC in different years

4 INFRASTRUCTURES

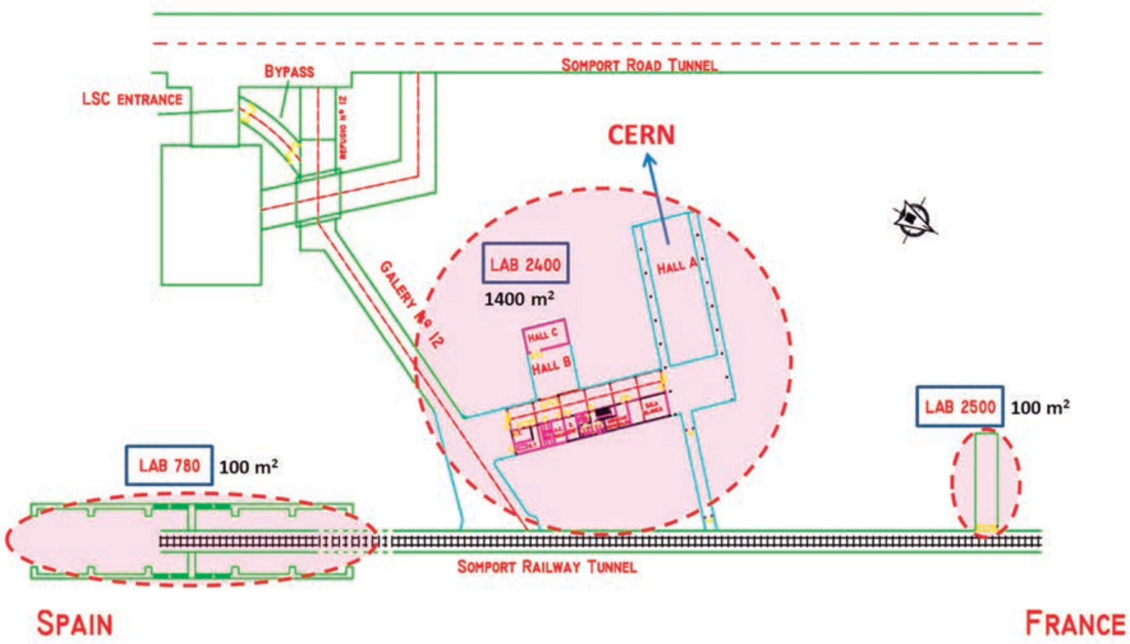


Fig. 4.1 . Map of the underground infrastructures at Lab 2400

Fig. 4.1 shows a map of the underground infrastructures Lab 2400. Hall A, measuring 40×15×12(h) m^3, is shown in Fig. 4.2. The structure of ArDM can be seen on the right and the platform were NEXT will be installed at the end of the hall on the left.

Hall B of 15×10×8(h) m^3 hosts ANAIS, in a separate hut as shown in Fig. 4.3. The second hut, complete of an internal Faraday cage, hosted the ROSEBUD experiment, which is now finished.

Fig. 4.3 . ANAIS and former ROSEBUD huts at Hall B

Fig. 4.2. Panoramic view of Hall A

Fig. 4.4. Hall C with the Ge counters

Fig. 4.5 Left: One counter while being mounted inside the copper and lead shields. Right: Opening of the shield by lifting the door

The further from the entrance part of Hall B, Hall C, is separated by a wall. It hosts seven hyper pure germanium counters with their lead and copper shields from the ambient radioactivity, shown in Fig. 4.4. During 2014 three of the detectors were upgraded to a new shield structure. This new shield has an extra of 5 cm of Cu to a total of 10 cm and 20 cm of Pb. This extra shielding helped in reducing the background of the detectors at low energies. Also a door that can be lifted with the help of an electric crane (see Fig. 4.5 Right) was designed and installed. This opening system reduces considerably the time necessary for sample change minimizing the exposure of the detection region to the Rn in the air outside the methacrylate anti-radon box. The radiopurity service is open also to external users (RMS service).

The Clean Room Service has a clean environment of around 45 m^2 of class ISO 7 and ISO 6, in a sector, and it is offered to both the LSC experiments and external users (CES service).

An aisle was built perpendicular to the halls. It is divided horizontally in two parts: the left one connects the entrance to the halls; the right one has two floors, hosting the services (high and low tension, water treatment, technical gases storage and distribution, toilets, a small mechanical workshop, etc. and offices for the researchers).

Fig. 4.8 shows the Lab 2500, which lodges three more hyper pure germanium counters and R&D activities of the Zaragoza Nuclear Physics Group. More space is available for future experiments of external users.

The complex of underground structures, Lab 2400, 2500, 780 L and 780 R and the corresponding accesses correspond to a total area of about 1600 m^2 and a total volume of 10 000 m^3.

The surface building of approximately 1800 m^2 is shown in Fig. 4.9

Fig. 4.6. The underground clean room

Fig. 4.7. The service aisle

Fig. 4.8. Lab 2500

Fig. 4.9. The service building on the surface

It hosts headquarters, administration, a library, offices (Fig. 4.10), a meeting room (Fig. 4.11), laboratories, storage areas and a mechanical workshop, safety structures and management.


Fig. 4.10. Inside the building

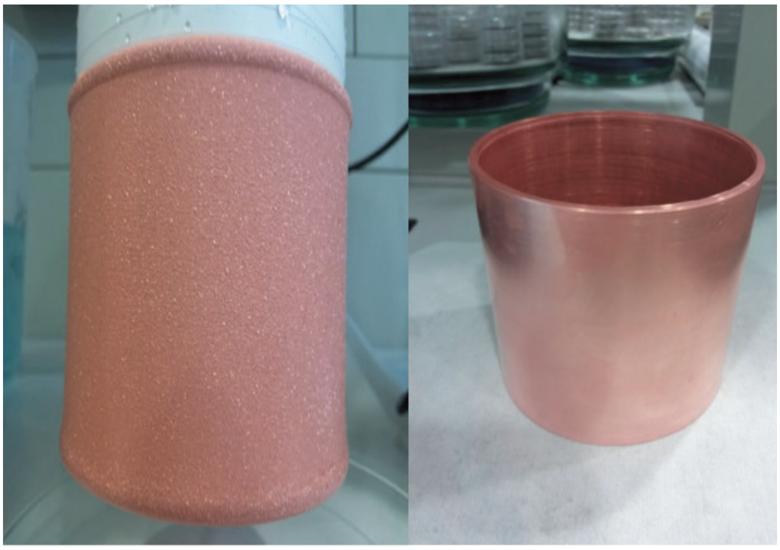

Fig. 4.11. Conference hall

The laboratories are specialised for electronics, informatics, physics and chemistry. The physics laboratory has been recently equipped with a counter of alpha and beta activity of small samples.

The installation and start-up of the Copper Electroforming Service started towards the end of 2014 at the chemistry laboratory located in the LSC surface service building.

The electroforming technique allows to obtain, through an electrolytic process, copper pieces of unmalleable geometrics, with excellent homogeneity and surface quality, and high purity levels of great use in this type of scientific applications at the LSC being shielded of the gamma radioactive background.

Surface and underground laboratories are linked with optical fibres lines. The high-speed connection to the Internet is provided by the Aragón Government, by means of radio bridges to the "Red de Investigación de Aragón"(RIA).


Copper piece during the electro forming service and Final copper piece after process


Electroforming facility

5 CHARACTERISTICS

There are a number of characteristics of an underground laboratory that must be known and taken under control to allow proper design, planning and operation of the experiments.

In order to further increase safety, a dedicated structure of optical fibres to monitor continuously the rocks stability has been designed and is continuously working. It is made of 18 optical fibres, 5 m long with associated humidity and temperature sensors, measuring the distance between their extremes with a sensitivity of a few micrometres. In addition convergence tape measurements are periodically taken in the most critical locations.

In 2014 a complete monitoring system has been installed. It monitors both the environmental parameters of the laboratory (temperature, humidity, air quality, radon activity in the air, etc.) and the operational parameters of the devices. The system is also used for increasing the security and maintaining the integrity of the laboratory through alarm warnings or malfunction warnings by sending text messages to the mobile phones on guard and emails to the technical support account.

The Laboratorio de Bajas Actividades (LABAC) of the Zaragoza University, in collaboration with the LSC services, performs systematic radiological analysis of different samples of water collected in various positions of the underground and surface laboratories. The analyses are done via gamma spectroscopy and analysis of the total alpha and beta indices. Biological and chemical analyses are also performed.

Radioactivity is a natural phenomenon that has sources everywhere.

Cosmic rays are charged particles, mainly protons but also nuclei and electrons, coming from the universe and penetrating the atmosphere. In the atmosphere, hitting a nucleus, they may produce a cascade of unstable secondary particles. Deep underground only the most penetrating components survive. These are the almost invisible neutrinos and the muons. The latter are charged particles similar to electrons with a larger mass. The muon flux decreases, but does not disappear, with the rock overburden. At LSC it is one hundred thousand smaller than on the surface. Muons have high energies, much higher than those of the nuclear decays.

Small quantities, traces, of radioactive isotopes are everywhere, in the rocks, in the water, in the air, and in our own bodies. Radioactive nuclei may decay in three main ways called α, β and γ decays, corresponding to the emission alpha particles (that are helium nuclei), electrons or photons respectively. Alpha particles emitted in the rocks and in the concrete are often captured by another nucleus, which is unstable and will decay emitting a neutron. In each case

Fig. 5.1. Image of the alarm monitoring system

the energies are up to a few MeV (millions of electronvolt).

Radon is a radioactive noble gas coming from uranium and thorium in the environment, in particular the walls and the water. Several isotopes of the Rn decay chain are dangerous to the experiments. Some of them, which may be α, β or γ emitters, stick on the surfaces and may contribute substantially to the background. The Rn activity in the air, both on the surface and underground, has large fluctuation both periodic (daily, seasonal, yearly) and non-periodic. Underground it depends also on the characteristics of the input duct and on the rate of air substitution. LSC input air system is ancillary to that of the freeway, exploiting the space between the pipes that bring air to that and the concrete lining of the corresponding civil structures. A 250 m long vertical pit takes the fresh air at Rioseta on the mountain. Rn activity was measured at a reference time as 15 Bq/m^3 at Rioseta and 38 Bq/m^3 at the bottom of the pit. To reach the LSC, the air further runs in a horizontal, 500 m long corridor. At the same time Rn activity was 70 Bq/m^3 at the LSC entrance. Systematic measurements showed that in the experimental halls Rn activity is equal to that at the entrance, indicating that there is no appreciable further contribution from Rn emanation from the surfaces, with a fresh air input of 11.000 m^3/h. The specific activity varies between 50 and 80 Bq/m^3.

