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Underground laboratories in Europe

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Abstract. The only clear evidence today for physics beyond the standard model comes from underground experiments and the future activity of underground laboratories appears challenging and rich. I review here the existing underground research facilities in Europe. I present briefly the main characteristics, scientific activity and perspectives of these Laboratories and discuss the present coordination actions in the framework of the European Union.

1. Introduction

Very high energy physics phenomena, such as proton decay and neutrinoless double beta decay, happen spontaneously, but at extremely low rates. The study of neutrino properties from natural and artificial sources and the detection of dark matter candidates requires 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 accelerators in the basic research of the elementary constituents of matter, of their interactions and symmetries.

It is remarkable that the only clear evidence today for physics beyond the standard model (SM) comes from underground experiments. 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 physics" issues: the problems of the solar and atmospheric neutrinos deficits, Majorana or Dirac neutrinos, baryogenesis, dark matter. These astroparticle physics issues can be faced by contemporary experimental physics and constitute a formidable motivation for the underground laboratories activity.

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, n) from U and Th in the rocks. As such, it depends on local geology, but 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 radon and its progeny, depends again on local geology and is practically depth independent.

Other sources of backgrounds, the ultimate contribution in some cases, include the detector materials, supports, shielding, electrical connections, etc. Cosmic rays may produce traces of radioactive nuclides 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. The process is called cosmogenesis.

The importance of the different background sources clearly depends on the experiment. For example the energy directly deposited by the muons in the detector is more relevant for $\beta\beta$ than for dark matter searches, while the neutron backgrounds and cosmogenesis are important for both; in any case a depth of 1000 m is enough. Even atmospheric neutrinos, interesting by themselves as they are, are a background; the principal one already at shallow depth, for proton decay experiments, which, as a consequence, need not to be too deep.

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

I review here briefly the existing underground research facilities in Europe. More complete information on underground laboratories can be found in the relevant WEB-sites[1]. Information on the experiments can be found in these proceedings.

2. The Gran Sasso National Laboratory

The INFN Laboratori Nazionali del Gran Sasso (LNGS) is located besides a freeway tunnel under the Apennines, in central Italy near the town of L'Aquila, 120 km from Rome.

The proposal to build a large, high technology, underground laboratory was advanced in 1979 by Antonino Zichichi, then President of INFN, and approved by the Italian Parliament in 1982. Since the original project the orientation of the three laboratory halls was towards CERN, in order to host detectors to study neutrino oscillations on a future beam produced at that laboratory. Civil engineering works, under the responsibility of ANAS, the Italian Road Department, started in autumn 1982 and were completed by 1987.

The horizontal access allows easy transportation and installation of large pieces of apparatus. The underground facilities consist of three experimental halls and a set of connecting tunnels and service areas, for a total surface area of 18000 m^2. The three halls are approximately 100x18x18 m^3. An almost angle-independent 1400m rock overburden provides a μ flux attenuation of 10^{-6}. The neutron flux is $= 3.7 \pm 0.3 \times 10^{-2} m^{-2} s^{-1}$.

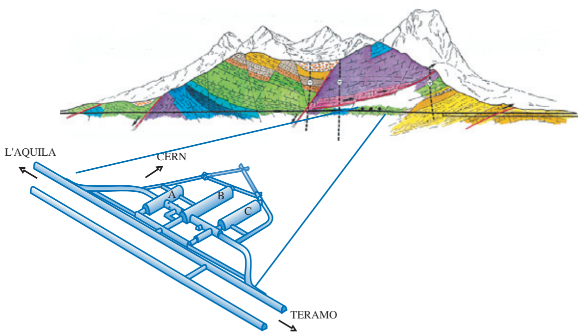

Figure 1. The underground facilities and the Gran Sasso massif geology.

The infrastructures of the laboratory are completed by a number of buildings on the surface, near the western entrance of the tunnel, hosting offices, laboratories, shops, library, canteen, etc. General services include the headquarters, the secretariats and user support offices, the administrative offices, the prevention, safety, security and environmental protection services, the general, electrical and safety plants services and, in direct support to the experiments, low activity techniques (including very low background facilities with Ge detectors underground), cryogenics, mechanics, chemistry, electronics, computing and networking. Last but not least, since many years now, the laboratory has an important activity in the outreach and in the diffusion of the scientific culture.

