UNDERGROUND LABORATORIES TODAY*

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Underground laboratories, shielded by the Earth's crust from the particles that rain down on the surface in the form of cosmic rays, provide the low radioactive background environment necessary to host key experiments in the field of particle and astroparticle physics, nuclear astrophysics and other disciplines that can profit of their characteristics and of their infrastructures. The cosmic silence condition existing in these laboratories allows the search for extremely rare phenomena and the exploration of the highest energy scales that cannot be reached with accelerators. I briefly describe all the facilities that are presently in operation around the world.

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1. Introduction

In the Bertolt Brecht's "Leben des Galilei" ("Galileo's life"), the scientist declares his thirst for knowledge: "*Sometimes I think I would let them imprison me in a place a thousand feet beneath the earth, where no light could reach me, if in exchange I could find out what stuff that is: Light!*". Scientists working in underground laboratories certainly do like this exclamation of the man whose observations made original and profound contributions toward understanding the physical laws of the Universe. 400 years ago, January 7th of the year 1610, Galileo Galilei observed with his telescope for the first time the Jupiter moons, realizing that Jupiter was the center of a small celestial system in its own. The discovery of bodies orbiting something other than the Earth dealt a blow to the then-accepted Ptolemaic world model and provided evidence in support of the Copernican system.

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Underground scientists are observing today the cosmos with new telescopes, very different from Galileo's one, but with the same aim and enthusiasm for discovering our place in the Universe. We want to be "imprisoned" deep underground to respond to vital scientific questions: What is the Universe made of? What is the nature of Dark Matter? What happened to the antimatter? What are neutrinos telling us about the fundamental symmetries of nature, and about the stars and the Earth?

Phenomena, such as proton decay and neutrinoless decay are predicted by theory to happen spontaneously but at extremely low rates. The study of neutrino properties from natural and artificial sources and the detection of Dark Matter candidates require capability of detecting extremely weak effects. Underground laboratories provide the necessary low radioactive background environment to investigate these processes. These laboratories appear complementary to those with particle accelerators in the basic research of the elementary constituents of matter, of their interactions and symmetries. Underground experiments have been successful in discovering the first clear evidence for physics beyond the standard model (SM). The discoveries that neutrinos are massive and flavor lepton numbers are not conserved have been made in underground laboratories using neutrino natural sources as the Sun and the cosmic rays.

In general, one can consider two classes of motivations to push beyond the SM. There are "particle physics" reasons: the SM does not truly unify the elementary interactions, it leaves the problem of fermion masses and mixings unsolved and it exhibits the gauge hierarchy problem in the scalar sector. The second class of reasons finds its origin in "astroparticle and neutrino physics" issues: the problems of the solar and atmospheric neutrinos deficits, Majorana or Dirac neutrinos, baryogenesis, Dark Matter. These astroparticle and neutrino physics issues can be faced by contemporary experimental physics and constitute a formidable motivation for the underground laboratories activity.

I report here concise information on the underground laboratories and facilities in the world.

2. Underground laboratories

In underground physics the struggle to advance the high energy frontier and to go beyond the standard model is the struggle for background control and reduction. Environment is the principal source of background. The environmental backgrounds of the laboratory depend on the depth and on the nature of the surrounding rocks and, as a consequence, may differ in the different facilities.

The high-energy cosmic rays muons flux decreases almost exponentially with increasing depth, this being the main reason to go underground. The neutron flux at low energies is mainly due to fission and α from U and Th in the rocks. As such, it depends on local geology and becomes depth-independent already at shallow depth. Muon spallation processes are negligible at low (MeV) energies but produce a depth-dependent flux of high-energy (GeV) neutrons. The gamma flux, including gammas from radon and its progeny, depends again on local geology and is practically depth independent.

Other sources of backgrounds, the ultimate contribution in some cases, are the detector materials, supports, shielding, electrical connections, *etc.* Cosmic rays may produce traces of radioactive nuclides (a process called cosmogenesis) both during the construction phase of the detectors and of its materials on the surface — often a period of several months is needed before the data taking can start — and during the operational phase underground.

Frontier experiments do not require to the laboratory only a low background environment, but also technological support, easy and safe access and general as well as specific support structures.