While this level of Rn activity is not dangerous for human health, it can contribute substantially to the background budget of some experiments or measurements, as those performed by the radiopurity service (RMS) with hyper pure Ge counters and by BiPo on contaminations of surfaces. In these

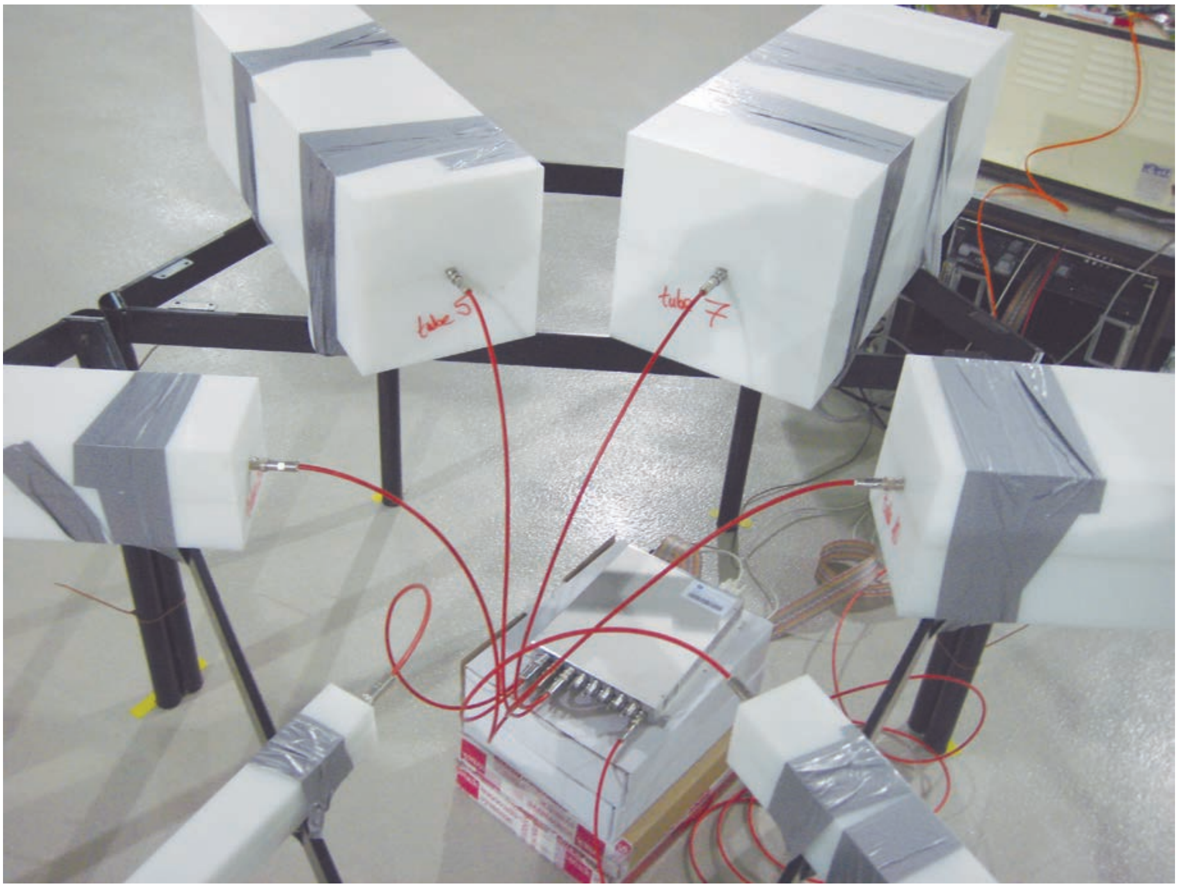


Fig. 5.2. Six ^{3}He proportional counters in Hall A

cases, the apparatuses are enclosed in a tight container in which pure N2 gas or Rn-clean air, are fluxed. The two methods are somewhat complementary, as, for example, the first one cannot be used if people have to work in the Rn free space.

Radon reduction in air can be obtained using industrially available apparatuses that compress, store and push the air through filters that selectively absorb the radon. The result is a reduction of the Rn activity by up to three orders of magnitudes. The proposal for a FEDER co-funding at 50% (the level foreseen for Aragon) for such an apparatus and for the necessary modifications of the infrastructures of the laboratory (mainly the cooling system) has been approved on 10.12.2014 by the Secretaría de Estado de Investigación, Desarrollo e Innovación, within the Programa Estatal de Fomento de la Investigación Científica y Técnica de Excelencia in the frame of the Plan Estatal de Investigación Científica y Técnica y de Innovación 2013-2016. The open tender for the Rn reduction system has been launched and its installation is foreseen by the end of 2015.

The neutron background level underground is also smaller than on the surface, where is typically about 100 n/(m^{2}s) at sea level. The CUNA Collaboration has measured the neutron flux and energy spectrum in the range between 1 eV and 10 MeV. They used a set of six ^{3}He proportional counters (Fig. 5.1), of the set-up that will be mentioned in the CUNA chapter, inside polyethylene matrices of different thickness. In such a way the neutron background rate was measured simultaneously at different energy ranges. The total flux in the centre of hall A resulted to be

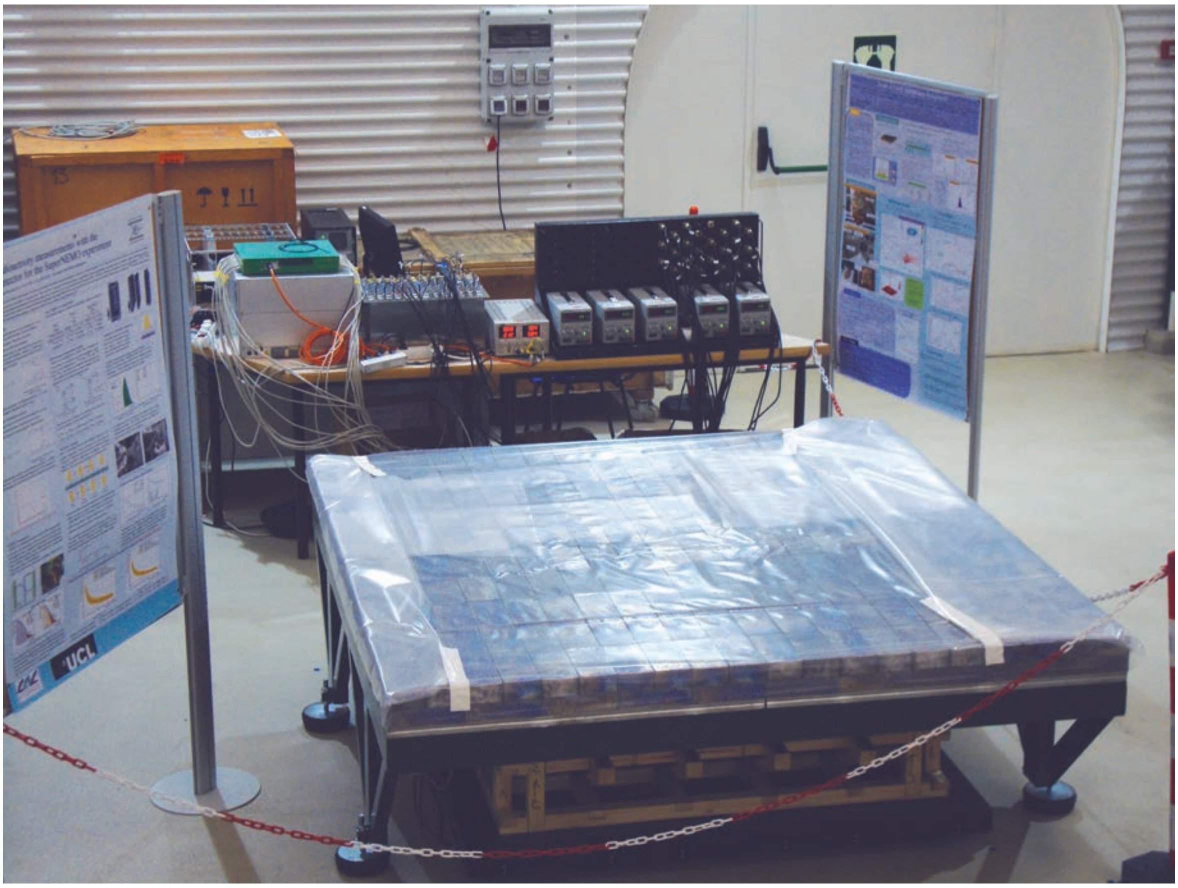


Fig. 5.3. Muon monitor

$3.44 \pm 0.35 \times 10^{-2}$ n/(m^2s), about thirty times less than on the surface.

These neutrons coming from the concrete of the wall wander in the halls making up a sort of very diluted gas. To have an idea, we have of the order of hundred neutrons in the total volume of Hall A. They are very few indeed, but enough to be dangerous for the experiments. Shields of neutron absorbing materials are built around the experiments for protection.

The gamma ray spectrum has been measured by the LSC low radioactivity service. Its total flux is 120 gammas/(m^2s). This is small, but, once more, experiments must build shields to protect themselves.

The total muon flux integrated over the angles was measured to be $4 \cdot 10^{-3}$ m^{-2} s^{-1} in Hall B and $5 \cdot 10^{-3}$ m^{-2} s^{-1} in Hall A, both with 10% uncertainty in 2006, by the University of Zaragoza. The difference is due to the shape of the mountain over the laboratory. New measurement of the muon flux as a function of the angles is undergoing with a segmented telescope designed and built by the Moscow Institute of Physics and Technology.

Knowing the background fields, the experiments can design their shielding to reduce the backgrounds effects to acceptable values. However, the materials of the shields and of the experiments themselves contain radioactive traces. In practice every single component must be screened to determine any small trace of radioactive isotopes. The already mentioned low radioactivity service of LSC helps the experiments in this fundamental activity.

We can have an idea of the issue considering the following example. Our body is radioactive, but we live happily with it. Potassium (K) amounts to about 2 per mille of our body, hence a person of 70 kg contains 140 g of potassium. About one on 10 000 of the K nuclei are the ^{40}K isotope, which is radioactive. These 17 mg produce 44 Bq, meaning 44 decays per second. Of these 89% are β and 11% are γ. The body absorbs the former, while the majority of the latter radiate out. We emit about 5 gammas per second.

As a comparison, consider the ANAIS experiment, which is made of sodium iodine (NaI) crystals. If a dark matter particle would hit a nucleus this would recoil, ionising a few atoms and producing a small flash of light, which we can detect. However, potassium is chemically similar to sodium, which remains in traces in the crystal after chemical treatment. A fraction of the ^{40}K decays gives a flash of light equal to the searched one, a background signal we say. Consequently, the potassium traces in the crystal must be reduced at an acceptable level. This is one hundred thousand times smaller than the 2 per mille of the human body.

6 THE SCIENCE

The scientific programme of the LSC is mainly on astroparticle physics, dark matter searches and neutrino physics and on geodynamics.

NEUTRINOS

The known elementary constituents of matter can be grouped in three groups, called "families". Each family is composed of two quarks, a charged lepton and a neutrino. The charged leptons of the three families are the electron (e), the muon (μ) and the tau (τ); the corresponding neutrinos are the electron-neutrino (ν_e), the muon-neutrino (ν_μ) and the tau-neutrino (ν_τ). We say that the pair of leptons of each family has electron-flavour, muon-flavour and tau-flavour respectively. Each particle, quarks, charged leptons and neutrinos have an antiparticle. The standard model assumes that neutrinos born with a flavour keep that forever. The conclusion was based on experiments done at accelerators with neutrino beams having lengths of the order of one kilometre.

Experiments in underground laboratories have studied neutrinos over much larger distances. Their sources are natural, rather than artificial: the interactions of cosmic rays in the atmosphere and the nuclear fusion reactions in the centre of our Sun. These experiments have shown that neutrinos change flavour if enough time is given them to do so. This phenomenon is called oscillation from one flavour to another and can happen only if the neutrinos have non zero masses. The oscillation times are so long because neutrino masses are small, much smaller than those of the other elementary particles. But neutrinos can give us other surprises.

As the electron has an antiparticle, the positron, so the antiparticle of the electron neutrino is the electron-antineutrino (and similarly the others). The charge of an antiparticle is opposite to that of its particle, i.e. electrons are negative and positrons positive. Even if they have no electric charge, in the standard theory, neutrinos and antineutrinos are assumed to be different particles, distinguished by the so-called lepton charge. But there is another possibility, outside the standard theory, i.e. that neutrino and antineutrino are one and the same particle, as originally imagined by Majorana in 1937.

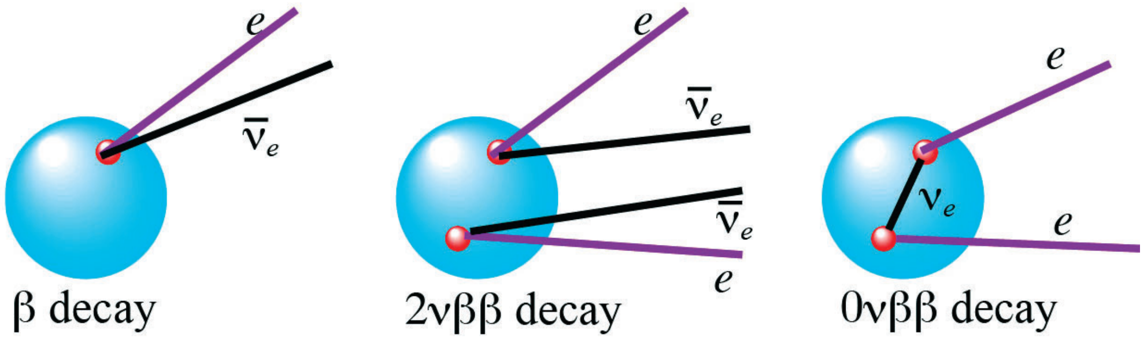


Fig. 6.1. a) Beta decay, b) 2νββ), c) 0νββ

How can we distinguish between the two possibilities? Several nuclei are unstable and experience beta decay. A neutron decays into a proton, emitting an $e^{-}\overline{\nu}_e$ (electron electron-antineutrino) pair. For some nuclei the beta decay is forbidden for energetic reasons but another decay path, the double beta decay (2νββ), is allowed. Two neutrons decay at the same into two protons emitting two $e^{-}\overline{\nu}_e$ pairs. The double beta decays have very long lifetimes, 10^{19}-10^{21} years, but are still a process foreseen by the standard theory. If the neutrino and antineutrino are the same particle another process is possible, the neutrinoless double beta decay (0νββ). Also in this case, two neutrons decay into two protons but only the two electrons are emitted. There is only one neutrino, which remains inside the nucleus, being exchanged between the two decaying neutrons. This is possible because in this case neutrino and antineutrino are the same. No experiment has reliably detected neutrinoless double beta decay, but limits have been given, which are in the range of 10^{25} years, namely 10^{15} times the age of the Universe.