The permanent staff is composed by 67 persons. Presently, the user are 800 in number, from 25 different countries.

After a more than twelve-years operational life, several first generation experiments have been completed and decommissioned, like MACRO and Gallex-GNO and a programme for the second phase has been implemented.

Neutrino physics and dark matter are the principals, but not the only chapters of this programme. Experiments both with naturally produced neutrinos (from the Sun, from the atmosphere and from Supernova explosion) and artificially produced ones are being built or planned. On solar neutrinos, after the Gallex-GNO experiments, BOREXINO is in its final phase of realization, after a a slowing down due to the 2002 spill accident. The measurements of thermonuclear cross-sections at energies relevant for the stars and Sun combustion processes is continuing with the underground accelerator facility LUNA2. On Supernova neutrinos LVD is taking data with an on-time larger than 99.5%.

The CERN to Gran Sasso neutrino beam (CNGS project) is optimised for tau neutrino appearance in the longer period oscillation phenomenon. The main experiment is OPERA, based on emulsion techniques, which is in advanced installation phase. ICARUS, based on liquid argon TPC, is in the installation phase of the 600 tons module, with the goal of demonstrating the capability of this new technology for present and future particle physics. A budget is allocated for the construction of a further module of a few thousand tons, based on a technology scalable to larger volumes.

LNGS has hosted and will host the most sensitive experiments in $\beta\beta$ decay in each of two different isotopes, ^{76}Ge (H-M in the past, GERDA in perspective) and ^{130}Te (presently CUORICINO, the most sensitive running experiment, and in perspective CUORE).

In the search for dark matter, LIBRA is in data taking, continuing with a larger mass the seven years observation of DAMA. The DAMA annual modulation signal is a model independent signature for WIMPs in the Galaxy, a result that must be independently checked. Unfortunately, the results of the other experiments not looking for the modulation cannot be compared in a model independent way.

At Gran Sasso a set of other complementary approaches is being pursued with CRESST, and with the planned experiments WARP and XENON, based on cryogenic liquid techniques.

Finally it must be mentioned that a number of experiments in different disciplines, mainly geology and biology are profiting of the peculiar conditions of the laboratory.

3. Laboratorio Subterraneo de Canfranc

LSC has been created by Angel Morales, who defined and led the scientific programme and directed the laboratory. Angel passed away two years ago, and I would like to recall here its contribution in the creation of the Canfranc Laboratory, in the development of novel techniques in the exciting searches for dark matter and for double beta decays, and in the realization of a workshop, initially mainly dedicated to underground science, now evolved in the main conference in the field of astroparticle physics: TAUP.

The staff, of the Zaragoza University, has 7 positions, the users are 35. The underground facilities are located inside the Somport railway tunnel (closed to traffic) under the Pyrenees and consist of two laboratories called Lab1 and Lab 3. Lab1 is formed by two small rooms (18 m^3 each) excavated at both sides of the tunnel, plus two galleries for storage, of 70 m^2. Lab 3 is an especially excavated gallery (about 118 m^2, 4.5 m high), equipped with standard facilities with about 900 m rock overburden. Temporally, a mobile pre-fabricated hut of 20 m^2 (Lab 2) is placed on the railway tracks, and moved along the tunnel to operate at different overburden. Muon flux is 2.5×10^{-3} m^{-2} s^{-1}, that of neutrons a few $\times$ 10^{-2} m^{-2} s^{-1}.

In 2003 the Spanish Government approved a substantial enlargement of the laboratory and the construction of new facilities is now completed. They consist of a main hall of about 400 m^2 area (Lab4) at 800 m rock overburden and underground service areas for a total of 1000 m^2. Surface facilities with mechanical workshop, storage, offices, etc. is completing the infrastructure. The new facilities are expected to be operational at the end of 2005.