The reported information on the underground labs makes use of and updates the one of the paper by Bettini: "*The world underground science facilities. A compendium*" [`arXiv:0712.1051`]. The facilities are reported in geographical order, from west to east, starting from Europe.

2.1. Europe

BUL — Boulby Palmer Laboratory (UK) [1]

The site was developed starting in 1988 by Neil Spooner and collaborators from RAL. An active potash mine at 1000 m depth under a flat surface hosts it. The access is through a shaft. The salt environment limits the cavities width to about 5 m. A clean area of approximately 1500 m^2 is available to experiments. The neutron flux with $E > 0.5$ MeV is 1.7×10^{-2} m^{-2} s^{-1}, the muon flux is 4.5×10^{-2} m^{-2} s^{-1}. A building on the surface (200 m^2) hosts laboratories for computing, electronics and chemistry, offices, conference room, changing rooms, mess rooms, mechanical workshop, storage and construction rooms. The scientific program is focused on Dark Matter search: ZEPLIN II is completed, ZEPLIN III is to be completed by the end of 2010 and DRIFT II is in research and development phase. There are low radioactivity measurements and geophysics research. About 30 scientists work at the laboratory. There is an excellent potential for expansion.

LSC — Laboratorio Subterráneo de Canfranc (Spain) [2]

The first underground facility under the Pyrenees, close to a dismissed railway tunnel, was created in the 1980s by Angel Morales and the Nuclear and High-Energy Physics Department of the Saragossa University. Taking profit of the excavation of a parallel road tunnel, the new laboratory was later built. The underground structures have been completed in 2005. Soon after, several design and construction defects have emerged and the necessary reparation works are now being made. LSC is managed by a Consortium between the Spanish Ministry for Education and Science, the Government of Aragon and the University of Saragossa. The surface building is under construction, to be completed by the end of 2010. It will contain headquarters, administration, library, meeting room, offices, laboratories, storages and a mechanical workshop, safety structures and management, for a total of approximately 1500 m^2. A dozen of employees are being hired.

The access is horizontal, via one of the tunnels. Entrance must be communicated to the freeway tunnel control. The available spaces underground are: Hall A measuring $40\times15\times12$(h) m^3, Hall B of $15\times10\times8$(h) m^3, Clean room of 45 m^2 and Services for 215 m^2. The old lab area is 100 m^2. The maximum rock coverage is 850 m. The muon flux is between 2×10^{-3} and 4×10^{-3} m^{-2} s^{-1} depending of the location, the n flux is 2×10^{-2} m^{-2} s^{-1}. The Rn activity in the air is 50–80 Bq/m^3 with a ventilation of 11 000 m^3/h, *i.e.* one lab volume in 40'.

The scientific program, defined with the advice to the director of an International Scientific Committee, includes the approved experiments: ANAIS and ROSEBUD on Dark Matter, NEXT and BiPo (ancillary to superNEMO) on double beta, the screening for SuperK Gd phase and the GEODYN geodynamical observatory. Proposals under discussion are ArDM on Dark Matter and a nuclear astrophysics facility. The scientific user community consists of 210 scientists from 7 countries.

LSM — Laboratoire Souterrain de Modane (France) [3]

The Laboratory is operated jointly by the CNRS/IN2P3 and CEA/DSM. The excavation of the Laboratory started in 1979 and was completed by 1982, to host a 900 t iron tracking calorimeter to search for proton decay. This "Frejus" experiment finished in 1988.

The access is horizontal through the Frejus roadway tunnel. Intervention of the tunnel control is needed to stop the traffic at the entrance or exit of a vehicle from the lab. The Main Hall is $30\times10\times11$(h) m^3, the Gamma Hall has an area of 70 m^2, two smaller halls have 18 m^2 and 21 m^2 areas, for a total of 400 m^2. The surface building includes offices (100 m^2), a warehouse and workshop (150 m^2) and a flat. The personnel are 8 technicians and engineers and one post doc.

The rock overburden is 1700 m. The muon flux is 4.7×10^{-5} m^{-2} s^{-1}. The n flux is 5.6×10^{-2} m^{-2} s^{-1}. A low Radon activity in the air, 15 Bq/m^3, is obtained by in taking fresh air at the rate of 1.5 lab volumes/hour. An "antiradon factory" produces 150 m^3/hr of air with 10 mBq/m^3. The laboratory is almost full with NEMO 3 ($\beta\beta$ decay), EDELWEISS (Dark Matter), which should run at least up to 2010, and a low radioactivity counting facility. About 100 scientists work at the lab.