How can we explore so long times? We can do that because the decays are statistical processes: if the half life is say 10^{25} yr one in 10^{25} nucleus would decay in a time of the order of one year. The experiments of the present generation aim to explore up to 10^{26} years. This means looking for a few events per year in a kilo-mole of substance, which is 6×10^{26} nuclei. Notice that we know exactly the energy released to the two electrons in the decay. We then measure the sum of the two electrons energies as accurately as possible. However, backgrounds are always present and can also simulate the signal. Extremely good energy resolution and extremely low background index are the necessary features for the search.

At LSC the NEXT experiment, presently under construction, will search for 0νββ of ^{136}Xe.

DARK MATTER

Enormous progresses have been done in elementary particle physics, in cosmology and in astrophysics, but we still do not know of what, for the largest fraction, the Universe is made of. About 68% of the mass-energy budget is made of something that accelerates the expansion rate. It acts as a pressure or energy pervading the vacuum. We call it dark energy, but we do not know what it is.

The remaining 32% is matter, but only 5% of that is luminous, the other 27% is invisible and called dark. This conclusion comes from many different observations at different epochs of the history of the Universe. One of them is the measurement of the rotation speeds of Galaxies. Newton's law tells us how the rotation speed of an object is related to the mass around which it is orbiting. So we can calculate the mass of a galaxy from the rotation speed of a gas cloud orbiting around it. We find that the masses of the galaxies are

Fig. 6.2. Collision of two clusters of galaxies, showing the presence of dark matter. Credits of NASA

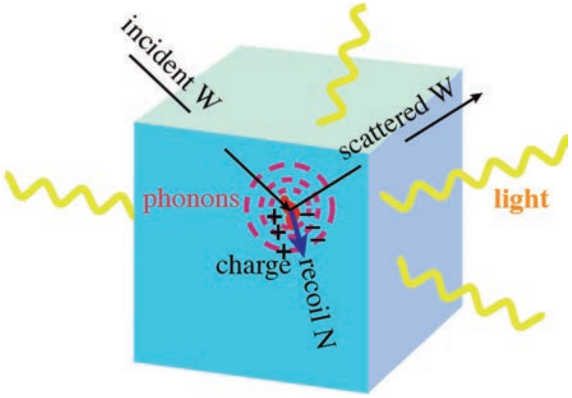


Fig. 6.3. Principles of WIMP detection

much larger than their luminous mass. Fig. 6.2 gives another example. It is a composite image of two clusters of galaxies that have just (on cosmic scale) crossed each other (bullet cluster). NASA made it (http://apod.nasa.gov/apod/ap060824.html) combining optical and X-ray observations, which give the "visible" matter and "gravitational lensing" observations that give the total matter. One sees that visible matter (red) slowed down interacting while crossing, while dark matter (blue) did not.

None of the known particles can explain dark matter. Dark matter particles have no charge and only weak interactions. In this they are similar to neutrinos. Neutrinos are indeed present in the Universe, but their mass is too small to contribute substantially to the budget. Dark matter particles must have bigger masses, but we do not know how big. We expect values between several GeV (the proton mass is about 1 GeV) and a few thousands GeV. They are generically called WIMPs, for "Weakly Interacting Massive Particles". A theoretical extension of the standard model, the supersymmetry, or SUSY for brief, does indeed foresee a good candidate of WIMP, the neutralino. The theory gives also indications on the neutralino interaction cross section (meaning probability to interact) with nuclei. It should be very small, like for neutrinos, but how small we do not really know.

If WIMPs exist they should fill our Galaxy, and the Earth should sail through them while moving in its orbit. To detect them we use materials such as a crystal (as ANAIS) or a liquid (as ArDM). When, very rarely, a WIMP hits a nucleus, this recoils and we try to detect the energy it releases to the medium. The recoiling nucleus will ionise some atoms, producing free charges (electrons), excite other atoms, which will emit light (photons), or produce vibrations of the crystal (phonons). In our experiments we try to detect those secondary particles. However, any small trace of natural radioactivity may produce similar effects and sophisticated techniques must be developed to distinguish this background from the signal.

There are two basic strategies. The most commonly followed is to build the experiment in such a way that the background is reduced to zero in the experimental window. This is achieved by measuring the radioactive traces in all the components of the experiment, before assembling them, and developing a "background model" by numerical simulation. A period of data taking follows providing a certain "exposure", which is the product of the sensitive mass by the exposure time. Our background model foresees zero background events. If we see no events, we conclude that there is no signal and we can put limits on the cross section as a function of the WIMP mass.

The second approach searches for a characteristic signature of the WIMP signal. Our detector moves in the Galaxy with the Earth, in the WIMPs "sea". The Earth velocity in the Galaxy varies during the year. In June the Earth moves in its orbit is in the same direction of the velocity of the Sun in the Galaxy. Consequently the Earth velocity relative to the Galaxy is maximum. It is minimum in December when the two velocities are opposite. As a consequence, the WIMP interaction rate should vary periodically over the year with maximum in June. The modulation is only several per cent, but should be observable. This signature looks to be a powerful means to distinguish the signal from the backgrounds. Unfortunately, however, several ambient parameters, like Rn activity and humidity, have also annual periodicity..

GEOLOGY

The LSC is located at depth in one of the most seismically active areas in Western Europe, at the Pyrenean chain that marks the boundary between the European plate and the Iberian microplate. Besides, the underground tunnel environment ensures a very low level of noise perturbations, either of natural or cultural origin. In addition, the dismissed train tunnel and several service tunnels give opportunities to have access to underground rocks.

HYDROLOGY

Rain water and water from snow melting gradually penetrate deep inside the mountains and sooner or later exit to the rivers. Looking to these phenomena from deep underground offers a unique opportunity to hydrologists.

BIOLOGY

Life is present practically everywhere on Earth, including environments in which it develops under extreme conditions, in particular deep underground. One can try to answer questions like:

- How deeply in the earth does life extend?

- What makes life successful deep under the surface?

- What can life underground teach us about how life evolved?

The LSC and the nearby service tunnels, some of which have been dismissed from human activity, can offer access to search for "dark life" in the bulk of the rocks.

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 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 the Somport tunnel this can be done at much larger depths.

7 ANAIS

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 scintillating crystals, in extremely low background and low energy threshold conditions. ANAIS aims at using an array of such detectors at LSC.

Along 2012 a prototype crystal, called ANAIS-0 (9.7 kg), grown by the company Saint Gobain and encapsulated at the University of Zaragoza, was in operation at the LSC. The main goal was the setting up and tuning of the shielding, electronic chain and acquisition and analysis software for ANAIS.

Along 2013 two crystals, 12.5 kg each, grown and encapsulated by the company Alpha Spectra Inc. were in operation at LSC, after being coupled to two Hamamatsu PMTs at LSC clean room by ANAIS staff. We shall refer to this set-up as ANAIS-25. These crystals were grown using NaI powder with the lowest potassium content from all the powders screened at the LSC radiopurity service. In the first months of 2013, ANAIS-25 potassium content was determined precisely by the measurement in coincidence between

Fig. 7.1. Coupling Hamamatsu PMTs to ANAIS-25 module at LSC clean room, June 2014

the gamma line at 1461 keV in one detector and 3.2 keV energy release in the other, resulting in a specific activity of 1.25 ± 0.11 mBq/kg corresponding to 41.7 ± 3.7 ppb potassium. This result meant an improvement of an order of magnitude with respect to ANAIS-0 and it is close to, but not yet at the ANAIS need of 20 ppb.

Alpha emitters radioactive traces contribute also to the background. The total alpha rate in both crystals was determined to be of about 280 /(kg day) (3.2 mBq/kg), which is much higher than what is needed. This is because it is related to backgrounds at low energies, in the region of interest in particular that coming from ^{210}Pb, progenitor of the alpha decaying isotope. The effect is presumably due to contaminations of ^{222}Rn during growing or machining of the detectors Alpha Spectra Company modified its processes accordingly, trying to minimize possible radon intrusion. A new module 12.5 kg mass was ordered to AS, similar in shape and performance to the previous ones, but built using the improved protocols of the company for the potassium purification (trying to reach the 20 ppb goal) and for the growing and encapsulation (trying to minimize the ^{210}Pb contamination).

The crystal reached LSC on 5 March 2015, and put into operation in the shortest time in the already existing ANAIS-25 shielding and using its acquisition system already working. The main goal of this set-up is the evaluation of the radiopurity of the new crystals both in alpha emitters and ^{40}K, in order to estimate the background level in the region of interest.

In 2014, main ANAIS-25 goals have been the global assessment and understanding of the radioactive backgrounds of the detectors and the energy threshold reduction down to 1 keV. In parallel, 42 Hamamatsu PMTs characterization in terms of relative quantum efficiency, dark current and radiopurity, started in Zaragoza laboratories and at LSC. This process is expected to be completed by the first semester 2015.

Data analysis performed using ANAIS-25 detectors has allowed to progress very significantly in the development of filtering protocols to reject anomalous events in the low energy region, which can be discarded as

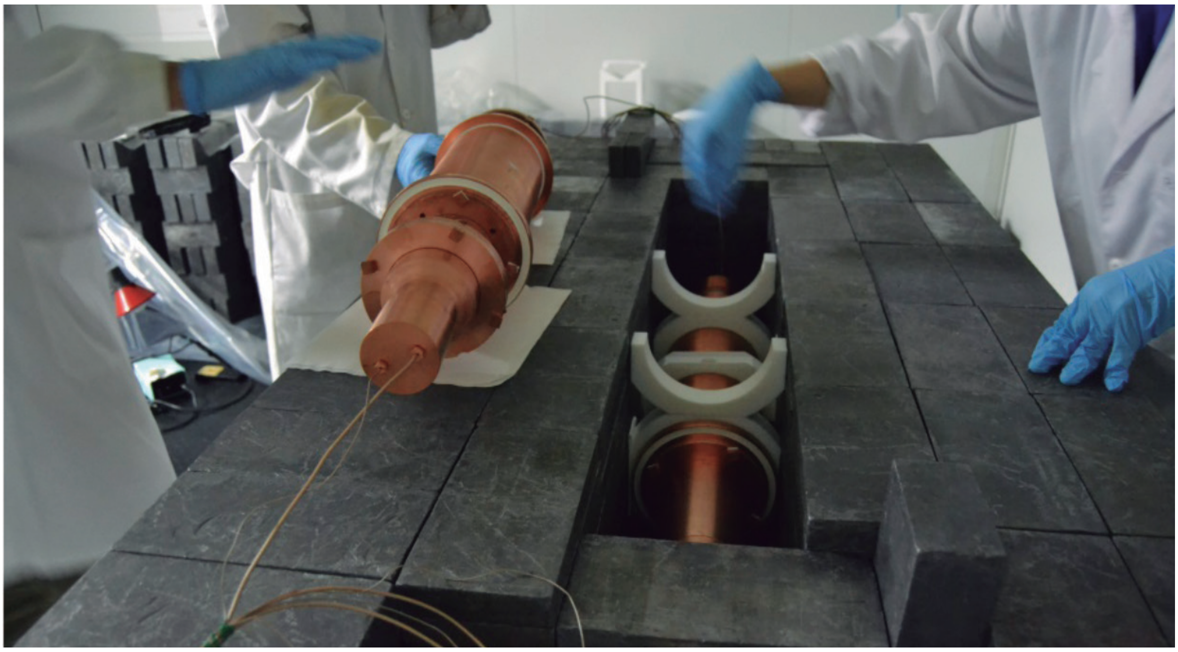


Fig. 7.2. ANAIS-25 detectors being installed at LSC, Hall B

Fig. 7.3. 12.5 kg NaI detector built by Alpha Spectra. It will arrive at LSC at beginning of March 2015

