Underground Laboratories

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Underground Laboratories are the main infrastructures for astroparticle and neutrino physics. Searches for rare events like $2\beta0\nu$ or proton decay, study of weak interactions from cosmic or artificial neutrinos, detection of dark matter candidates and nuclear astrophysics studies require low-background environments that can only be achieved in a shielded underground environment. Thanks to the reduction in the cosmic ray flux and c.r.-spallation induced neutrons, the rock coverage provides the necessary low background environment to investigate these processes. The most important underground laboratories all over the world together with their future projects will be reviewed.

1 Introduction

Going back over the scientific path of these last 30 years, it's worth mentioning the impressive growth of astroparticle physics, a research field which connects elementary particle physics, astrophysics and cosmology. The community of researchers involved has considerably grown and dimensions, complexity and technology of the experimental apparata have increased as well. Underground laboratories are the main infrastructures devoted to astroparticle physics; underground experiments have produced the first clear evidence of physics beyond the standard model (SM), the discovery on the flavor lepton changing by using neutrino natural sources. Neutrinoless $\beta\beta$ decay, direct detection of dark matter particles, proton decay are all weak and rare processes that require very impressive efforts to be observed. Underground laboratories with low radioactive background environments are the ideal places where experiments aiming to discover such processes can be performed.

2 Backgrounds for underground Physics

The challenge towards greater sensitivities in underground experiments turns into a continuous fight against radioactive background. The depth of the laboratory and the nature of the rocks around specifically characterize each facility. Background main sources are:

- Flux of high-energy muons induced by cosmic rays interactions decreases as depth increases while the angular dependence is due to the surface profile.
- At low energies, neutrons are generated by α particles and fission processes of Uranium and Thorium in the rocks: this contribution depends on the site but it is independent on depth.

- At higher energies, neutrons (energy up to GeV) are generated by muon spallation processes: this contribution is related to the site depth.
- Radioactive radon concentration in the air depends on local geology, but increases in closed halls. This can only be tuned by proper ventilation.
- Cosmogenic processes may produce radioactive nuclides.
- Concrete around the detector, supports, shielding, electrical connections, etc. contribute to the radioactive background.

3 Overview of underground laboratories

All the main sites available for astroparticle physics are reported in figure 1: Features of some of the main underground laboratories and facilities will be now taken into account.

Figure 1: Worldwide map of underground physics laboratories.

3.1 European facilities

- The INFN Gran Sasso National Laboratory (LNGS) is the largest underground laboratory and it is a worldwide facility for scientists - presently over 900 from 30 different Countries - working in one of the fifteen experiments currently in operation. LNGS (see figure 2) is near the town of L'Aquila and at about 120 kilometres from Rome. The underground facilities are located on one side of the ten-kilometre long highway tunnel crossing the Gran Sasso massif. They consist of three large experimental halls, each about 100 m long, 20 m wide and 18 m high and linked by service tunnels, for a total volume of about 180000 m^3. The average 1400 m rock coverage (3400 m.w.e.) gives a reduction factor of one million in the cosmic ray flux; moreover, the neutron flux is thousand times less than the one on the surface. LNGS scientific program is quite rich and includes: CNGS Project (CERN neutrinos to Gran Sasso) for OPERA and ICARUS experiments; dark matter search (DAMA-LIBRA, CRESST2, XENON, WARP); neutrinoless double beta decay (COBRA, CUORE, GERDA); neutrinos from Sun and geoneutrinos (BOREXINO);

neutrinos from galactic Supernova explosion (LVD); nuclear astrophysics (LUNA2). A special facility is dedicated to low radioactivity measurements.

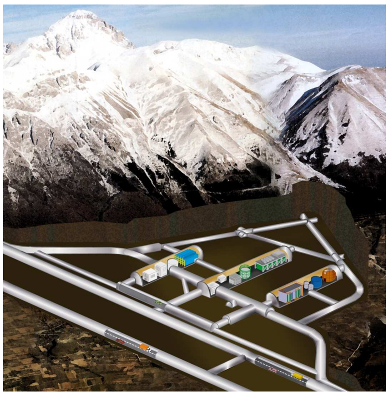

Figure 2: Sketch of the internal site of the Gran Sasso National Laboratory in Italy.

