N2 – Network of the EU Deep Underground Laboratories

WP1 – Performance, Improvement, and possible extesions of the underground labs

Status report for 2004 of LNGS infrastructure, logistics and scientific activities

Draft Version 1 (25-nov-04)

A. Features of the lab

A.1 Location, context, short history

Laboratori Nazionali del Gran Sasso is an underground laboratory located below the Gran Sasso massive in Abruzzo (central Italy) at about 120 km from Roma (see map in figure 1). The lab was conceived in 1979 by A. Zichichi, and escavated at the end of the 80s besides the highway tunnel L'Aquila-Teramo which goes through the Gran Sasso massive for a lenght of 10 km. The latitude and longitude of the underground area are respectively 42° 27' E and 13° 34' N. The lab is located on the vertical of Monte L'Aquila (2370 meters high), and has an average rock coverage of 1400 meters.
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 180000 m^3 and a total surface exceeding 6000 m^2. A sketch of the underground area is shown in Figure 2.
The escavation of the underground lab started in 1982, and the logistic of the underground area was completed in 1987.
The lab is operated by INFN (Istituto Nazionale di Fisica Nucleare) and hosts many experiments in the field of astroparticle physics, and underground sciences.
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 Figures 3 and 4.
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.

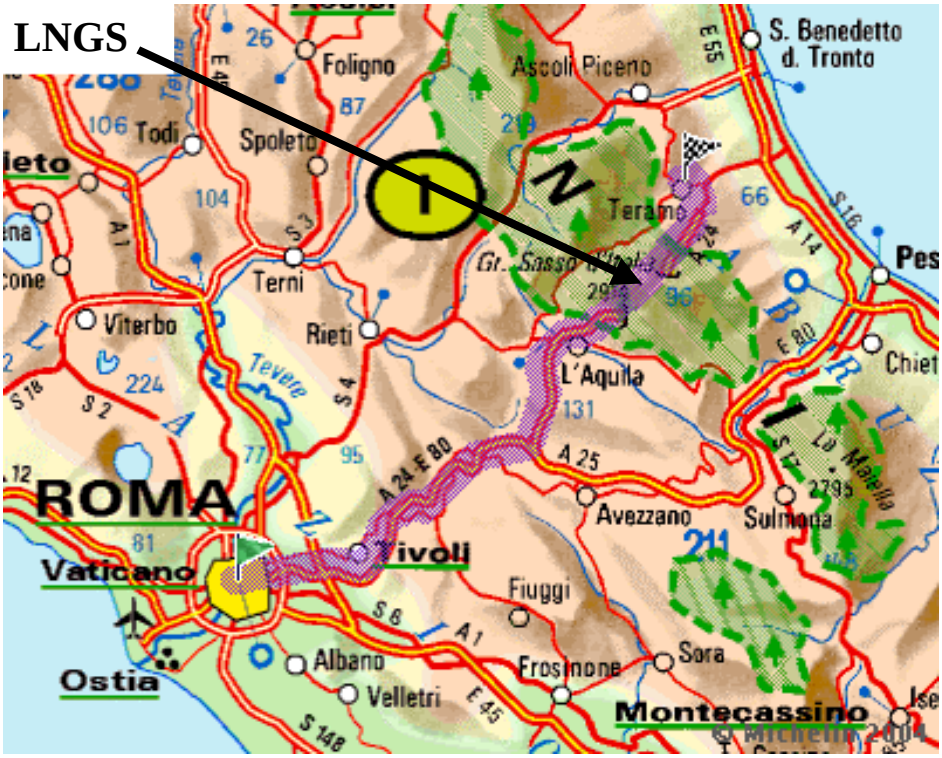

Fig. 1: Map of the location of LNGS

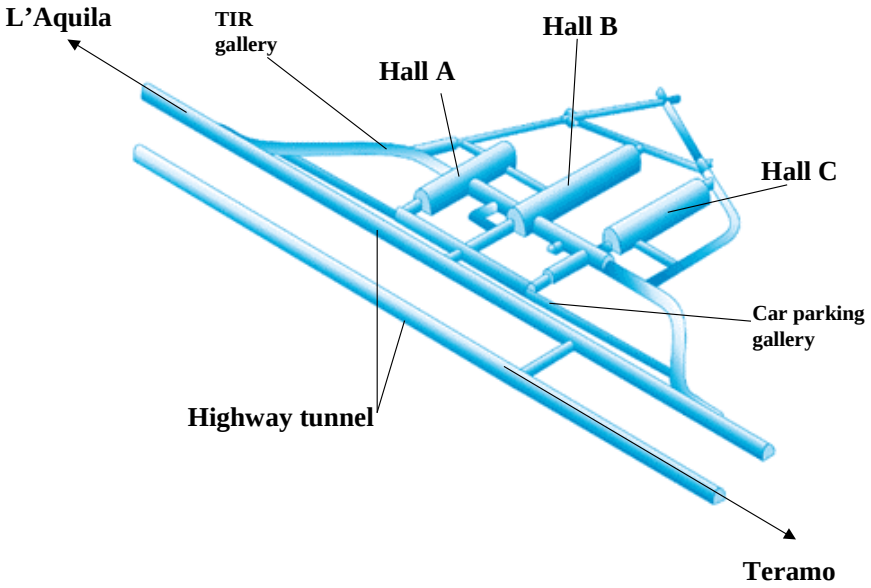

Figure 2: Sketch of the LNGS underground area

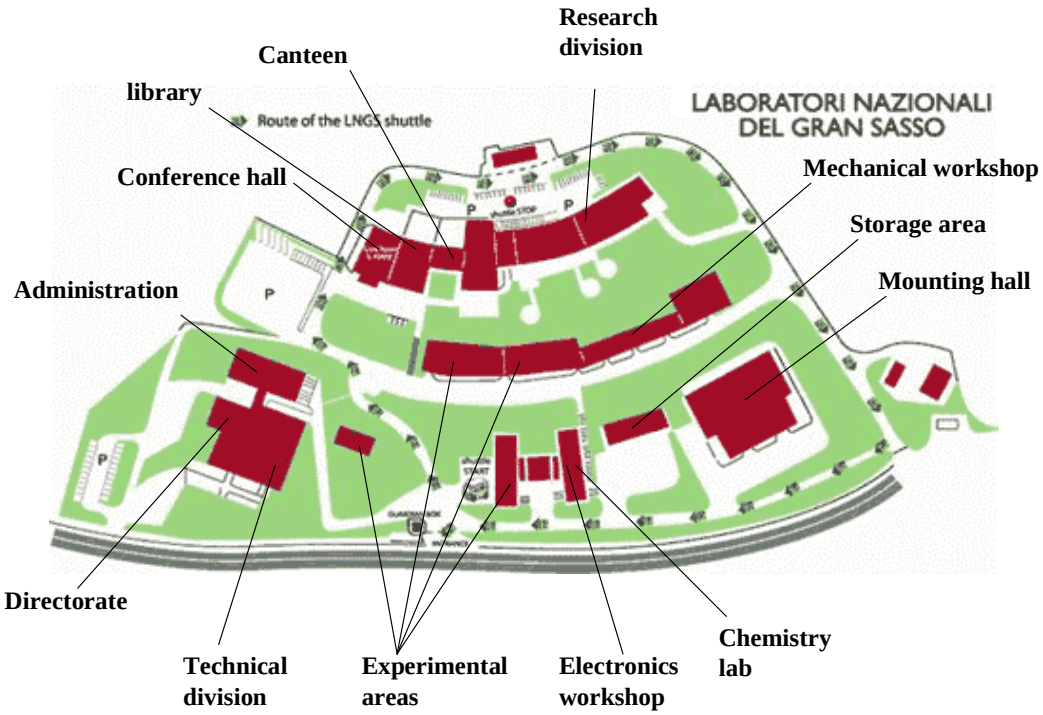

Figure 3: Sketch of the LNGS outside facilities