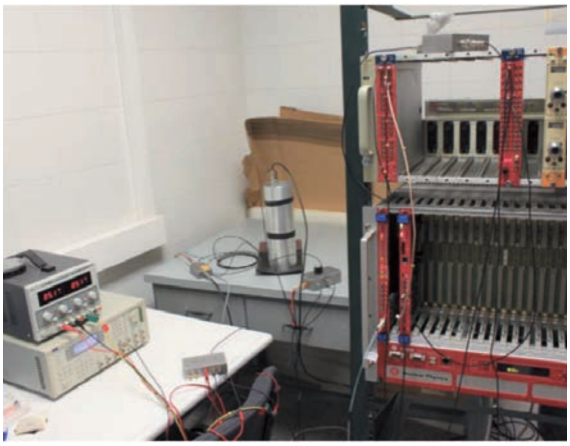


Fig. 7.4. Facility for PMT characterization at Zaragoza laboratories

dark matter interactions, in the understanding of radioactive backgrounds and the building of a background model able to reproduce experimental measurements. In particular, it has been developed a detailed analysis of the cosmogenic activation in NaI crystals, implying a relevant background in the low energy region by isotopes of long mean life as ^{22}Na and Tritium. It is the first time such a thorough study has been carried out for NaI detectors.

Along 2014 an important progress has been achieved in the energy threshold reduction down to 1 keV, profiting from the high light collection efficiency of Alpha Spectra modules. In June 2014 PMTs of one of the ANAIS-25 modules was replaced by the model with the higher quantum efficiency, finally chosen for the experiment. Analysis of the filtering protocols efficiencies down to 1 keV is still in progress. It will published in the first months of 2015. Results are very encouraging, achieved for the first time with this detection technique such low energy level. We notice that a specifically developed calibration system enables irradiation of the NaI crystals through a thin Mylar window with gamma rays under 25 keV, and allows a very precise calibration in energy down to 1 keV. The reduction of the energy threshold below 2 keV is a relevant achievement in the field.

Results of the ANAIS have been published in international journals and presented in the most important conferences of the dark matter detection and underground physics field.

8 ARDM

http://www.ipp.phys.ethz.ch/research/ArDM

The ArDM (Argon Dark Matter) Experiment aims at direct Dark Matter search based on a ton-scale liquid argon double-phase time projection chamber (TPC). Elastic scattering of Dark Matter particles (hypothetical WIMPs) off target argon nuclei is measurable by observing photons from scintillation and free electrons from ionisation, which are produced by the recoiling nucleus interacting with neighbouring atoms. The ArDM detector is designed to measure both signals in its double-phase (liquid-vapour) TPC operation mode. The ionisation electrons, produced in the liquid, drift up to the liquid surface and are extracted into the saturated argon vapour above the liquid, thanks to strong electric fields of the order of one thousand volts per centimetre (this requires a very high voltage of ~100 kV in the system). The extracted electrons further interact with argon gas atoms producing secondary scintillation light (S2). The S2 photons, the intensity of which is proportional to the ionisation charge, are detected by "photomultipliers" (PMTs). The ionisation signal thus is recorded via S2, while the primary scintillation light (S1) is recorded promptly by the same PMTs. The time interval between S1 and S2 (the electrons' drift time) is proportional to the distance from the event vertex to the liquid surface, and is used to know precisely the vertical coordinate of the event. The two horizontal coordinates are reconstructed from the distribution of the S2 photons falling onto the two-dimensional PMT array. Full 3D position information thus is obtained. This working principle of the ArDM detector is sketched in Fig. 8.1, with a diagram of argon scintillation processes.

Due to the very small WIMP-nucleus interaction cross-section very rare events are expected. Typical kinetic energy of recoils is in the range of 10–100 keV. The signal is therefore quite elusive and requires an experiment in a deep underground location such as LSC. Besides, very good background discrimination capabilities and good detector shielding are indispensable.

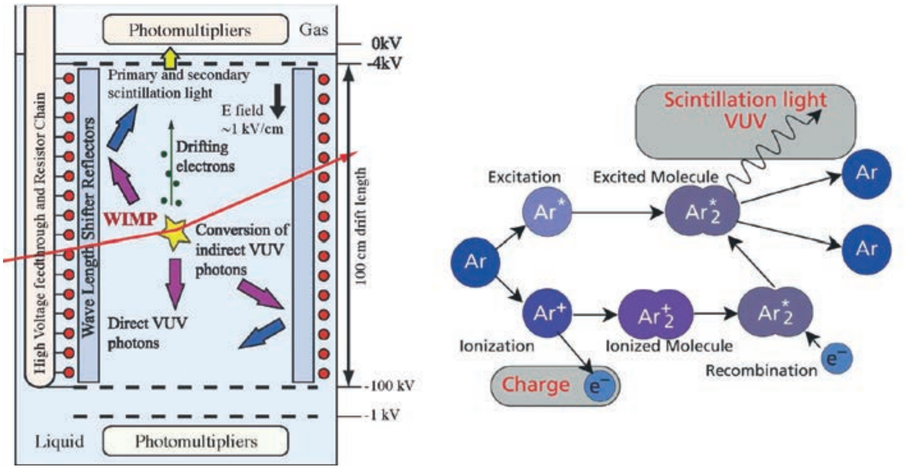


Fig. 8.1. Principles of the liquid Ar two-phase TPC

Noble liquids such as argon and xenon are two of the best options for large-size Dark Matter experiments. Having high scintillation and ionisation yields that are essential for the detection of such low energy events, they are commercially available in large quantities, so that ton-scale detectors can be conceived. These provide simultaneously detector mass and self-shielding against external sources of background, two features essential for the detection of rare events. Our choice of argon as target material was motivated by the following arguments.

1. The event rate in argon is not very sensitive to the recoil energy threshold (the minimum detected one) due to finite nuclear sizes (on the contrary, for xenon the event rate is reduced at high recoil energies). To understand the orders of magnitude, assume a standard distribution of WIMPs in the Galaxy and consider typical values of 100 GeV for the WIMP mass and 10^{-44} cm^2 for the WIMP-nucleon cross-section. With energy threshold of 30 keV the rate on argon is one recoil event per day per ton of argon.
2. Argon is much cheaper than any other noble gas. Consequently, an even larger (multi-ton) scale detector that might be required for the future is conceivable.
3. The scientific relevance of obtaining data with both argon and xenon is given by the fact that recoil spectra are different, providing an important crosscheck in case of a positive signal.
4. The charge to light ratio and the pulse shape of the S1 signal provide efficient discrimination against gamma and beta electron recoil backgrounds.

An important aim of ArDM thus is to demonstrate the feasibility of an argon-based ton-scale experiment with the required performance to efficiently detect WIMP induced nuclear recoils and sufficiently discriminate backgrounds for a successful WIMP detection.

A one-ton ArDM prototype initially was built on surface at CERN (Geneva, Switzerland) and was operated successfully in cryogenic (−186°C at 1 bar) liquid argon. The vacuum and cryogenic infrastructure, the detector control and the data acquisition systems were then transported to LSC in February 2012 and installed underground in Hall A.

In Fig. 8.2 a picture of the ArDM installation in Hall A at LSC is presented. The blue platform built for the installation, the cryogenic vessels and the polyethylene neutron shield structure covered by aluminium fire protection panels can be seen.

For a safe underground operation ArDM has a fully automatized control system, which monitors and regulates actively the different subsystems of the experiment. The control system is based on a programmable logic controller and is integrated in an array of seven racks as shown in Fig. 8.3. It monitors all the pressures, temperatures and liquid argon

Fig. 8.2. ArDM experimental structure in its shielding (November 2014)

Fig. 8.3. The ArDM control system

levels in the ArDM detector and its cryogenic system. It also regulates the vacuum system, the cooling of the liquid argon, the argon purification and the power supply of the high voltage generator.

In February 2013 the upgraded ArDM detector with a new light readout system was installed at LSC. A picture of the detector hanging on the crane in Hall A, being installed into the detector vessel, is shown in Fig. 8.4 together with its drawing and a close-up view of one of the PMT arrays. The detector has total of 24 cryogenic 8-inch PMTs in two arrays, one in the vapour phase above the target/drift volume (called "drift cage") and the other below immersed in liquid argon. The PMTs are not sensitive directly to the scintillation light in argon, which is far in the ultraviolet (λ=128 nm). The light wavelength is shifted up to become detectable by coating the windows in front of the PMTs and the reflectors on the side of the volume with a chemical that absorbs ultraviolet photons and re-emits blue light (around λ=430 nm).

The ArDM data acquisition system is capable of handling a kHz-scale event rate in ~1-ton liquid argon target, and can record data at a rate of ~300 MB/s. A data storage system involving 192-TB hard disk is installed for storing the large amount of data.

Substantial efforts have been undertaken also on the software for the physics analysis. Fully functioning data analysis framework has been developed and also a Monte Carlo simulation programme, involving the full detector geometry and all the physics processes. ArDM is ready to analyse physics data as soon as available.

Like many other LSC experiments, control and screening of neutron background is a critical issue for ArDM. For this purpose a systematic material screening campaign is actively being pursued at LSC, thanks to the strong support from the lab. Radioactivity of different detector components is being measured using a high-purity germanium facility of the underground lab. Based on the measured activities, a careful assessment of

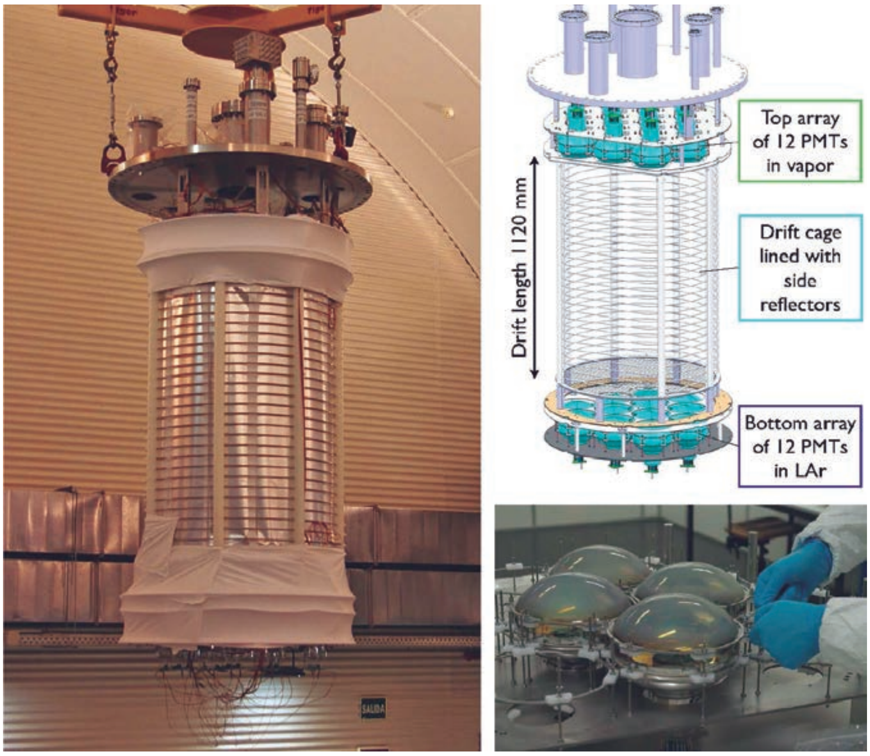


Fig. 8.4. The ArDM detector

the expected number of neutron background events has been made, which lead to the projected sensitivity showing a high potential of ArDM in particular for high-mass WIMP searches.

