LABORATORI NAZIONALI DEL GRAN SASSO AND THE ILIAS[†] INITIATIVE

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Laboratori Nazionali del Gran Sasso (LNGS) is actually the largest deep underground laboratory in the world completely devoted to fundamental science. In this talk I give a review of the main characteristics of the infrascructure and of the past and ongoing scientific activities. LNGS is taking part in the EU initiative ILIAS (Integrated Large Infrastructures for Astroparticle Physics). Within ILIAS LNGS is collaborating with the other three european deep underground sites: Laboratoire Soterrain de Modane (France), Laboratorio Subterraneo de Canfranc (Spain), and Boulby Mine Underground Laboratory (UK).

1. The Laboratori Nazionali del Gran Sasso (LNGS)

1.1. *The infrastructure*

Laboratori Nazionali del Gran Sasso are located in the Gran Sasso highway tunnel connecting L'Aquila to Teramo, in central Italy, at about 120 km from Roma. The laboratory is operated by Istituto Nazionale di Fisica Nucleare (INFN).

The underground area includes 3 main halls (called A, B, and C) with dimensions of about 100 m x 20m x 15 m, and a number of service tunnels, for a total volume of about 180000 m^3 and a total surface exceeding 6000 m^2. A sketch of the underground area is shown in Figure 1. The escavation of the underground lab started in 1982 and was completed in 1987.

The lab is located on the vertical of Monte L'Aquila (2600 meters high), and has an average rock coverage of 1400 meters. The muon flux is reduced by a factor 10^6 with respect to the surface; the neutron flux is also reduced by a factor

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1000, thanks to the low content of U and Th in the dolomite rocks of the mountain.

Outside facilities are located near the village of Assergi (on the L'Aquila side of the tunnel) at a height of about 1000 m. They include offices for the lab staff and for host researchers and technicians, mechanical workshop, chemical laboratory, electronic workshop, computing center, library, canteen, conference rooms, large assembly rooms, and the administration department. A view of the external facilities is shown in Figure 2.

The permanent staff of the laboratory is composed by 60 people (physicists, technicians, engineers, and administration staff). The scientists involved in LNGS experiments includes more than 700 researchers from 24 countries.

The laboratory structure is organized into Divisions and Services including research division, technical and general services division, directorate, administration, public affairs, prevention and protection service. Two separate bodies, the Laboratory Council and the Scientific Committee, assist the director in the guidance of the laboratory.

The geographical location (inside the Gran Sasso-Monti della Laga National Park) and the special operating conditions (near the highway tunnel and in proximity to water basins) requires special attention to safety and environmental aspects.

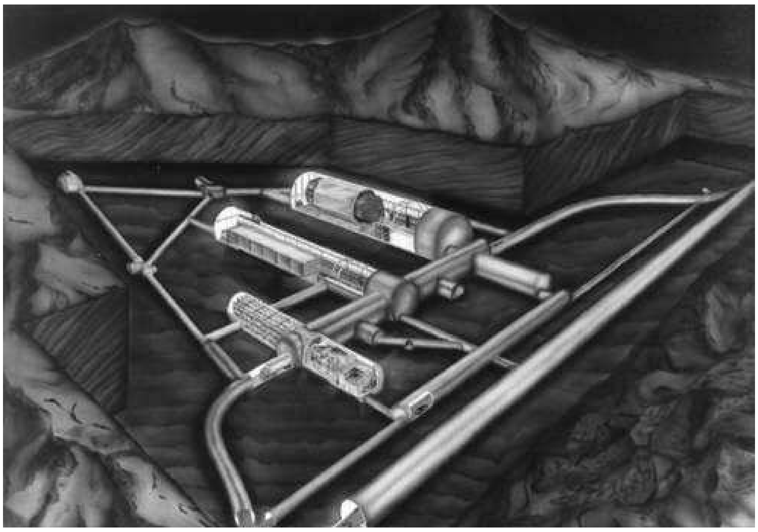

Figure 1. Sketch of the LNGS underground area. The three Halls (A, B and C) are linked by several interconnecting tunnels and directly accessible from the highway connecting Teramo to L'Aquila.

Figure 2. The LNGS outside facilities.

1.2. *The scientific programme*

The experimental activities ongoing at LNGS include all major research topics in the field of underground science. We give here a short review of each sector. For a complete review and bibliography of the experiments described in this section see [1] [2] and the references quoted therein.

1. ***Neutrino astrophysics***: thanks to the large areas available underground, LNGS is an ideal infrastructure for large experiments designed for the detection of astrophysical neutrinos. Many experiments have been and are being carried out for the study of neutrinos from the sun, from supernovae, and from the atmosphere.
   The Gallex/GNO experiment has been measuring low energy solar neutrinos with a radiochemical technique using a 30 t gallium target. The experiment was successfully taking data between 1991 and 2003, and detected for the first time the low energy “pp neutrinos”; moreover it gave evidence at the beginning of 90s for neutrino oscillations, and was monitoring the low energy solar neutrino flux for a complete solar cycle.
   After the success of GNO, the solar neutrino observations at LNGS are expected to continue in the next future with the Borexino detector, made of 300 tons of ultrapure liquid scintillator (+ 1000 tons of buffer). The scintillator is contained in a stainless steel sphere surrounded by water; the

detection of solar neutrino interactions via elestic scattering off electrons, requires ultra-low level radiupurity in all the components of the apparatus. The aim of Borexino is to study in real-time the ^{7}Be component of the solar neutrino flux. Borexino is now ready for filling after a partial stop of the activities due to an accident occurred in august 2002. Besides solar neutrinos, Borexino will also be able to detect supernova ν, geophysics ν, and to test ν magnetic moment.