The scientific programme includes the search for cold dark matter, both with bolometric techniques (ROSEBUD) and with NaI scintillators (ANAIS), searching for annual modulation, and the search for $\beta\beta$ decay with IGEX-2β, one of the most sensitive experiment on ^{76}Ge. New experiments are under consideration.

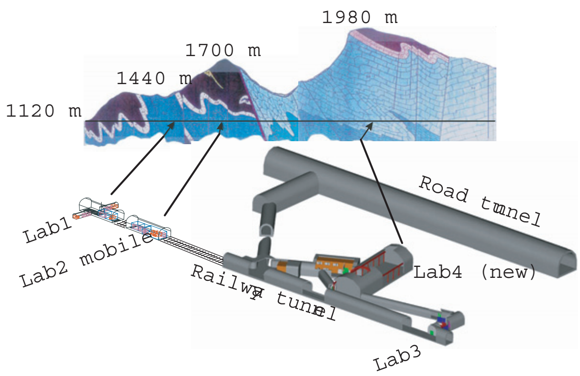

Figure 2. Artist view of the underground facilities of the Canfranc Laboratory

4. Laboratoire Souterrain de Modane

LSM is a French laboratory belonging to the IN2P3 (CNRS) and DSM(CEA) institutions, run with a staff of 4 people and with about 60 scientific users. It is located besides the Fréjus Tunnel on the highway connecting Lyon to Torino at about 6.5 km from both entrances. The underground facilities, under about 1750 m overburden, consist of one main hall about $30\times 10 \times 11$ m^3 and three secondary halls of 70 m^2, 18 m^2 and 21 m^2. The μ flux is attenuated by about 2 millions, the fast (1 MeV) neutron flux is of about 1.6×10^{-2} m^{-2} s^{-1}. The radon concentration is particularly low: of the order of 10 Bq m^{-3}.

The laboratory was created at the beginning of the 80's to house a large tracking calorimeter for a proton decay experiment and now hosts dark matter and $\beta\beta$ decay experiments. A low background underground facility with 13 Ge counters is available. The construction of a new external building with support infrastructures is in progress. On the longer run, a project for a megaton size water Cherenkov detector, MEMPHIS, is under study. Its science includes proton

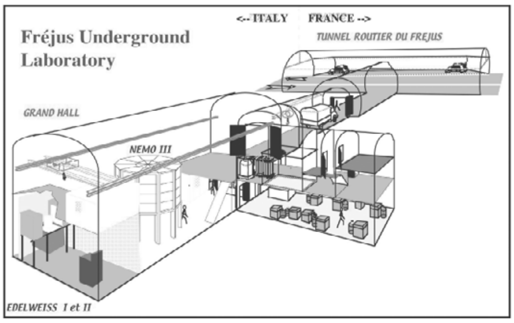

Figure 3. Artist view of the underground facilities of LSM

decay, Supernova and atmospheric neutrinos and neutrino oscillations on a low energy neutrino beam being studied at CERN.

The present scientific program comprises experiments on $2\nu\beta\beta$ and $0\nu\beta\beta$, NEMO III, a tracking calorimeter running with several sources, mainly ^{100}Mo (7 kg) and TGV on ^{48}Ca being upgraded to a mass of about 20 kg and dark matter searches with Ge bolometers: EDELWEISS I (about 1 kg mass), now finished, and EDELWEISS II (9 Kg) being installed this year.

5. Boulby mine underground facility

The facility was established in 1988, dedicated to the search for non-baryonic dark matter. It is operated and recently upgraded by the UK Dark Matter Collaboration. The mine is a working potash and rock salt mine located near Sheffield in northern England. This implies that the access to the underground research facilities must be scheduled to be compatible with the production of the mine but also that some services, as medical & safety support, and, security procedures are provided by the mine. The caverns of the facility are situated 1100 m underground causing an almost 10^6 reduction in cosmic ray muon flux. The neutron flux has not been measured as yet; a preliminary evaluation gives an estimate of about 2×10^{-2} m^{-2} s^{-1}. We may notice at this point that, even if the rock composition of the laboratories discussed so far is very different, the neutron fluxes are quite similar.