Figure 4: Pictures of the LNGS outside buildings

A.2 *Residual muon flux*

The total muon flux in the undergground area is 1 $h^{-1}m^{-2}$, with a reduction factor 10^6 with respect to the surface. The angular distribution of the muon flux was precisely measured by the MACRO experiment (see Figures 5). A correlation of the muon flux with the seasonal temperature variations of the atmosphere was observed [Amb97].

A.3 Rock composition, and environmental radioactivity :

The structure of the rock overburden surrounding the Gran Sasso underground laboratory is quite irregular; it is essentially calcareous, mixed with other materials, such as aluminium, silicon, magnesium and organic compounds. The rock in proximity of the underground lab has an average density of 2.7 g/cm^3, and consists mainly of $CaCO_3$ and $MgCO_3$: its elemental composition of the is reported in Table 1. The chemical composition of the concrete has been recently reanalized [Wul04], and is reported in table 1. The radioactivity of the LNGS rock and concrete is reported in Table 2 [Cat86]. The remarkably higher radioactivity level of the rock in Hall A is due to the particular type of rock surrounding this area.
The neutron flux is reduced by a factor 1000 with respect to the surface, thanks to the low content of U and Th in the dolomite rocks of the mountain. Measurement performed up to now giving information in different energy ranges are reported in Table 3.
Typical Rn levels inside the underground laboratory are 50-100 Bq/m^3. In a few areas of secondary tunnels where ventilation is not effective, Rn concentration can reach values of the order of 1000 Bq/m^3. Rn level in the air is constantly monitored in several location in the underground lab.