An extension of the lab of 60 000 m^3 is planned (Ulisse project), profiting of the unique opportunity given by the construction of a new tunnel approved by the French and Italian Governments to increase the safety conditions of the traffic. Two large halls are foreseen: Hall A of 24×100 m^2 and Hall B of 18×50 m^2. An extremely low background environment will be obtained in Hall B by surrounding its central volume with a water shield and by artificially producing a very low Rn content atmosphere (0.1 mBq/m^3).

LNGS — Laboratori Nazionali del Gran Sasso (Italy) [4]

LNGS is a national laboratory of the INFN. It is the largest in the world, serving the largest and most international scientific community. In 1979 the President of the INFN Antonino Zichichi proposed to the Parliament to build a large underground laboratory close to the Gran Sasso freeway tunnel then under construction (an opportunity that reduced substantially the cost). In 1982 the Parliament approved the construction, which was completed by 1987.

Access is horizontal, through the freeway. The underground laboratory consists of three main halls (called A, B and C), about $100 \times 20 \times 18$(h) m^3 plus ancillary tunnels, providing space for services and small scale experiments. Two 90 m long tunnels were built for two Michelson interferometers for geology studies. The total area is 17 300 m^2, the total volume 180 000 m^3.

Services hosted on the surface campus include offices, mechanical workshop, storage facilities, chemical lab, electronic workshop, assembly hall, computer and networking, library, canteen, sleeping rooms, conference rooms, headquarters, administration. Special care has been given to the development of structures, instrumentation, procedures and training activities in matter of safety, of the users and of the citizens, and environmental impact. A number of outreach activities and visits to the lab are systematically organized by a dedicated Service. A Training Service has been created to exploit the technological and scientific transfer of the lab expertise to young people of the Abruzzo region. Personnel (physicists, engineers, technicians, administration) include a permanent staff of 76 and about 20 non-permanent positions.

The rock overburden is 1400 m. Muon flux is 3×10^{-4} m^{-2} s^{-1}. The n flux is 3.78×10^{-2} m^{-2} s^{-1}. Radon in the air is 50–120 Bq/m^3 with a ventilation system providing one lab volume of fresh air in 3.5 hr. Major civil engineering works have been performed in 2004–2007 to upgrade the safety conditions of the interacting structures of the free-way, the water collection systems and the laboratory.

LNGS is operated as an international laboratory. An International Scientific Committee, appointed by INFN, advises the Director. The rich experimental program includes the CERN to Gran Sasso neutrino beam experiments OPERA and ICARUS; Dark Matter search, with LIBRA, CRESST2, XENON, WARP; neutrinoless $\beta\beta$ decay with COBRA, CUORICINO, GERDA; Solar neutrinos (and geoneutrinos) with BOREXINO; Supernova neutrinos with LVD; Nuclear astrophysics with LUNA2. A special facility is dedicated to low radioactivity measurements. The laboratory also supports several experiments on geology, biology and environmental issues. Almost all the experiments are second generation ones and are approved for several years of data taking. The scientific user community consists of 752 scientist from 26 countries.

Coordination in Europe

The directors of the four Western Europe underground laboratories (Gran Sasso, Modane, Canfranc and Boulby) initiated actions to co-ordinate activities and to optimise the use of the available resources, taking into account the different characteristics of the infrastructures. In the 6th "framework programme" the ILIAS project (Integrated Large Infrastructures for Astroparticle Science, putting together the underground and the gravitational wave communities) was submitted successfully to European Commission (EC) by ApPEC, the European inter-agency committee for astroparticle physics.

ILIAS was launched on April 2004 as a 5 years project, and got a total EC financial contribution of €7,5 million. ILIAS contained several elements: the co-ordination of a number of activities of the laboratories, such as environmental background measurement and control, safety procedures, outreach activities, and the funding for access of new users to the labs.