After the recent upgrade, the facility comprises now more than 1500 m^2 of clean laboratory space underground with workshop, storage space, computer facilities, etc. In addition a surface facility has been built, with 500 m^2 surface including lab & storage space, workshops, offices, computing facilities, conference room, kitchen & laundry facilities.

The scientific programme is focused on dark matter search. Three experiments are operational: ZEPLIN-I, a 3.1 kg liquid xenon target and DRIFT-1, a prototype direction-sensitive detector, a 1 m^3 low pressure gas negative ion drift TPC. Two-phase (liquid and gas) Xe detectors are under construction using scintillation and ionisation measurements for signal identification; larger drift chambers are being studied.

6. Coordination in Europe

Western Europe has four underground laboratories, one of which (Gran Sasso) is much larger, internationally used, with dedicated service structures and support personnel. The three smaller laboratories, born as University or national laboratories are evolving toward facilities capable

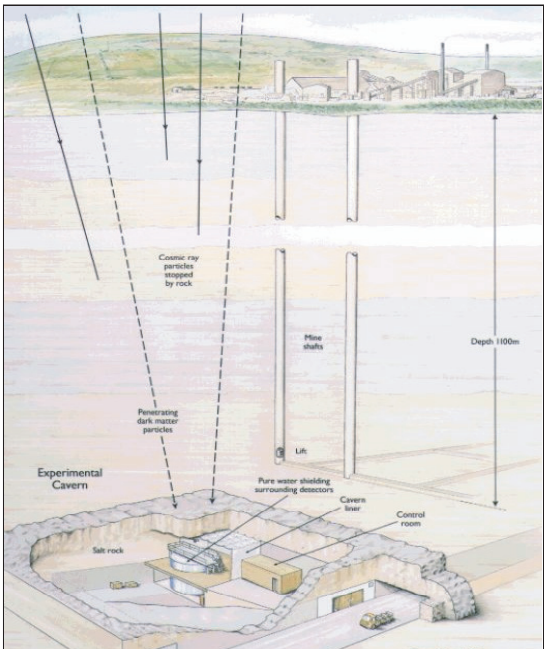

Figure 4. Schematic layout of the Boulby Laboratory

to provide more space for experiments and support to the users. Under these circumstances the directors of the main laboratories initiated consultations on possible actions to co-ordinate activities and to optimise the use of the available resources, taking into account the different characteristics of the infrastructures.

A first concrete action had been done by LNGS, which has been recognized by the European Union (EU) as an European Large Scale Facility. A contract between EU and INFN, started in December 2002, funds access to LNGS for (new) European users. Recently EU is taking more responsibilities in basic research, a sector that had been previously left to the member states, with the declared aim of the Commission to build a "common European research area". This new policy has been fully embedded in the 6^{th} "framework programme" started in 2003. In this framework, the ILIAS project was submitted to EU by ApPEC, the European inter-agency committee for astroparticle physics. The EU approved the project in the parts of underground science, gravitational waves and theory.

ILIAS contains several elements: the co-ordination of a number of activities of the laboratories (such as environmental background measurement and control, safety procedures, outreach activities, etc.), the funding for access of new users and common R&D in $\beta\beta$, dark matter and gravitational waves search. Clearly, in both fields the world leadership is European: in $\beta\beta$ with the three most sensitive experiments (H-M, CUORICINO and NEMO3) and with leading next generation proposals (GERDA and CUORE); in dark matter with, again, the most sensitive experiments LIBRA, ANAIS, EDELWEISS, ZEPELIN, CRESST and with the previously mentioned future projects WARP and XENON. But it is also clear that a co-ordination of the efforts is necessary. In both cases detectors will evolve toward much larger masses, experimental setups and analysis tools will become much more complex, the experimental collaborations, used to work as rather small groups, will evolve toward larger organisations. ILIAS is a good opportunity to foster the necessary convergence.