	H	C	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Fe
Rock	-	11.88	47.91	-	5.58	1.03	1.27	-	-	1.03	30.29	-	-
Concrete	0.89	7.99	48.4	0.60	0.85	0.90	3.86	0.04	0.16	0.54	34.06	0.04	0.43

Table1: Percent elemental composition of the rock and concrete in the LNGS underground lab

	^{238}U (ppm)	^{232}Th (ppm)	^{40}K (ppm)
Rock Hall A	6.80	2.167	
Rock Hall B	0.42	0.062	
Rock Hall C	0.66	0.066	
Concrete	1.05	0.656	

Table2: Radioactivity levels of the LNGS rock and concrete[Cat86]

Energy range	Ref. [Bel89]	Ref. [Arn99]	
0-0.05 eV	1.08 +- 0.02		
0.05 eV – 1 keV	1.98 +- 0.05		
1 keV – 1 MeV	0.54 +- 0.01		
1 MeV – 2.5 MeV		0.14 +- 0.12	
2.5 MeV – 5 MeV	0.27 +- 0.14	0.13 +- 0.04	
5 – 10 MeV	0.05 +- 0.01	0.15 +- 0.04	
>10 MeV	0.0006 +- 0.0002	0.0004 +- 0.0004	

Table3: Neutron flux measurements at LNGS. Units are 10^{-6} cm^{-2} s^{-1}

A.4 *Technical characteristics of the underground infrastructure*

Entrance to the underground lab is from the Teramo side of the highway; access from the L'Aquila side (where outside facilities are located) is possible through a special bypass linking the two directions of the highway at the exit of the tunnel on the Teramo side. A shuttle service running every 20 minutes from 8:15 am to 19:30 pm to the undergrund area is available for the access. When necessary, entrance is also possible by private cars, which can be parked in a dedicated tunnel besides the three halls. The entrance to the underground area is controlled 24 hours per day by guards.
All three halls allows easy access also for large trucks through the so called "TIR gallery" which goes across all the underground area. Each Hall has a big crane for moving and mounting heavy weights up to 40 tons.
The total electric power available is xxxxxx. Ventilation of the lab can support an air flow of 50000 m^3/h. Cooling of experimental apparata is done by means of a closed water cicuit.

A.5 *Local logistic and technical support* :

Local technical support includes the following:

- mechanical workshop. It includes several machines for designing and building mechanical structures, and a staff of technicians.
- computing center: the central computing resources include CPU farms, disk space on storage pools, public tape drives, backup service, printing facilities, management of Xterminals, central mailing and web hosting. The local area network extends to all the outside buildings and to the underground experimental areas and is connected to the italian reasearch network GARR. The plans for the development of the central computing resources are developed through an User Commission, which includes also the Service Head and a representative for each approved experiment.
- elecronic workshop: it includes facilities for designing and buiding specific electronic components dedicated to the experiments.
- chemical laboratory. The Chemical Service manages a microbiological area, a washing area for specific cleaning, precision balances and chemical instrumentation for both quantitative and qualitative measurements. There are also instruments for atomic absorption spectroscopy, a gas-chromatographer and two photometers. In the chemical lab it is possible to perform physical-chemical measurements, chemio-biological measurements, quantitative and qualitative analysis, metal or surface cleaning, mixing preparation. All these operation can be carried out on a self-service base or with the help of the service technical personnel. The Service provides also collaboration for analysis carried out in external laboratories, like CCR in ISPRA. A Clean Room of class 1000 is available, with class 100 regions (laminar flow hood). It is possible to carry out all kind of operations (cleaning, assembling, measurement, analysis), which require a minimal presence of dust and contaminants. In the Clean Room an Inductively Coupled Plasma Mass Spectrometer is installed for metal trace analysis.
- Mounting hall: it is a large assembly area located in the outside facilities, where parts of detectors to be installed underground can be mounted and tested.

The logistic support offered to researchers working at LNGS include:

- Cantine, open all working days
- Library
- One large conference room and four medium-size meeting rooms.
- Offices

- A limited number of guest rooms located inside the external lab buildings. Several hotels are also available in the immediate surroundins of the lab.