In May 2014, ArDM transitioned to a continuous data taking phase, first in pure argon gas at room temperature. After an extensive safety review process by LSC regarding, in particular, the use of a large quantity (~2 t) of cryogenic liquid argon underground, the first cryogenic operation of ArDM underground was inaugurated in September 2014. The entire cryogenic system was cooled from room temperature (25°C) down to liquid argon temperature (–186°C) within a week. Then the detector response was studied in "cold" argon gas, approximately three times denser than that at room temperature, employing radioactive calibration sources. The amount of data taken as of November 2014 reached ~80 TB.

Meanwhile, the ArDM Control Centre has been set up at CERN. The control system of ArDM as described above can eventually allow a full remote operation of the entire system via internet. Such a feature is particularly important for a long-term physics data taking in the underground lab that will continue over several years. Currently, a local staff is operating the system with a remote shifter from the Control Centre.

Since November 2014, ArDM is in filling process, i.e. condensing pure argon gas in the detector vessel with the aid of three 300-W cryo-refrigerators. The vessel is expected to be full with ~2 t of liquid argon tarfet at the beginning of 2015. After a successful commissioning and a full characterisation of the system during the first data taking in liquid argon, physics data taking for Dark Matter search is expected to start during the year 2015.

The ArDM Collaboration is composed of scientists from: ETH Zurich (Switzerland) and CIEMAT (Spain).

9

NEXT

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

The NEXT experiment has the aim of detecting neutrinoless double beta decay ($0\nu\beta\beta$) in xenon gas, enriched in the isotope ^{136}Xe, the one that decays double beta. The signature of such a decay is a peak in the distribution of the energy released by the two electrons in the decay, which must be constant, since no neutrinos are present to carry away part of the total energy. Thus, a good $0\nu\beta\beta$ experiment must be able to measure energy at a great level of resolution and have the capability of rejecting those background events with almost the same energy as the electrons of the decay.

Neutrinoless double beta decay, if it exists, is an extremely rare event, with a half-life greater than 10^{25} years. In order to be able to measure it, an experiment needs to shelter the detector from all the possible radiation that could produce a signature similar to the signal one. For this reason, NEXT is placed underground at LSC, where the earth itself blocks most of the cosmic radiation. Moreover, the materials used to build the detector must be extremely radiopure, in order not to introduce further radiation that can be confused with a double beta decay.

NEXT consists of a high-pressure time projection chamber, that is, a vessel full of 100 kg of xenon gas at 15 bar, in which an electric field is applied, and of two different sensor planes. The first is used to measure the energy and the other to provide a "picture" of the event. Fig. 9.1 shows the principle of detection.

When a charged particle enters the gas, it releases its energy interacting with the gas molecules in two ways. On one hand, the molecules pass to an excited state and then go back to their normal state by emitting light, in the range of the ultraviolet wavelengths. This light (called scintillation) is registered by the sensors on one side of the detector and gives the starting time of the event. These sensors are photomultipliers, that are devices capable of converting light into electric current. On the other hand, the energy released by the particle can also extract electrons from the xenon atoms, through the ionization phenomenon. These electrons are drifted by the electric field all the way through the drift region until they enter a region of moderately higher field where they are accelerated and secondary scintillation (but not ionization) occurs. This process results in an amplification of the signal, which grows linearly with the electric field. The photomultipliers detect this secondary light, giving a precise measurement of the energy of the event. On the opposite side, the distribution of the light on another, denser array of silicon photomultiplier is, in every moment, a 2D picture of the event

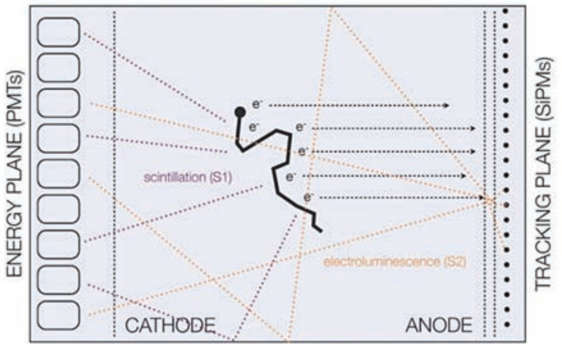


Fig. 9.1. The NEXT detection principle

Fig. 9.2. The NEXT-DEMO prototype at the IFIC Valencia

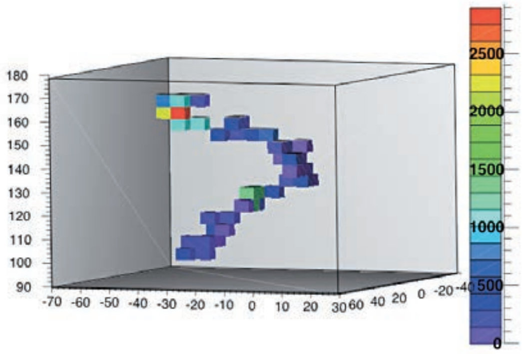


Fig. 9.3. An electron track reconstructed by NEXT-DEMO

at a given position along the axis. Knowing the starting time of the event, the absolute position along the chamber axis can also be reconstructed.

This novel concept meets the essential requirements of a $0\nu\beta\beta$ experiment mentioned above. As far as concerns the energy resolution, the fluctuation in the quantity of ionization electrons produced and secondary scintillation light are very low. On the other hand, in xenon at 15 bar it is possible to take advantage of the topological signature of the event: the two electrons of $0\nu\beta\beta$ leave a track with almost constant energy deposition and two big "blobs" of energy at the ends, caused by the more twisted walk that the electrons follow when they have low energy left. This signature is an excellent instrument for background rejection.

From 2009 to today an intense R&D program has been carried out by the Collaboration. The feasibility of the technology has been demonstrated with the NEXT-DBDM and NEXT-DEMO prototypes, which have shown the excellent performance (energy resolution, electron reconstruction) of the apparatus, as well as the robustness of the EL technology. NEXT-DEMO has had the aim of testing the instrumental concept of NEXT: it is a chamber with the same proportions in size as the final NEXT detector, and holds 4 kg of natural (non-enriched) xenon at 10 bar. In Fig. 9.2, the detector inside the clean room is shown. NEXT-DEMO has been operating successfully for more than two years and has demonstrated::

a. operation stability, with no leaks and very few sparks, even at high voltages.

b. energy resolution better than 1% once extrapolated to the energy of the 0nbb.

c. capability of reconstructing tracks..

In July 2013 the spokesperson of NEXT has obtained an Advanced Grant of the European Research Council (ERC). The LSC Scientific Committee has recommended that a first-phase of the NEXT detector, deploying 20 % of the sensors of the final apparatus is installed and operated at the LSC, with the double target of assessing the NEXT background model from the data themselves, and observing (measuring) the mode with two neutrinos double beta decay, which will allow a clear demonstration of the unique NEXT topological signal (observation of two electrons). As a consequence, the collaboration has decided to deploy a first stage of the NEXT detector, the NEW (NEXT-WHITE) apparatus (the name honours the memory of Professor James White, recently deceased and one of the key scientists of the NEXT Collaboration). The construction of NEW and the completion of the infrastructures needed at LSC (which are the same for NEW and the final detector) started in 2014 and will end in the first months of 2015. It is therefore

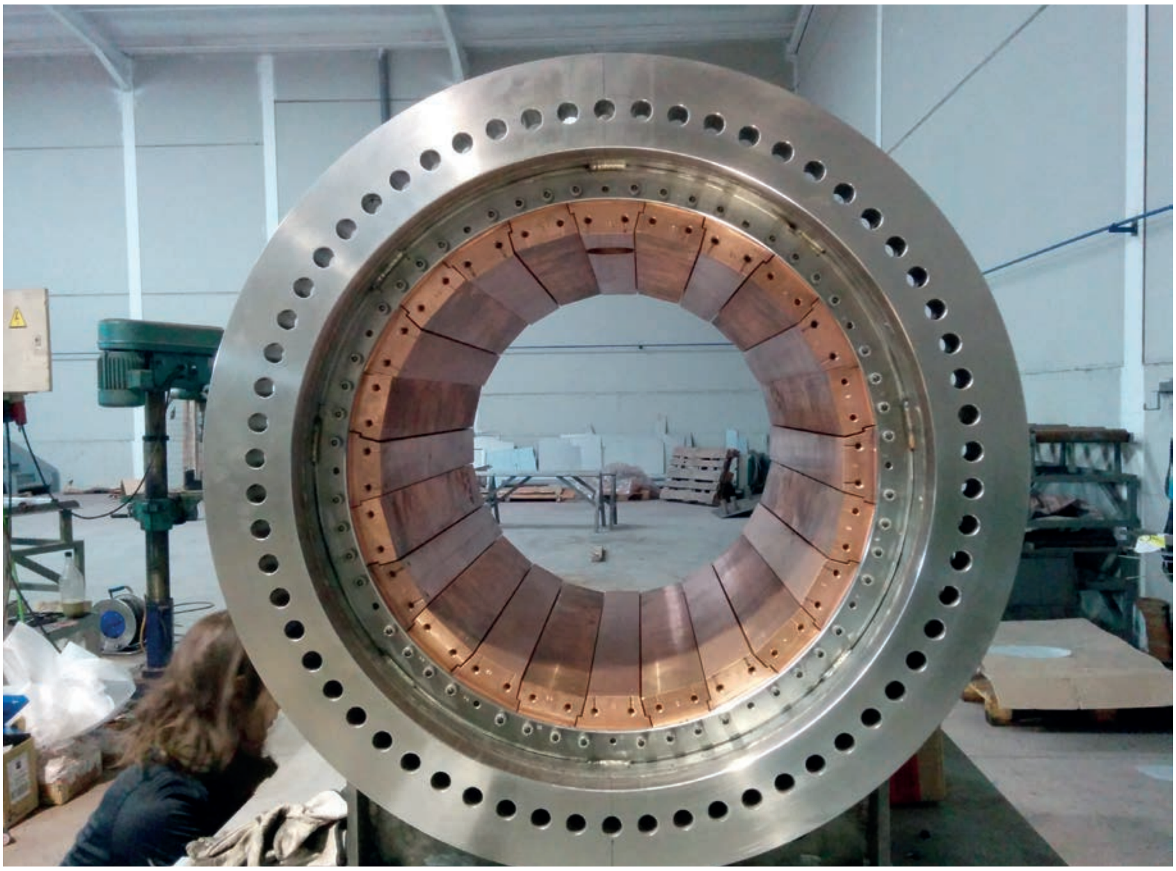


Fig. 9.4. The NEW chamber with the copper shielding

foreseen to commission and take data with NEW during 2015 and 2016, in parallel with the construction of the NEXT-100 detector. A picture of the vessel of the NEW detector is shown in Fig. 9.4, with the inner ultrapure copper shielding.

The installation of the NEXT final detector at LSC started in late 2012. The working platform has been put in place, as well as the gas system. In 2014 the seismically insulated central part of the platform, which will support the detector, its shield and the "castle" that will host the shield, has been completed. The shield consists of pure lead bricks externally and pure copper, which is less radioactive then lead, internally.

A screening campaign of all the materials to be used in NEXT is being performed by the LSC service, measuring the activity of each sample by means of germanium detectors.

The stainless steel vessel has been manufactured in Madrid, by the Spanish company Movesa, and has been delivered at LSC. The other components (the structure that creates the electric fields, the energy plane, the tracking plane, the feedthroughs...) are being designed and built by different parts of the NEXT Collaboration

The NEXT Collaboration is composed of scientists from: Universidad Antonio Nariño (Colombia), Universidad de Aveiro and Universidad de Coimbra (Portugal); JINR (Russia); IFIC - Instituto de Física Corpuscular, Valencia; Universidad Autónoma de Madrid; Universitat de Girona; Universidad Politécnica de Valencia, Universidad de Santiago de Compostela and Universidad de Zaragoza (Spain); Iowa State University, Lawrence Berkeley National Laboratories, Texas A&M University (USA) .