The MACRO experiment was taking data on atmospheric neutrinos between 1991 and 2001 with a massive detector made of streamer tubes and liquid scintillator modules. The results after 10 years of successful data taking supported a strong evidence for neutrino flavour oscillations, in agreement with the japanese experiment of Superkamiokande. Other results by MARCRO are a complete and precise characterization of the muon energy spectrum and angular distribution underground, and the best upper limit in the world on magnetic monopole parameters.

The LVD detector, made of 1000 tons of liquid scintillator in 840 counters is looking for neutrinos and antineutrinos from a galactic supernova. The detector is continuously taking data since 1992 with a very high duty cycle waiting for the next galactic supernova to explode.

2. ***Long baseline neutrino detection***: the CNGS project has the aim to study the neutrino oscillation parameters with a neutrino beam produced at CERN and shot to LNGS. Two experiments will detect at LNGS neutrinos produced at CERN after travelling a 720 km distance.

   OPERA is a 1.8 kton detector made of Pb sheets and nuclear emulsions in the form of 230000 emulsion cloud chambers, and two big magnetic spectrometers (RPC and scintillating fibers). The main goal of OPERA is to detect for the first time in the world the appearance of tau neutrinos from a muon neutrino beam. The emulsion chamber technique will allow identification of the tau emitted by ν interactions with an almost zero background. The experiment is under construction: the magnetic spectrometers are expected to be completed in 2005 and data taking should start in 2007.

   ICARUS is a 3 kton detector based on the use of liquid argon as a large time projection chamber. The first 600 ton module of ICARUS was built and tested above ground, and is going to be transported to LNGS before the end of 2004. Installation of the complete 3 ktons requires major works in the underground infrastructure, so it is still not clear if the complete detector will be ready for the neutrino beam commissioning in 2007. In any case ICARUS is a general-purpose innovative detector with a broad programme not limited to the CNGS project.

3. *ββ-decay search*. At LNGS a lot of efforts are ongoing on this issue, crucial for the determination of the absolute neutrino mass. Different and complementary techniques are being employed.
   The ββ Heidelberg-Moscow experiment operated 11 kg of enriched ^{76}Ge crystals in the form of HP-Ge detectors at liquid nitrogen temperature. Data taking was going on regularly in the period 1993-2003; this experiment is presently the most sensitive in the world in the ββ decay sector. Evidence for a possible ββ decay signal is claimed, corresponding to a neutrino mass in the range 0.1-0.9 eV. This evidence calls for furher confirmation possibly using different isotopes.
   Cuoricino (upgrade of the Mibeta experiment) has recently started to operate 40.7 kg of TeO_2 crystals as thermal detectors at the temperature of a few millikelvin. Cuoricino is expected to reach a sensitivity of the order of 0.3 eV on the neutrino mass after 3 years of data taking. In a few years Cuoricino will be upgraded to Cuore: the TeO_2 mass will be increased to 750 kg and the expected sensitivity on the neutrino mass will go down to about 30 meV.
   The aim of the recently approved GERDA experiment is to build a setup of HP-Ge detectors enriched in ^{76}Ge with a total mass of about 20 kg and improved background reduction.
4. *Dark matter search*; due to the extreme importance of this subject for cosmology and particle physics, many experiments are ongoing at LNGS looking for WIMPs dark matter candidates. Detailed reports from all the experiments have been presented at this conference.
   Dama/NaI was operating a 100 kg detector of ulta pure NaI crystals with the aim to detect the scintillation light produced by elastic scattering of WIMPs. The experiment was taking data between 1995 and 2002 with increasing sensitivity. Data from 7 annual cycles show a modulation compatible with WIMPs interactions. The DAMA/NaI setup was recently upgraded to 250 kg of sensitive mass, and the new detector (LIBRA) started data taking in 2003.
   CRESST is operating a thermal detector made of $CaWO_2$ crystals at low temperature. The readout of both the thermal and scintillation signals produced by particle interactions in the crystals allows a powerful discrimination of WIMPs signals against background.
   WARP is an argon double phase (liquid+gas) detector planned for installation at LNGS in the next years. Particles interacting in the liquid Ar phase give a double signal, the first from the primary scintillation light, and the second from scintillation in the gas originated by multiplication of ionization electrons drifted and extracted into the gas phase by an electric field. A 2.3 liters prototype is being successfully operated; the installation of the 100 liters detector will start in 2005.