7. Baksan Neutrino Observatory

In 1963 the President of the of Academy of Sciences of the USSR Mstislav Keldysh requested to the Central Committee of the Communist Party the construction of an underground facility for neutrino physics and astrophysics. In 1966 the Government issued a decree for the construction of the underground and surface facilities. George Zatsepin and Alexander Chudakov led the construction of the laboratory and of its scientific programme, which included a wide spectrum of aspects of cosmic rays and particle physics ranging from atmospheric to solar, to Supernova neutrinos. BNO is located in Baksan Valley of Northern Caucasus mountains, in southern Russia. Experiments are situated at different distances from the entrance, in low background chambers, along two horizontal entrances excavated under Mount Andyrchi.

The solar neutrino telescope, SAGE, is in the deepest location, with about 1800 m overburden (μ flux is 3×10^{-5} m^{-2}). Closer to the entrance is the Underground Scintillation Telescope (BUST) for cosmic ray physics and supernova neutrinos, operational since 1977. An air shower experiment, CARPET, is located on the surface and has an uninterrupted area of 200 m^2.

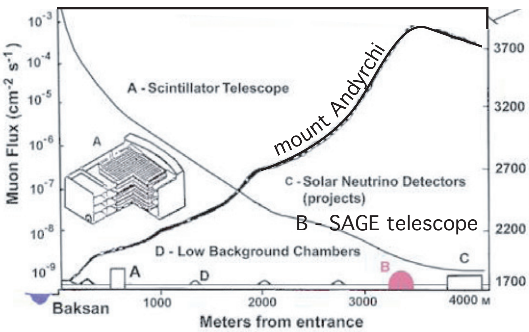

Figure 5. Schematic view of the Baksan observatory

The Neutrino village, close by, with about 500 staff, hosts the administration, the conference room, the technical and engineering services, electronic and chemical laboratories. The scientific users are about 70.

8. Other laboratories in Europe

CUPP is a new facility being developed in Finland in the working Pyhasalmi mine. Underground spaces are available at different depths, down to about 1000 m, which can be reached both by road - with lorries - and, faster, by lift.

Deeper halls will be excavated down to more than 1400 m. The development of a laboratory on the site has the strong support of the regional and national governments.

Two small laboratories exist in Ukraine, both in salt mines (low U and Th radioactivity); both are rather shallow. The first, the Slovotvina Underground Laboratory (SUL) of the INR of Kiev, is operational since 1984, 430 m deep and is dedicated to rare decays (β and $\beta\beta$, particularly on ^{116}Cd). The second, Arteomovsk, is a scientific station of the Russian INR 200 m deep. It contains a Supernova neutrino scintillator detector of 130 m^3.

9. Conclusions

The perspectives for underground physics in the next 5-10 years is brilliant. The principal challenges are the following:

- Determine neutrinos absolute masses and nature (Majorana vs. Dirac), searching for $0\nu\beta\beta$ decay. Ton to multi-ton scale detectors and drastic background reduction are needed, but not very large depths.

- Dark matter search. Requires ton-scale detectors with reduced background and good stability to be sensitive to the annual modulation signatures.

- Measuring or limiting $|\theta_{13}|^2$. Requires a very intense ν_μ beam at low, but not too low, energy (of the order of 1 GeV) and a very massive Cherenkov detector or liquid argon TPC. May be at shallow depth. This step is necessary before seriously launching a project for a neutrino factory.

- Solar Be and pp neutrino fluxes should be measured with flavour sensitivity and high (few percent) precision. Weak Interactions may be still richer than what we know today (remember lessons of J. Bahcall and of neutrino oscillations). Overburden is between 1000 and 2000 m depending on the experiment.

- p-decay. A defined project might be close. Needs Megaton scale Cherenkov detector or tens of kiloton liquid argon TPC. May be at shallow depth.

References

[1] Information on the European underground laboratories can be found on:
- www.lngs.infn.it
- www-lsm.in2p3.fr
- www.unizar.es/lfnae/lfnae_eng.html
- www.ppd.clrc.ac.uk
- cupp.oulu.fi/
- www.inr.ac.ru/INR/Baksan.html