The continuation of this program (a new proposal called ILIAS-Next has been submitted to EC) and the continuation of the coordination among the four underground labs (a new agreement called EuLAbs is being signed by the agencies Presidents) has been favored by ASPERA. Created by ApPEC and funded by the EC through the 7th Framework Programme, ASPERA is an European Union ERANET project for the coordination of national research efforts in Astroparticle Physics in Europe, see [5].

In the same Framework Programme, EC also funded a Design Study project (LAGUNA) focusing on the design of an European infrastructure able to host underground new large-volume instruments with a fiducial mass from several tens of ktons up to 1 Mton for low-energy neutrino astronomy and proton decay search.

CUPP — Centre for Underground Physics in Pyhäsalmi (Finland) [6]

The Centre is hosted in a working mine. Several cavities, dismissed by the mine, are available at different depths down to 980 m, for a total area of more than 1000 m^2. Presently the mine works between 1000 m and 1400 m depth. Access is both via shaft and via an inclined tunnel. The EMMA experiment is being installed. Small lab and office space is available in a surface building. A guesthouse is also available. The personnel consist of bout 3 people on site and 3 in Oulu University.

SUL — Solotvina Underground Laboratory (Ukraine) [7]

The Laboratory was constructed in 1984 under the leadership of Yuri Georgievich Zdesenko by the Lepton Physics Department of the Institute for Nuclear Research (Ukrainian National Academy of Sciences) in a salt mine. The laboratory space is divided in a Main Hall: $25 \times 18 \times 8$(h) m^3 and four chambers $6 \times 6 \times 3$(h) m^3. The total is area about 1000 m^2. On surface, three living rooms are available. Staffs consist of 14 technicians and engineers. Access is vertical by the mine cage, taking into account the time-table of the mine. The lab is 430 m deep in salt (≈ 1 km w.e.). The muon flux is 1.7×10^{-2} m^{-2} s^{-1}. The n flux is 2.7×10^{-2} m^{-2} s^{-1}. Radon concentration in air is 33 Bq/m^{-3}. Eleven researchers and PhD students of the LPD work at SUL mainly on $\beta\beta$ decay, preparing a new ^{116}Cd experiment using 1–2 kg ^{116}CdWO4 higher quality crystal scintillators and developing research and development projects on scintillators and for SuperNEMO.

Baksan Neutrino Observatory (Russia) [8]

The Laboratory is operated by the INR of the Russian Academy of Sciences. It is managed as an observatory, with very long duration experiments. It is the oldest facility in the world built specifically for scientific research. M. Markov, the Head of Nuclear Physics Division of the Academy of Sciences of the USSR, obtained in 1966 a special Decree of the Soviet Government and construction of the Baksan Neutrino Observatory started under Mount Andyrchi in the Caucasus. A new village, called "Neutrino", was built as a part of the original project in a previously empty space with personnel providing all necessary services (heating station, water supply system, first medical help, transportation, safety, *etc.*). The staff directly related to science is 50–60. The scientific activity started under the leadership of Alexander Chudakov and George Zatsepin. The access is horizontal via two dedicated tunnels, with train transportation. A large hall, $24 \times 24 \times 16$ m^3 in volume, 300 m deep, hosts the Baksan Underground Scintillation Telescope. BUST is ready to observe neutrinos from galactic supernovae since 1978. Another hall, $60 \times 10 \times 12$ m^3 at a vertical depth of 2100 m, hosts SAGE, the Gallium Germanium Neutrino Telescope. In this lab the muon flux is 3×10^{-5} m^{-2} s^{-1}. The neutron flux ($E > 1$ MeV) is 1.4×10^{-3} m^{-2} s^{-1}. The Rn activity is 40 Bq/m^3 with a fresh air input of 60 000 m^3/h. The construction of a larger and deeper hall, about 40 000 m^3 in volume, was started in 1990 and stopped in 1992, when the Soviet Union collapsed. The fate of this unfinished construction is under discussion. Low Background Chambers with volume from 100 to 300 m^3 are used for research and development of Dark Matter and neutrinoless decay search as well as for gravitational wave search and for some geophysics measurements. The number of users is 30–35.

For the sake of completeness, I report information on two more facilities in East Europe, which may turn of interest in the near future as underground laboratories.