10 BIPO

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

SuperNEMO is an experiment on $0\nu\beta\beta$ proposed for the future extension of the LSM underground laboratory at Modane, France. The project foresees a source of 100 kg of ^{82}Se in the form of very thin foils. The electrons will be detected with gas detectors on the two sides of the foils, while their energy will be measured using organic plastic scintillators. These foils must be ultra radiopure in ^{208}Tl and ^{214}Bi, which are two isotopes produced from the decays of the natural radioactive ^{232}Th and ^{238}U isotopes. The required radiopurity of the selenium foils must be better than 2 μBq/kg in ^{208}Tl (less than 5 decays of ^{208}Tl per month and per kg of selenium) and better than 10 μBq/kg in ^{214}Bi. This level of radioactivity is so small that cannot be measured by the traditional gamma spectroscopy Ge detectors. Thus, the SuperNEMO collaboration developed the BiPo detector to qualify these double beta source foils. The BiPo detector needs to be hosted in an underground laboratory. It was proposed to and approved by LSC in the frame of the collaboration existing between European deep underground laboratories (LNGS, LSC and LSM).

Fig. 10.1. General view of the BiPo-3

In BiPo, the foil of interest is inserted between two thin ultra-radiopure plastic organic scintillators to detect the ^{214}Bi and ^{208}Tl contaminations both via the so called BiPo process. The ^{214}Bi isotope decays through β decay emitting an electron, into ^{214}Po, which is an α emitter with a half-life of 164 μs. The ^{208}Tl isotope is measured by detecting its father, the ^{212}Bi isotope. The latter decays β (64%) into ^{212}Po, which is an α emitter with a half-life of 0.3 μs. In both cases the electron and, later, the α are detected by the scintillators on the two sides of the foil.

The two modes are distinguished by the different delay between β and α. The experiment started with two prototypes, BiPo-1 and BiPo-2, which were necessary to develop the technique. Finally the BiPo-3 detector was built and installed at LSC.

The BiPo-3 detector is composed of two separate modules. Each one consists of 40 ultra radiopure plastic scintillator plates seen by low radioactivity photomultiplier tubes. The size of each scintillator is 300×300 mm^2 and 2 mm thick, for a total detector surface of 3.6 m^2. Each module is tightly closed by pure iron plates and installed inside a low radioactive shield contained in a large tight stainless steel tank. The two BiPo^{-3} modules have been installed at LSC in July and November 2012 respectively. The shield was completed in January 2013.

The first measurements were devoted to background measurements until May 2013. They showed an extremely low

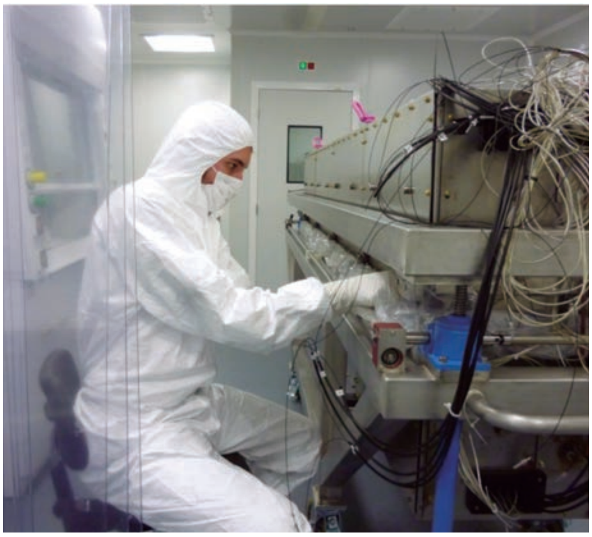


Fig. 10.2. Assembling of one of the BiPo-3 modules in the underground clean room

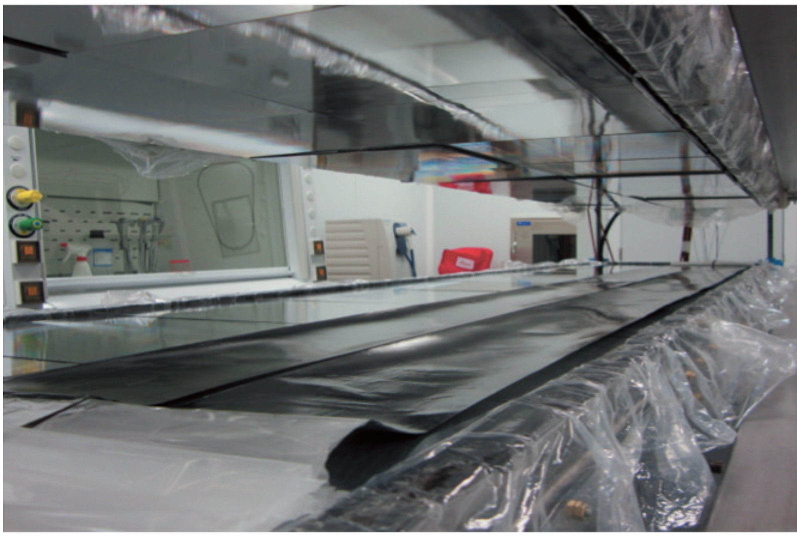


Fig. 10.3. Two SuperNemo Se source foils installed in one of the BiPo modules

background for both modules, well within the requirements. It corresponds to a surface radiopurity of 1.0 ± 0.2) μBq/m^2 in ^{208}Tl and 1.8 ± 0.4) μBq/m^2 in ^{214}Bi.

These background levels correspond to sensitivities for a measurement of ^{82}Se SuperNEMO foils of about 3 μBq/kg in ^{208}Tl and 30 μBq/kg in ^{214}Bi for the full BiPo-3 detector after 6 months of data collection.

The SuperNEMO source foils are composed by a mixture containing the isotope, held by a low density material sheet. Samples of these different components were measured in two modules of BiPo in 2013 and 2014 to control their radiopurity before the final assembling of the source foils. The source foil measurement was started in August 2014 with two strips covering one quarter of the detector surface (Fig. 10.3). A first analysis showed that the Se-mixture produced no BiPo events in the detector in 3 months measurement. This result indicates that the activity of ^{208}Tl and ^{214}Bi is below 18 μBq/kg and 1015 μBq/kg respectively. Two additional strips were installed in December 2014 and are being measured together with the first two strips. The BiPo-3 detector is now a unique high-sensitivity planar detector, able to measure ultra-high radiopurity of a large variety of materials with thin foil geometry. An example is the measurement of radioactive traces of Si substrates used in microelectronics memories, in which radioactive contaminants are responsible of logical soft errors. Samples of various double-beta experiments and prototypes were also measured, including polyethylene for the CUORE experiment at LNGS, Micromegas detectors and reflector-foils for LUMINEU proposal.

11 SUPERKGd

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

Super-Kamiokande is a large detector containing 50 000 t of ultra-pure water in which the tracks of charged leptons produced by neutrino interactions, electrons and muons, are observed through the light they produce in the liquid via the so-called Cherenkov effect. It is located 1000 m overburden in the Kamioka Observatory (ICRR, U.Tokyo) at the Japanese Alps; it is the successor of the smaller Kamiokande, the first neutrino telescope. The latter studied neutrinos from the sun and measured for the first time (yet the only one) neutrinos coming as a burst of few seconds duration, from a supernova explosion occurring in the Large Magellanic Cloud in 1987. This discovery led to the Nobel Prize for physics to Prof. M. Koshiba.

Super-Kamiokande started operation in 1996; it discovered neutrino oscillations in 1998, this implying unambiguously a massive character of the neutrino particle. It is still producing very important physics results (for instance evidence of the appearance of atmospheric tau neutrinos, precise analysis of solar neutrino oscillations, most stringent proton decay limits, others) and astrophysics results (indirect dark matter searches in the Sun and Galactic Centre, world's most precise limits on relic supernova neutrinos, others).

Even so it can see supernova neutrinos only if the explosion happens in our Galaxy or in the nearby Magellanic Clouds. Such explosions unfortunately happen only a few times per century. However, due to the weakness of their interactions, neutrinos from the supernovae of past epochs, since the early times of the Universe, are still wandering around and can be detected. These relic supernova neutrinos (and antineutrinos) have rather low energies and flow in a continuous manner; they are therefore very difficult to distinguish from backgrounds.

We can enhance the sensitivity of the detector by identifying the neutron produced, together with the positron, by the low energy antineutrinos. This can be done by dissolving in the water a salt of gadolinium, $Gd_2(SO_4)_3$; the Gd nucleus has a very large cross section (probability) for neutron capture, after which it decays with observable gamma rays. However, the Gd salt must be ultra clean from radioactive traces to avoid the risk to contaminate all Super-Kamiokande making it blind to observations and, of course, to minimize background reactions that might mimic the physics that we want to measure. A specific R&D programme is going on. It includes a full test water detector at Kamioka and a systematic action of screening of the materials at the LSC.

The LSC radio-purity service has an internationally recognised excellence both in the quality of the Germanium detectors and in the related analysis software. The team of the ***Universidad Autonoma de Madrid*** (UAM) involved in the Super-Kamiokande experiment and on its Gd R&D program, got approved its proposal to the LSC of a complete series of measurements of the radioactivity contamination of different samples of Gd salts and other relevant materials.

After the results of the first measured batches, it was clear that the radioactive contamination of the Gd salts is a serious issue, being the current values not acceptable for the experiment. Thus, a thorough worldwide search of providers was started and it is still going on with positive results: we have identified at least one factory able to produce at least one batch of radioactive very clean Gd salt, and another one featuring rather similarity in the properties of batches produced after time intervals of several months and even years.

The UAM activities at the LSC have yet a long way to go. We are working on a routine procedure for controlling the two hundred ton of Gd salt that will be dissolved in Super-Kamiokande at the final stage of the project expected by 2016; the key facility is the LSC radio-purity service. The goal is to ensure the lowness of the remaining radioactive contaminations and to monitor its constancy along the mass production of this very large amount of material. This is a crucial part of the Gd project.

12 GEODYN

The LSC is located at depth in one of the most seismically active areas in Western Europe, at the Pyrenean chain that marks the boundary between the European plate and the Iberian microplate. Besides, the underground tunnel environment ensures a very low level of noise perturbations, either of natural or cultural origin. These features make it particularly suitable and interesting for hosting an advanced integrated geodynamic observatory, to monitor very precisely local and regional seismic activity and internal deformation processes.

The geodynamic facility in the LSC consists of a broadband seismometer, a strong-motion seismometer, two laser strainmeters, and two superficial continuous GPS stations. This multidisciplinary instrumentation allows advanced studies of geodynamic phenomena, both local and global, in a spectrum ranging from short period seismic waves to tectonic deformation. Hence, it is of great interest for a large community of researchers in Earth Sciences.

The management of the geophysical equipments is carried out in cooperation between expert teams from the Institute of Earth Sciences J. Almera – CSIC (seismic), the University of Salerno, Italy (laser interferometers) and the University of Barcelona (surface GPS).The GEODYN LSC data is integrated in regional and European networks and databases, within large-scale projects as Topo-Iberia and Topo-Europe, as well as the research infrastructure programme EPOS (ESFRI road map), thus ensuring widespread scientific access to this LSC geodynamic facility.

Seismic component. The two sensors (Broad Band seismometer and accelerometer) and the data-logger installed on the Lab 780 are fully operational since June 2011, when the time synchronization was achieved by installation of the GPS time antenna outside, nearby the entrance of the tunnel together with a 800 m long optical fibre cable that brings the signal to the Lab 780. Moreover, since July 2011 the seismic equipment is connected to the internet, which allows remote checking of the components, as well as remote downloading of data. The status of parameters of this equipment, as well as the visualization of the three components is accessible online at the website:

http://193.146.122.114:8083/pages/taurus/status.page.

During 2014 the technical activity related to the seismological component of Geodyn has focused in the final implementation of the SeedLink protocol to provide remote access to the data in real time. This has allowed to fully integrating the station in the EIDA node hosted in the Orfeus Datacenter (http://www.orfeus-eu.org/eida/eida.html), which receives the seismic data in near-real time and makes them available to the seismological community. The six seismic channels (three components of broad-band and accelerometer sensors) can be requested using the proper network and station codes (LC, CANF).