The Cuore and GERDA experiments, mainly designed for $\beta\beta$ decay search, will also be potentially sensitive to dark matter. Special investigations have been carried out to study the sensitivity of Ge detectors to dark matter search by the heidelberg-Moscow collaboration with the HDMS and GENIUS-TF experiments.

5. *Nuclear astrophysics*. LNGS hosts one of the best facilities in the world for the study of nuclear reactions relevant for astrophysics. The facility consists of two electrostatic accelerators (50 kV and 400 kV) operated by the LUNA collaboraton. In almost 10 years of measurements, LUNA obtained very important results from precise measurements of the cross sections of the reactions $^{3}He(^{3}He,2p)^{4}He$ (relevant for the pp chain inside the stars), $d(p,\gamma)^{3}He$ (relevant for the pp chain and reaction rates in proto-stars), $^{14}N(p,\gamma)^{15}O$ (the slowest reaction of the CNO cycle in the stars). The location of the accelerator and detectors underground in absence of backgrounds from cosmic rays makes possible to measure the extremely low cross sections at stellar energies.
6. *Geophysics, biology and environmental sciences*. The low background environment inside the Gran Sasso laboratory and its location on a particularly active seismic area, is ideal for a number of interesting research projects in the fields of geophysics and environmental sciences.
   Operating in the field of geophysics, GIGS is a laser interferometer for geophysical purposes operating inside the LNGS area since 1994 and monitoring the microseismic movements of the Gran Sasso fault. The TELLUS project is designed to carry out a continuous tilt monitoring to detect aseismic creep strain episodes associated with earthquakes preparation. UNDERSEIS is an underground seismic array aimed to monitor seismic radiation with vey high sensitivity by short period seismometers.
   In the field of environmental sciences several activities are ongoing at the LNGS low background facilities. For example ERMES is a project for the monitoring of radioisotopes in the seabed and seawater: extremely low levels of radioactivity in selected samples can be measured in the LNGS facilities by HP-Ge and liquid scintillation detectors.
   In the field of biology PULEX is an ongoing experiment whose aim is to investigate the effects of background radiation on the methabolism of cells.

2. ILIAS (Integrated Large Infrastructures for Astroparticle Physics)

2.1. *What is ILIAS*

ILIAS [3] is an Integrated Infrastructure Initiative funded by European Union within the 6^{th} framework Programme. It is based on the cooperation of many EU institutions operating in the sector of Astroparticle Physics. ILIAS was proposed under the coordination and review of APPEC (AstroParticle Physics European Coordination).

The ILIAS project is based on three groups of activities: Networking, Transnational Access, and Joint research activities.

- Networking activities have the objective to favour the contacts and collaborations among researchers working on the same fields in different EU countries. Five different networks are active in ILIAS: deep underground science laboratories, direct dark matter detection, search on double beta decay, gravitational wave research, and theoretical astroparticle physics.
- Transnational access activities have the aim to support the access of research teams to the major EU research infrastructures in the field of astroparticle physics to carry out research activities. The support includes travels and subsistence, and technical support on site. Within ILIAS a coordinated transnational access to the four EU deep underground sites is active.
- Joint research activities (JRA): the objective of these activities is to carry out joint R&D projects among different EU instutution working on common subjects in astroparticle physics and underground sciences. Three JRA are active within ILIAS: Low background techniques for deep undergroun science, double beta decay european observatory, and study of thermal noise reduction in gravitational wave detectors.

2.2. *ILIAS and the EU Deep Underground Laboratories*

Four deep Underground Laboratories in Europe are hosting important experiments on underground sciences: Laboratori Nazionali del Gran Sasso (LNGS, Italy), Laboratoire Souterrain de Modane (LSM, France), Laboratorio Subterraneo de Canfranc (LSC, Spain), and Boulby Mine Underground Lab (UK). The LNGS infrastructure and scientific programme was discussed in the previous section; a similar discussion for LSM, LSC, and Boulby is given with specific talks at this conference.

The four labs are major infrastructures where important experiments on fundamental rare-event and astroparticle physics are underway. ILIAS is offering for the first time the opportunity to start an effective collaboration among the labs.

The underground labs are deeply involved in three activities of ILIAS:

The network of the Deep Underground Laboratories is aimed to support the management of common issues relevant in the operation of the underground sites, such as communication and coordination, service and facilities improvement, extension of underground sites, safety problems and accident prevention, communication and outreach, scientific coordination.

Transnational Access to the underground laboratories gives the opportunity to EU researchers to access the underground sites outside their home country in order to carry out experiments, with priority given to new users and less favoured countries.

The Joint Research Activity on low background techniques gives the opportunity to strengthen and enlarge the low background facilities in the underground labs with a common R&D, and to share the know-how.

References

1. "LNGS Annual report 2003", LNGS Internal report LNGS-EXP/01-04 available online at http://www.lngs.infn.it.
2. A. Bettini et al., ""The Gran Sasso Laboratory 1979-1999" edited by R. Antolini, ISBN 88-86409-20-6.
3. For a complete description of the ILIAS initiative see the web page http://ilias.in2p3.fr