The Polkowice–Sieroszowice mine in Poland

Situated near Wrocław, south-west of Poland, is easily accessible from the Wroclaw airport and from the A4 motor-way, 950 km from CERN. The Sieroszowice mine (178 km^2 of underground excavation area), belongs to the KGHM holding of copper mines and metallurgic plants. Existing big chambers in salt: volume: $85 \times 15 \times 20$ m^3, at a depth of about 950 m from the surface (2200 m.w.e.). Very low humidity, temperature $\sim 35°C$, and very low natural radioactivity of the salt rock. Work together with the mine management staff is going on to start the initial laboratory in 2011.

The Unirea salt mine, in Romania

It is situated in Unirea salt mine, in Slanic Prahova town, in Prahova County, in sub-Carpathians hills, about 100 km N from Bucharest. In this environment, a Low Background Radiation Laboratory has been situated at a depth of 208 m beneath the surface at water equivalent thickness of $\sim$ 600 m. This mine consists of a hive-like structure composed of more galleries 32 or 36 meters wide, 52 to 57 m height and hundreds of meter long. Also it must be pointed out the remarkable stability of the microenvironment characterized by a constant temperature all over the years of 12°C and relative humidity of 60 to 65%.

2.2. Asia

Y2L — YangYang Laboratory (Korea) [9]

The lab is operated by the Dark Matter Research Centre (DMRC) of Seoul National University. The presently available area is 100 m^2. Expansion to 800 m^2 is planned but not yet funded. 100 m^2 space for offices, computing and detector test facility is available on surface. Access is horizontal by car. The lab uses the space in the tunnel of the host YangYang Pumped Storage Power Plant. Researchers are requested to obey the safety and security regulation of the Plant.

Rock overburden is 700 m with a muon flux of 2.7×10^{-3} m^{-2} s^{-1}. Neutron flux is 8×10^{-3} m^{-2} s^{-1} for 1.5 MeV $< En <$ 6.0 MeV. Radon activity is 40–80 Bq/m^3. The underground space is mostly occupied by the Korea Invisible Mass Search (KIMS) experiment, currently data taking for

WIMP search with 100 kg CsI(Tl) crystal detectors. Other activities include research and development for $\beta\beta$ decay and background measurements with HPGe counter. Scientific users are about 30.

Oto Cosmo Observatory (Japan) [10]

The laboratory has been developed by H. Ejri of the Osaka University and collaborators. Its area consists of Lab. 2 (50 m^2) hosting ELEGANT V and MOON-1 on Dark Matter search with NaI and neutrinoless $\beta\beta$ decay of ^{100}Mo and Lab. 1 (33 m^2) hosting ELEGANT VI on neutrinoless $\beta\beta$ decay of ^{48}Ca and Dark Matter search with CaF_2. The rock coverage is 470 m, with a muon flux of 44×10^{-3} m^{-2} s^{-1}. The neutron flux is 4×10^{-2} m^{-2} s^{-1}. The Radon inside "radon free" containers is 10 Bq/m^{-3}. The access is horizontal through non-used railway tunnel, which provides also the non-forced ventilation.

Kamioka Observatory (Japan) [11]

The Kamioka Observatory is operated by the Institute for Cosmic Ray Research, University of Tokyo. It was established in 1983 by M. Koshiba as Kamioka Underground Observatory. The original purpose of this observatory was the KamiokaNDE experiment, to which Super-Kamiokande followed, the largest existing underground experiment. The KamLAND experiment is operated by the Neutrino Centre, Tohoku University.

Recently, a process of enlargement has started, in order to accommodate more experiments. Buildings for offices and computer facilities are available on surface. The staffs are 13 scientists, 2 technical support units, one for administration.

The coverage is 1000 m and the muon flux is 3×10^{-3} m^{-2} s^{-1}. The thermal neutron flux is 8×10^{-2} m^{-2} s^{-1}, the non-thermal is 11×10^{-2} m^{-2} s^{-1}. The ventilation is 3000 m^3/h. The access is horizontal by car, with no interference with mining activity. The underground structures are as follows: Hall SK (50 m diameter) hosting Super-Kamiokande, to be continued 10 years, at least. Clean room (10×5 m^2) with XMASS prototype. Hall 40 (L-shape, 40 m $\times$ 4 m arms) hosting the purification tower for XMASS and the NEWAGE experiment on Dark Matter. Hall 100 (L-shape, each arm 100 m $\times$ 4 m) with CLIO, a prototype of Gravitational Antenna (to be terminated in 2013) and a Laser displacement detector. The new Hall A (15×21 m^2) hosting XMASS 800 kg (till 2012) with space available for another experiment. The new Hall B (6×11 m^2) hosting CANDLE on decay, to be occupied till 2012. Small areas are available in the dismissed mine. The scientific users are more than 200 in number. Budget request for the underground large cryogenic gravitational antenna LCGT has been submitted.