The seismic component of GEODYN has continued the regular record and identification of local/regional and tele-seismic events in both the accelerometer and the broad-band seismometer. Figure

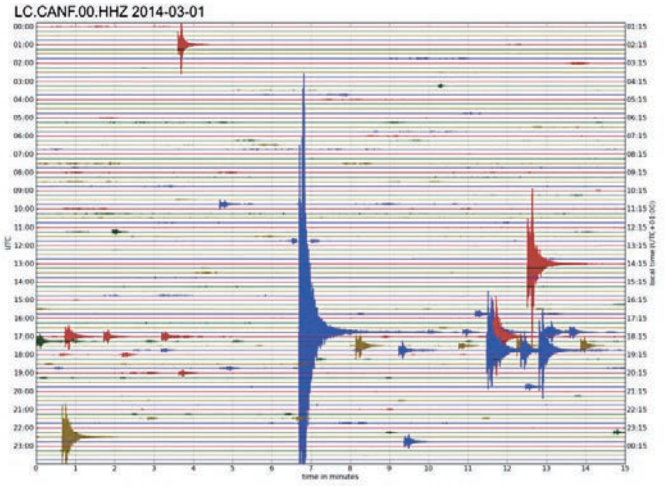


Fig. 12.1. Seismic record at LSC of the earthquake cluster close to Lourdes on March 1st, 2014

12.1 shows the records corresponding to the vertical component of the broad-band sensor during 1st March 2104, showing a seismic swarm with epicenters located close to Lourdes, at about 35 km of our site. The main event reached a magnitude of 3.5 according to Renass (French seismic network). It is worthy to note that the LSC station has detected a large number of unlocated events than those included in the RénaSS catalogue.

Regarding teleseismic activity, we can highlight the two large events (Mw 8.2 and 7.7) with epicentre in northern Chile in early April (Figure 12.2) It is worthy to note that the energy bursts in the 0.04-0.08 Hz band (reddish colours) corresponds to additional aftershocks, not seen in the time series as its amplitude is much smaller than for the largest events. Looking at the lowest frequencies, the energy bursts observed every 3h 20' denote the arrival of the global

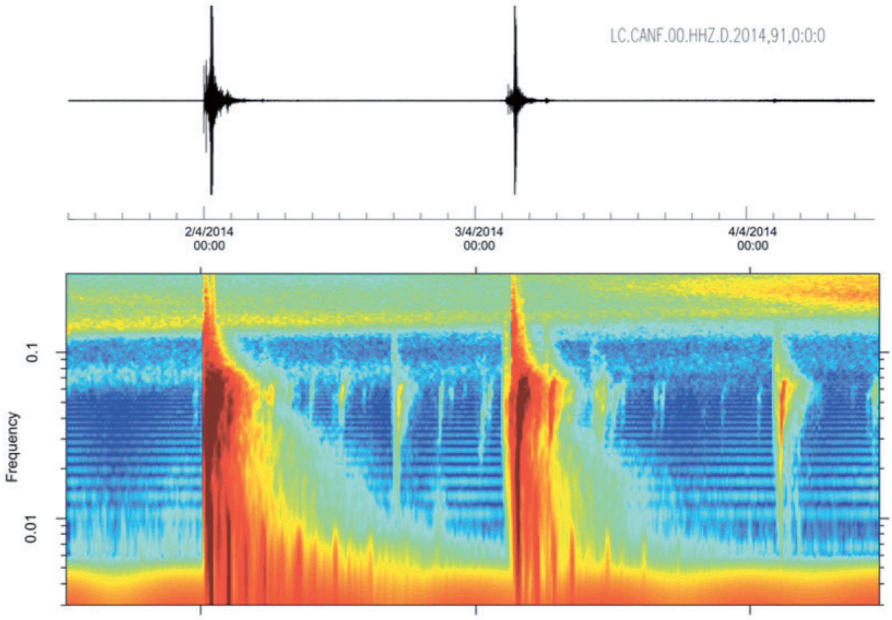


Fig. 12.2. Vertical component and spectrogram of the seismic signal of the two main 201404 earthquakes in northern Chile

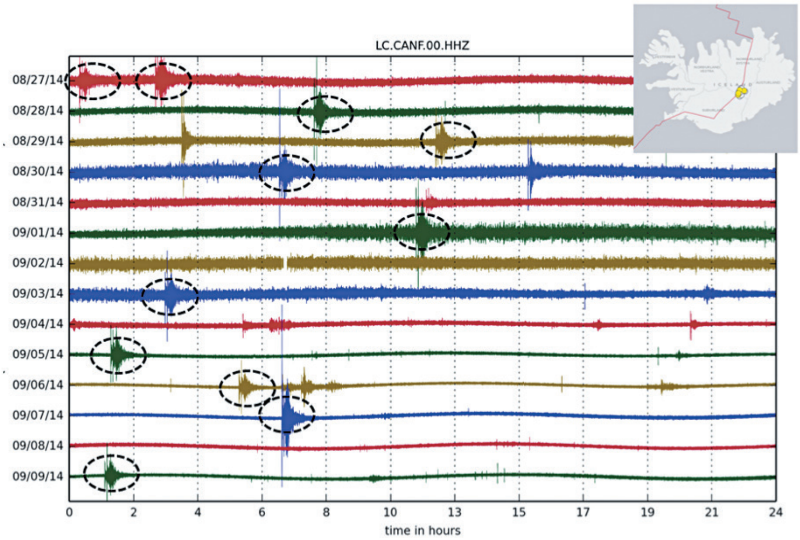


Fig. 12.3. Seismic record of the of the Bardarbunga crisis, with a large amount of events clearly recorded at LSC, most of them with Mw higher than 5.0. (each line is for 1 day)

seismic waves, that is, the surface waves circling the earth and detected at each lap.

Another relevant seismic record during 2014 is the crisis associated to the Bardarbunga volcano in Iceland, started in August 2014. During the period of maximal activity of the eruption, a large amount of events were clearly identified in the seismic components (Figure 132.3)

Laser interferometers. A laser interferometer gives information on the variations of the strain of the rock, by measuring the strain component in its direction, hence namely being a strainmeter. In order to have the information of two perpendicular directions, two interferometers, active since December 2011, are located along bypass 16 and in Lab 780 L (Fig.12.4). The two strainmeters measure distance changes between two end points by means of Michelson-type optical interferometers. The two end points of each interferometer are anchored to the rock; their distance is about 70 m. Two photodiodes measure the intensity of the vertically and horizontally.

Strain data acquisition suffered long breaks during the second semester of 2014, because of failures of the vacuum pumps and the acquisition PCs of both interferometers. In addition, the GAL16 interferometer optics and electronics are often covered by dust raised by car transits. LSC technicians are working to solve those problems, which are not yet completely overcome.

During 2014 the investigation on strain data has been focused to validate non-linear ocean tidal models on larger spatial scales. Signal-to-noise ratio for strain data obtained at LSC appears even higher than for high accuracy gravity measurements. We have obtained continuous precision measurements of local strain in terms of dL/L, where L is the interferometer length and dL its change over time. Its spectra show clear tidal peaks whose frequencies range from the diurnal band to at least 8 cycles per day (cpd). Tidal peaks at frequencies higher than 2 cpd are ascribable to ocean loading of shallow-water non-linear constituents, mainly from the Bay of Biscay, because body tides are very small. We have compared observations and predicted strain tides, computed using ocean-tide loading

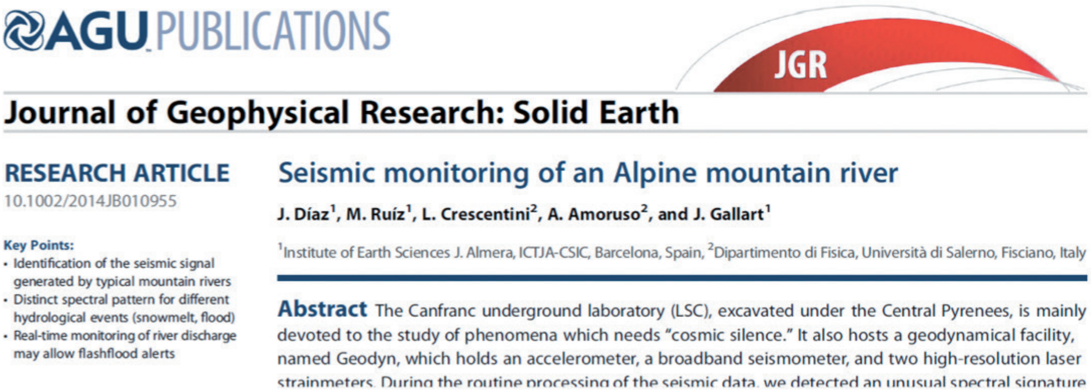
Fig. 12.4. The interferometer in Lab 780 L

programs included in the SPOTL package (Agnew, 2013) and two up-to-date ocean tidal models, namely TPXO8-atlas (enriched with the European Shelf 2008 regional solution) and FES2012.TPXO8-atlas includes only M4, MS4, and MN4 while FES2012 also includes M6, M8, MKS2, N4, and S4. (Figure 12.5). The accurate representation of these nonlinear tides and of their loading effects is a challenging task to be accomplished in the next years.

Hydrological signals. As described in previous reports, during the routine processing of the seismic data we detected an unusual spectral signature, also recognized in the strain records, which has been related to variations in the discharge by the Aragon River, an Alpine-style river, located about 400 m from the GEODYN facility.

The investigation of these hydrological signatures recorded in the Geodyn facility, has lead during this year to the publication of a paper in Journal of Geophysical Research – Solid Earth, a first rank journal published by the American Geophysical Union. (Díaz, J., Ruíz, M., Crescentini, L., Amoruso, A., Gallart, J., 2014. Seismic monitoring of an Alpine mountain river.

GPS component. Two continuous GPS stations are foreseen to monitor deformations around the tunnel area from outside. Basic elements for each station are a choke-ring antenna, the receiver-recorder, power system, communication-remote



AGU PUBLICATIONS

Journal of Geophysical Research: Solid Earth

RESEARCH ARTICLE
10.1002/2014JB010955

Key Points:
- Identification of the seismic signal generated by typical mountain rivers
- Distinct spectral pattern for different hydrological events (snowmelt, flood)
- Real-time monitoring of river discharge may allow flashflood alerts

Seismic monitoring of an Alpine mountain river

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Abstract The Canfranc underground laboratory (LSC), excavated under the Central Pyrenees, is mainly devoted to the study of phenomena which needs "cosmic silence." It also hosts a geodynamical facility, named Geodyn, which holds an accelerometer, a broadband seismometer, and two high-resolution laser strainmeters. During the routine processing of the seismic data, we detected an unusual spectral signature

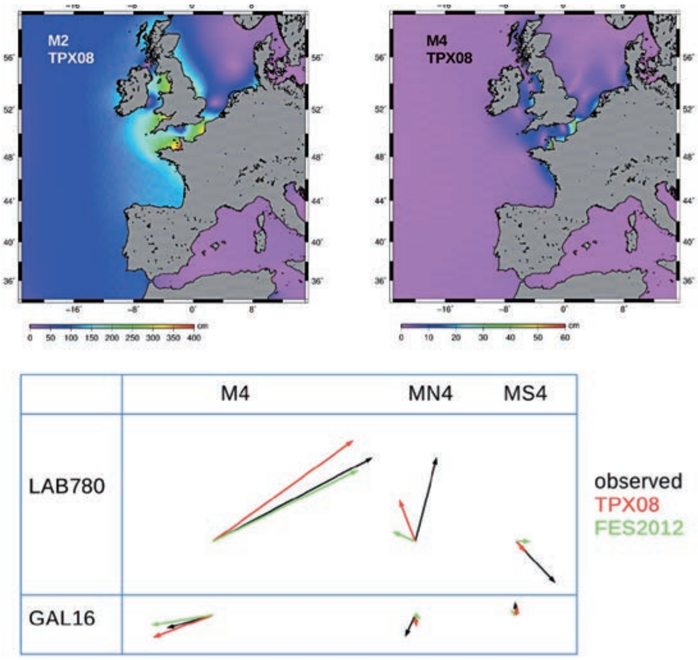


Fig. 12.5. Upper panel: Ocean tide amplitudes (left, M2; right, M4) according to TPXO8 ocean model. Lower panel: Phasor plot of observed (black) and predicted (red, TPXO8; green, FES2012) tidal load

access to the equipment and accessories. The continuous GPS nets measure the displacement of a set of benchmarks with respect to a reference one; distance between benchmarks is of the order of kilometres.

In June 2014 the final locations of the two continuously recording Global Positioning System stations (CGPS) have been fixed in i) Fuerte de Rapitán, on the outskirts of Jaca, about 18 km south of the LSC and ii) Candanchú, inside the "Escuela Militar de Montaña ", 4 km north of the LSC.