- Laboratoire Subterrain de Modane in France is running since 1982. The available volume for the experimental apparata is about 5000 m^3 while the rock overburden is 1700 m (4800 m.w.e.). The Laboratory houses two main detectors: NEMO3 (neutrinoless double beta decay) and EDELWEISS (dark matter), plus a low radioactivity counting facility. A huge expansion of the lab of 60000 m^3 is planned ('Ulisse project'), profiting of the construction of a new tunnel approved by French and Italian Governments.
- Underground structures of the Laboratorio Subterráneo de Canfranc were completed in 2005 though, due to several design and construction defects, repairs were needed. Surface infrastructures are under construction and the Lab will be completed by the end of this year. Its entrance is horizontal via one of the tunnels and access must be notified to the freeway tunnel control. The available volume for underground physics is about 9000 m^3, while maximum rock coverage is 850 m (2500 m.w.e.). The scientific plan for astroparticle physics includes experiments on dark matter (ANAIS and ROSEBUD) and on neutrinoless double beta decay (NEXT and BiPo, ancillary to superNEMO).
- The Boulby Palmer Laboratory is located in United Kingdom inside a potash mine 1100 m (2800 m.w.e.) deep under a flat surface. The salt environment limits the cavities width to about 5 m. The area for experiments is about 7000 m^3. The scientific program is focused on dark matter search: ZEPLIN III now running and DRIFT II in $R\&D$ phase. There are low radioactivity measurements and geophysics research. There is an excellent potential for expansion but the future is uncertain.

3.2 Asian facilities

- The Kamioka Observatory is located inside the Kamioka mine in Japan at a depth of about 1000 m (2700 m.w.e.). It was established in 1983 in order to host the Kamiokande experiment; the present observatory which belongs to the Institute for Cosmic Ray Research (ICRR) was established in 1995 after the completion of the excavation for the Super-Kamiokande project, the largest underground experiment presently devoted to T2K. The present facility also contains KamLand and the XMASS experiment devoted to dark matter detection by using a single-phase liquid xenon detector. The research activities include neutrinoless $\beta\beta$ decay (Candles) and gravitational waves search (CLIO). To face the request from experimental collaborations for more space, the underground laboratory will be further extended.

- The Yangyang Underground Laboratory (Y2L) in Korea hosts KIMS experiment, and the China JingPing Laboratory (CJPL) in China hosts CDEX experiment; both Labs are planning expansions of their experimental area.

3.3 North America Laboratory

- The Canadian underground laboratory Snolab, located two kilometres below the surface in the Vale Inco Creighton Mine (near Sudbury), is an expansion of the facility constructed for the SNO solar neutrino experiment. Excavation and installation of the basic infrastructures of the new experimental halls and the outfitting in Phase I areas are complete. The experimental programme includes solar neutrinos, dark matter searches, neutrinoless $\beta\beta$ decay and the detection of neutrinos from Supernova. The SNO+ experiment will use the SNO detector filled with liquid scintillator; DEAP-I and PICASSO are currently operational and devoted to dark matter searches.
- Soudan Underground Laboratory (SUL) is located in the Soudan underground mine State Park and it is run by University of Minnesota. There are two major experiments, MINOS on the NUMI long baseline neutrino beam and CDMS devoted to dark matter searches.
- The proposed Deep Underground Science (physics, biology, and geology) and Engineering Laboratory (DUSEL) should be realized inside the Homestake mine in South Dakota. Due to the rich scientific program, Laboratory spaces will be built separately for biology, geology and physics. The two experimental sites for physics will be about 1450 m (3300 m.w.e.) and 2200 m (5000 m.w.e.) deep (see figure 3).

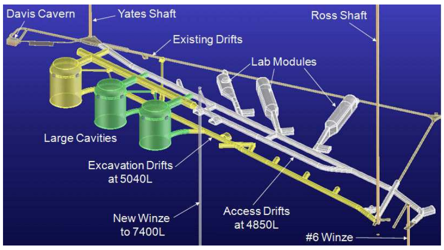

Figure 3: Layout of DUSEL in South Dakota (US).

4 Conclusion

Underground physics has therefore a glorious past but also a very bright future ahead. It will continue to significantly contribute to discovering fundamental laws that rule Nature and at the same time to unveil the mystery of the constituents of the Universe and its evolution.