This year the T2K experiment is starting. It is a second generation long baseline neutrino oscillation experiment. The J-PARC facility will produce an intense off-axis beam of muon neutrinos. The beam is directed towards the Super-Kamiokande detector, which is 295 km away. The main goal of T2K is to measure the oscillation of ν_μ to ν_e and to measure the value of θ_{13}.

INO — India based Neutrino Observatory (India) [12]

One of the two experiments that first observed the atmospheric neutrinos in 1964 was located at 2700 m depth in the Kolar Gold Mine in India. The India based Neutrino Observatory is the project to create an underground laboratory in southern India. It will be located near the PUSHEP hydroelectric pumping station, under 1 300 m rock overburden.

The lab will be organized with international laboratory standards with a Scientific Advisory Committee, services to the users, environmental, safety, security and outreach activities. Two main underground cavities are foreseen, Lab 1 with a volume of $26 \times 135 \times 25$(h) m^3 and Lab 2 with $53.4 \times 12.5 \times 8.6$(h) m^3 plus connection tunnels and services. Access will be horizontal through dedicated 2 km tunnel. On surface it is planned to have: a 1400 m^2 building for administration, offices, shops, *etc.*, a 2750 m^2 building with lecture hall and guest house and a residential complex with 20 quarters. Personnel will be 50 to 100. The main foreseen experiment is ICAL, a 50 kt magnetized Fe tracking calorimeter for atmospheric and very long base-line accelerator neutrinos. It will occupy only a fraction of Lab 1.

2.3. North America

SNO-Lab (Canada) [13]

The SNO experiment has completed its glorious life and its cavity, 200 m^2 area, is now being freed for further experimental activity. New structure have been constructed: a Main hall of volume 18×15 (15 to 19.5 height) m^3, a service hall of about 180 m^2 and a number of narrow (6–7 m) volumes called "ladder labs". The volume for a further structure, called cryopit, has also been excavated. This hall is designed to cope with the safety issues surrounding large volumes of cryogenic fluids. The total area is 7 215 m^2, of which 3 055 m^2 available for the experiments, the total volume is 46 648 m^3 of which 29 555 m^3 available for the experiments. The access is vertical, through the shaft of the working mine, available daily. All the laboratory will be clean, class 1500. On the surface a 3 159 m^2 building will host clean room, laboratories, staging and assembly areas, office space (60 users), meeting rooms, control rooms, IT server room, emergency generator, high speed network link off-site, high speed network link surface/underground, safety structures and management. Staff will be of 30 people full time. Rock coverage is 2000 m under flat surface. Muon flux 3×10^{-6} m^{-2}s^{-1}, thermal neutron flux is 4.7×10^{-2} m^{-2} s^{-1}, fast neutron flux is 4.6×10^{-2} m^{-2} s^{-1}. Radon in the air is high, 120 Bq/m^3. The ventilation in the smaller lab spaces provides 10 air changes per hour, in the larger ones 5 air changes per hour.

The full PICASSO detector, searching for Dark Matter with the superheated bubbles technique, is running. SNO+ is hosted in the former SNO cavity; it is based on liquid scintillator with dissolved ^{150}Nd and is dedicated to the study of low energy solar neutrinos, geoneutrinos and $\beta\beta$ decay of ^{150}Nd. Dark Matter search includes DEAP/CLEAN with noble liquids, which is operating with a prototype, and the installation of superCDMS with bolometers. More Letters of Interest are expected to be reviewed by the Experimental Advisory Committee.