Jointly with the Universitat de Barcelona (UB) team, in June 2014 we have performed measurements using high-quality GPS stations on those locations, in order to assure the reception of good quality signal from GPS and GLONASS satellites. UB team has made detailed guides describing the step-to-step procedures to construct the GPS monuments. The budget for all the required material (batteries, solar panels, building materials) has also been prepared.

Fig. 12.6. Sketch of the two GPS sites

13 CUNA

Hydrogen and helium, formed during the Big Bang nucleosynthesis, are the constituents of the first generation of stars. The synthesis of heavier species is achieved through more and more complex nuclear processes within stars. Most of the known isotopes above iron are produced by neutron capture reactions that occur in significantly different astrophysical environments. On the one side, rapid neutron captures (the r-process) are believed to occur in Core Collapse Supernovae, while slow neutron captures (the s-process) takes place in red giant stars on the Asymptotic Giant Branch (AGB) phase producing the main component and in massive stars producing the weak component.

The s-process is thought to produce about half of the isotopes above iron. Nevertheless, an open question still remains, namely the source of the required stellar neutron flux to produce such reactions. Neutrons can be produced via (α,n) processes, the most likely candidates being the ^{22}Ne(α,n)^{25}Mg and ^{13}C(α,n)^{16}O reactions, depending on the specific scenario for the s-process.

The probability of a reaction to happen is given by of the reaction cross section, and thus precise cross section measurements are required to evaluate both the expected neutron flux and the s-process efficiency. These reactions must be accurately known at the temperature where reactions occur in stars, which defines the kinetic energies of the atomic nuclei in the stars, and is coined Gamow peak. The cross sections depend on the energy and decrease very rapidly with decreasing energy, becoming extremely small in the Gamow peak.

The measurement of the majority of the cross sections needed to understand the astrophysical processes cannot be performed in the usual nuclear physics laboratories due to the interference of the cosmic rays that produce background interactions at rates much larger than those looked for. One needs to work in an underground laboratory. Since many years one such facility exists, LUNA at LNGS-INFN in Italy. Nonetheless, higher intensities and a larger energy range are required to do the measurements of interest. Moreover, in consideration of the LUNA-MEV programme at LNGS, a single facility is not enough to cover the entire scientific programme in a reasonable time, considering that the measurement of a single cross section takes several years of work, and that the results need to be crosschecked for scientific consistency. This is why the Canfranc Underground Nuclear Astrophysics (CUNA) project was developed.

The CUNA project proposes an underground nuclear astrophysics laboratory at LSC based on state-of-the-art high-current low-energy accelerator. An “Expression of Interest” titled "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. A full “Letter of Intent” was submitted in October 2012. 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 one event per hour or even lower. Aside from the high current, the controlled operation with low voltage ripple of the accelerator is of key importance, since it allows for the efficient use of the beam time and precise knowledge of the beam energy and intensity. The installation of two experimental stations with two beam lines, in order to be able to perform preparations in one of them while measurements proceed in the other, is envisaged.

The LSC performed preliminary studies for a new experimental hall to be excavated near to the existing underground facilities. The hall shall host the linear ion accelerator and the detectors of the various experiments that will use the facility along the years.

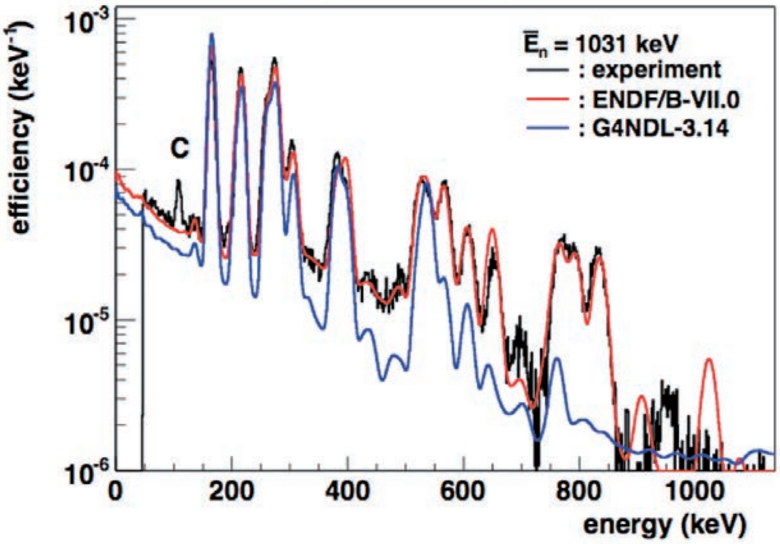
Since the alpha (and proton) beam has sufficient energy to become a source of neutrons through nuclear reactions, the CUNA collaboration has performed numeric simulations to evaluate the neutron background attenuation in the rock. The results show that a metre of rock reduces the flux by three orders of magnitude, and consequently, the neutrons will not affect experiments installed in other halls. Moreover, using a complete model of the LSC, including the additional hall for CUNA, the numerical simulations show that neutron escaping the CUNA hall through access points do not reach other experimental areas.

The extremely low cross sections of the nuclear reactions to be studied at CUNA dictates the requirements of the corresponding detection setups: high detection efficiency and high discrimination capability for the reaction channel of interest. 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. It unites detection efficiencies of the order of 50%, a very clean signature of neutron events and relatively 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.

Six of the tubes have been already used to measure the neutron background in the hall A of LSC. The weighted average of the integral flux in the centre of Hall A at LSC the interval 1 eV to 10 MeV is FHall-A = $(3.44\pm0.35) \times 10^{-6}$ cm^{-2}s^{-1}, where the uncertainty is dominated by the 10% systematic uncertainty in the normalization of the response coming from the calibration measurement. A new neutron background measurement is ongoing at the low background laboratory in Felsenkeller (Germany) using eight polyethylene neutron moderated ^{3}He counters. Apart from the characterization of the neutron background at Felsenkeller, interesting in itself, the measurement will allow the comparison between the background in a shallow laboratory (Felsenkeller) and a deep laboratory (LSC) and thus a better understanding of the conditions for a successful (α,n) measurement.

Signals due to α-radioactivity present in the walls and other materials of 3He tubes can mask the rare neutron signals arising from the proposed (α,n) reactions. The CUNA collaboration is investigating this intrinsic background. Measurements at the LSC using small ^{3}He tubes internally covered by a thin carbon layer preventing alpha-radioactivity from the tube walls entering the gas volume have been performed, using pulse shape discrimination to distinguish the origin of the signals.

Radiative capture reactions of astrophysical interest of the type (X,γ) are another goal of the CUNA project. Detection systems based on highly performing scintillator materials are under development for these measurements. Several studies aimed at the optimization of



beam-induced background, a key point for the underground measurements. In addition, high-sensitivity scintillation materials, such as CeBr3, are being investigated with special emphasis in assessing the radiopurity, energy resolution and efficiency for such programme. Moreover, the study of the neutron sensitivity of inorganic scintillation detectors is also underway. Neutrons are easily produced by accelerators and will induce signals on scintillation detectors through capture or inelastic scattering, which might limit (α,γ) or (p,γ) measurements. The work for a small LaBr3(Ce) crystal has just been completed, showing that the native capture cascade generator in the Geant4 Monte Carlo code needs to be replaced by an improved one on order to adequately reproduce the measurements.

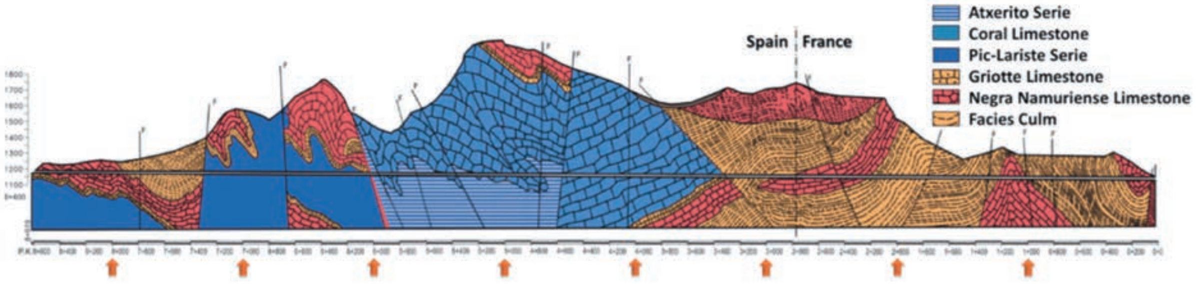
Several workshops have been organized to discuss the feasibility, the Physics programme and the future prospects of the CUNA facility. They started by "Nuclear Astrophysics Opportunities at the Underground Laboratory in Canfranc" (February 2009) in Barcelona, followed by "Background and simulations for CUNA" (December 2010), in Zaragoza and finally "Nuclear Astrophysics at the Canfranc Underground Laboratory" in March 2012, at the LSC. This international workshop was the latest in a series of meetings dedicated to exploring prospects for experiments in nuclear astrophysics at existing and nascent underground laboratories. A key goal was to further develop and discuss CUNA in an international context by soliciting the advice and opinions of leading nuclear astrophysicists outside Spain. The justification for several facilities has already been pointed out in the Letter of Intent, but more importantly by world leading researchers in nuclear astrophysics that wrote letters of support, and also by international bodies such as NuPECC: "There is currently only one underground facility worldwide, at Gran Sasso, Italy, sufficiently sensitive to measure the required cross sections. Given the length of time needed for the measurement of a single reaction, as well as the number of reactions outstanding for which measurements are desired, construction of another facility is of crucial importance for fundamental astrophysics questions". Furthermore scientific independent verification calls for several facilities to compete and complement each other. The LSC offers a unique opportunity for a competitive nuclear astrophysics facility.

14 GOLLUM

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 describe 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 methane producers, amongst others.

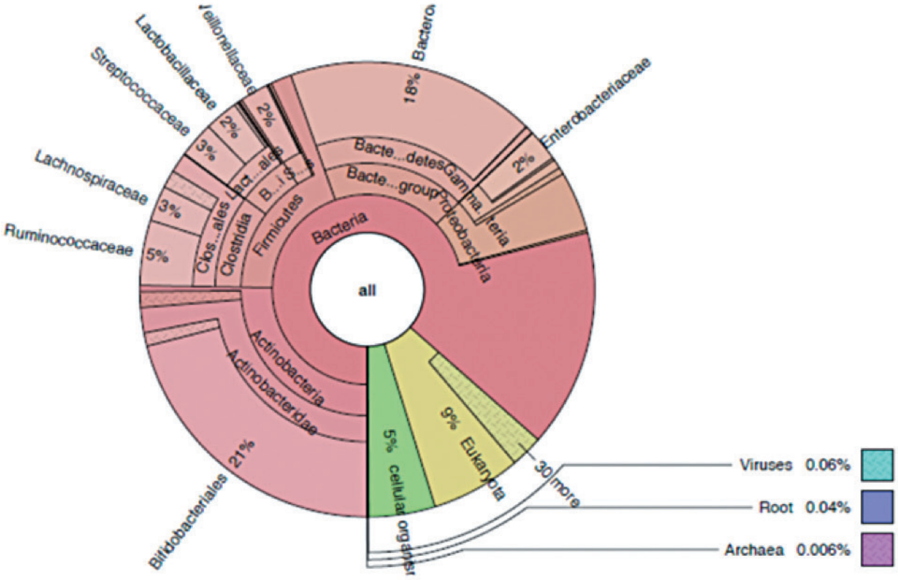
Gollum goal is the identification and characterization of the microbial communities living in a range of different rocks throughout the length of the Somport tunnel, from the surface to the maximum depth. This will be accomplished through 16S amplicon and shotgun high throughput sequencing of the combined 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.



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The NEXT Collaboration, Present status and future perspectives of the NEXT experiment, Advances in High Energy Physics, vol. 2014, Article ID 907067, special issue

ArDM

Long-term operation of a double phase LAr LEM Time Projection Chamber with a simplified anode and extraction-grid design. C. Cantini et al., JINST 9:P03017, 2014.

GENERAL

During 2014, 19 presentations to International Scientific Conferences have been made by users of the LSC.

Also a total of 26 Thesis related to the experiments have been developed.

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