SUL — Soudan Underground Laboratory (USA) [14]

The underground structures include: the Soudan lab ($20 \times 7 \times 10$(h) m^3) that hosts: (a) CDMS, expected to run until 2010–2011; (b) a low-background counting facility that currently occupies $5 \times 5 \times 3$ m^3 and will expand to $25 \times 14 \times 14$(h) m^3, if funded. The MINOS lab, in which MINOS occupies $35 \times 16 \times 14$(h) m^3 is expected to run until 2010–2011. There is a possibility of a LAr medium sized prototype to replace MINOS to bask in the NuMI beam. The users are 265 in number. The access is vertical via a two-compartment slightly angled shaft. Diameters in excess of 1m and lengths in excess of 10 m pose a problem. Access outside normal operating hours is possible. There is an access charge paid to the host institution, Soudan Underground Mine State Park. Normal laboratory safety requirements are in place. The laboratory coexists with an historic State Park, which offers mine tours during the summer months to the public, and winter tours to school groups. Some tours utilize a visitor's gallery available in the MINOS laboratory. There is no active mining activity.

The overburden is 700 m of rock. The muon flux is 2×10^{-3} m^{-2} s^{-1}. The neutron interaction rates are approximately 10 kg^{-1} d^{-1} (from U/Th, low energy) or 0.01 kg^{-1} d^{-1} (muon generated in the rock). The radon concentration is seasonal, varying from 300 Bq/m^3 in the winter to 700 Bq/m^3 in the summer. The mine has natural ventilation, about 550 m^3/h for the level of the laboratories. Half of this is diverted to ventilate the MINOS and Soudan spaces. This results in a complete air change every 110'. The major facility on the surface is a building of approximately 650 m^2 with offices, kitchen and sanitary facilities. The laboratory has a staff of 9, including secretarial and accounting assistance and network and computer maintenance personnel. It is staffed 10 hours/day, 5 days per week, but the staff is on-call all the time and responds to requests for emergency access.

DUSEL — Deep Underground Science and Engineering Laboratory (USA) [15]

Solar neutrino physics started in the Homestake mine in South Dakota with the experimental work of Ray Davis and the theoretical sun model developed by John Bahcall. After a long and complex process, in spring 2007, NSF selected amongst several proposals the Homestake mine in South Dakota as the site in which the Deep Underground Science (physics, biology, and geology) and Engineering Laboratory (DUSEL) should be designed. The project foresees a funding by NSF of about \$ 250 M for the facility plus a contribution to the initial set of experiments, costing about \$ 250 M. In addition, to prepare the site, SD provides \$ 46 M on its own and \$ 70 M from a donor: T.D. Sanford. NSF is expected to fund with \$ 15 M the design of the facility. For the time being, the facility is a SD State Laboratory, funded primarily from SD controlled money. Water constantly flows into the mine at a rate of 1.2 Mt/yr. Dewatering and site preparation is in progress, as well as the pre-costruction design. This phase should last until 2013, when the DUSEL construction should start to end in 2019.

On the surface several existing buildings will be rehabilitated for about 10 000 m2 to host offices, support structures and laboratories. A major science education centre has been funded by Sanford. The initial staff is estimated 30–50, to increase to 100–150 when the State Lab will become DUSEL. The Scientific Committee has been established with an USA composition in 2006. Laboratory spaces will be built separately for biology, geology and physics. Service and research and development structures (*e.g.* electroforming) will be available for physics at 100 m deep level. Two main campuses are foreseen for physics about 1450 m and 2200 m deep. Each will contain a number (4 and 3 respectively) of standard modules of $50 \times 20 \times 15$ m^3 plus service areas. A staged construction of the upper campus using SD and private funding is foreseen. For the lower campus NSF and Congress approval will be necessary.

3. More science

Recently a new community, belonging to the astroparticle field, got interest in an underground environment: the gravitational wave researchers. The evolution of the current (first generation) gravitational wave detectors is well defined: the laser interferometers will evolve toward their second generation: the advanced (Virgo and LIGO) detectors. According to the current gravitational wave sources modelling, when these apparatuses will reach their nominal sensitivity, the detection of the gravitational waves seems assured in few months of data taking. But the sensitivity needed to test the Einstein's gravity in strong field condition or to realize a precision gravitational wave astronomy goes beyond the expected performances of the advanced detectors. The fundamental limitations at low frequency of the sensitivity of the 2nd generation detectors are given by the seismic noise, the related gravitational gradient noise (so-called Newtonian noise) and the thermal noise of the suspension last stage and of the test masses. To circumvent these limitations new infrastructures are necessary: an underground site for the detector, to limit the effect of the seismic noise, and cryogenic facilities to cool down the mirrors to directly reduce the thermal vibration of the test masses. ET (Einstein Telescope `http://www.et-gw.eu/`) is a Design Study project supported by the EC under the Framework Programme 7. It concerns the study and the conceptual design for a future European third generation gravitational wave detector to be realized underground. Specific tests of seismic and gravity gradient noise have started, or are planned, in Homestake and Gran Sasso.

There are other fundamental questions increasing the interest in underground science. Questions are raising from life sciences: How deeply in the Earth does life extend? What makes life successful at extreme depth and temperature? What can life underground teach us about how life evolved on earth and about life on other planets? And other questions are raising from Earth sciences: How rock mass strength depends on length and time scales? Can we understand slippage mechanisms in high stress environment, in conditions as close as possible to tectonic faults/earthquakes? Which are the mechanisms behind the constant Earth evolution? There are more questions on rock mechanics at large scales and on geo-hydrology. Some activities in these fields are going on in some labs, like Gran Sasso. More attention should be put on these activities in future. The program of DUSEL is taking seriously this issue.

4. Conclusions

The laboratories present activities give an idea of how brilliant are the perspectives for underground physics in the next decade. The main scientific goals of the underground research in the next decade are:

— The direct detection of Dark Matter particles, searching down to the lowest cross-section limits (10–46 cm^2) with ton scale detectors.

— The discovery of the nature of neutrino and the resolution of the neutrino mass spectrum with ton scale neutrinoless $\beta\beta$ detectors.

— A realistic project of a Megaton-scale detector (and the definition of a site and of an international collaboration) for the search for proton decay, for neutrino astrophysics and for the investigation of neutrino properties and CP violation in the leptonic sector.

Both in the search of Dark Matter and in $\beta\beta$ decay the sensitive masses of the experiments need to reach the ton to multi-ton size. Experiments starting to produce data now, as those based on noble fluids (liquids and gases) with 100 kg mass, appear to have good chances to be scalable at larger masses at not prohibitive costs. This will be useless, however, if the present levels of radioactive backgrounds will not be reduced by as many orders of magnitude below the present status of the art. Only a limited fraction of these backgrounds can be reduced going at larger depths. To reduce the largest fraction of the background, a large investment in research and development will be necessary. We have to consider that, because of the increase of the thickness of the shielding structures, experimental halls having heights and diameters in the 20 m range will be required; and because of the limited number of producers of the key materials used in these experiments, their procurement in large amount could be difficult and exceedingly expansive. So innovation will be of paramount importance, and young scientists should be encouraged to think differently and to risk.

We do not know today which will be the successful approach. Consequently, premature choices should be avoided, as, for example, between liquid Xe and liquid Ar in Dark Matter, or between one or the other isotope in $\beta\beta$. On the other hand, duplications of the same, or almost so, technique should be avoided.

On the Megaton scale project, the LAGUNA design study should provide useful information on the possible sites, bringing elements of convergence to a common proposal. Input to the physics perspectives and feasibility of a large underground facility is expected from present experiments, like BOREXINO (liquid scintillator) and ICARUS-T600 (liquid argon) in Gran Sasso. Evidence for a non-vanishing mixing between the lightest and heaviest neutrinos from the oscillation experiments Double Chooz (France) and T2K (Japan) would boost our understanding of CP violation. The observation of different oscillation behaviour of accelerator-generated neutrinos and anti-neutrinos would have fundamental consequences for matter–antimatter asymmetry in the Universe.

These observations would impact plans for studying accelerator neutrinos with a Megaton detector and also motivated proposals for dedicated liquid argon detectors. It appears important to support the work towards a large infrastructure for proton decay and low energy neutrino astrophysics, and also accelerator neutrinos in long baseline experiments, in a worldwide context.

Finally, I think we have to favor the increasing interest for underground facilities from other scientific communities. It is certainly a benefit to widen the underground frontier and look to underground labs from a global multidisciplinary perspective.

I would like to warmly thank all the "underground" colleagues for providing much of the information reported here.

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