A.6 Management structure and human resources

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 present director of LNGS is Prof. Eugenio Coccia, and the technical manager Ing. Alberto Scaramelli.
The laboratory management structure is organized as follows:

- Research division: The Division is headed by a Leader; it is organized into Services, headed by a Service Leader appointed by the Director, after a review by the Division Leader. The services of the division are:
  Chemistry and cryogenic plants: The Service cooperates with the experimental groups at the LNGS providing technical support in the use of conventional chemical plants (absorption, stripping, distilling, etc.) and more general type (osmosis and water demineralisation, fluid handling and stocking, etc), particularly regarding the handling of cryogenic liquids and compressed gases. In this latter case the Service deals also with the purchase, the delivery and the handling inside the LNGS area
  Computing and network service: The Computing and Networks Service deals with the computing resources for the scientific community, the data network of the Laboratory and the data infrastructure.
  Electronics. The electronics service is in charge of design and manifacturing of electronic devices for the laboratory experiments; realization of programmable logic circuits; development of detectors and related front-end electronics; development of acquisition, monitoring and control systems; design and management of monitoring and calibration devices for detectors and electronics; CAD support in the design an planning of electronic circuits; support to the design, building and data taking phase of the experiments; maintenance of experimental devices; management of the electronic stock
  Special techniques service. This service operates the low level counting laboratory and facilities installed underground. It deals with measurements and development of detection techniques for low radioactivity and rare nuclear processes*;* radioactive contamination measurement of materials employed in the construction of low background detectors; environmental radioactivity measurements; support to the experiments on usage and maintenance of vacuum systems; support to the experiments on usage and maintenance of dilution refrigerators and helium liquefiers.
  Secretary: This Office provides support for users and deals with the logistics, organization and coordination of the activities of the Research Division and of the Director's Office
- Technical and general services division: It deals and coordinates the planning, realization and management of technical infrastructure, plants and civil works necessary to the Laboratory and the hosted experiments. The Division is headed by a Leader. The Division is organized into Services, headed by a Service Leader appointed by the Director. The services include:
  Civil works service: It supportsstructural controls on existent apparata, introductory planning, assembling of special tenders, estimate of quantities, price analysis etc, planning and commitment, updating of technical laws, use of structural computing software, hydraulic-plant engineering, management of common spreadsheets; relations with Offices and/or Public Entities for administrative discharges; management of PC and paper archive in the Laboratories; management of the access to the Laboratories; commitment and management of the orders related to the ordinary and extraordinary maintenance service of

the external buildings as well as the underground halls of the Laboratories, staging of offices and conference rooms; handling of materials (boxes, containers, etc.).

Electrical plants service: It supports design, management and maintenance of the electrical plants se up in the external and underground structures of the LNGS such as transport, transformation and distribution in medium and low voltage; emergency plants; low voltage distribution plants concerning the apparatus and the electrical aspects of the experiments; telephone plants. The service also deals with purchase, management and maintenance of electrical and electro mechanic machinery such as generators, UPS and motor generators, and performs measurements and monitoring of electrical quantities and quality of electrical network.

General plants service: The Service is in charge of planning, management and maintenance of technological plants such as: Air conditioning and air disposal plants; Thermal plants; Waterworks, sanitary and refrigeration appliances; Compressed air; Lifting plants; Flowing back waters disposal plants; Storage and waste disposal areas, waste differentiate collection.

Mechanical service: The service is in charge of Design and construction of mechanical structures; Management of the mechanical shop; welding; Management of the metal store; assistance and consultancy for the mechanical workshop users

Safety plants service: The service is responible for design and realisation of LNGS safety systems, including, in collaboration with the experimental teams, the safety equipment dedicated to experimental areas. It is also in charge of operation, maintenance, consolidation, extension and upgrade of the LNGS existing safety systems

- Prevention and protection service: The LNGS Prevention and Protection Service (PPS) deals with all the problems related to the Laboratory Safety and Security Management. It is directly depending on the LNGS Director and on the Technical Co-ordinator. The mandate of the service is safety training organisation and management for the LNGS Staff, Personnel, Users, External Companies; Identification and management of the Protective equipment and devices; Emergency Plans study, editing, publishing, diffusion and updates; Escape routes definition and diffusion; Access control management, with a “special view” on the truck permit and on the External Companies access; Co-operation with the Technical Division as regards the definition and design of safety systems and plants; Co-operation with the Health at Work Office, Management of the radio-protection services under the consultancy of a “Qualified Expert”; Loss Prevention study and Risk Analysis applied to the experimental apparatus.
- Public affairs and scientific information office. The mandate is relation with media, organization of scientific communication activities, realization, printing, and distribution of scientific and educational resources about the laboratory, archive of photografic and written documentation about the laboratory and its activities, management of the library.
- Administrative office: it is in charge of the administration of the laboratory: Budget management; Update of the legal aspect of the administrative procedures; Links with the central offices of the INFN, dispositions archives; Relations with the European Union; Cash management; Payments, budget and cash planning; Contracts and bids for purchasing, external servicing and advices; VAT and taxes related procedures; Import-export and relation with the Custom office; Personnel related procedures; Conferences expenses and payments; International contracts; Administrative aspects of third party services (canteen, bar, shuttle, etc.); Administrative procedures related to the car pool; Materials inventory; Laboratory store
- Directorate: It assists the director in the organization and coordination activity especially for secretariat activities, links with other research institutions, public relations, conference organizations, etc.

Two separate bodies, the Laboratory Council and the Scientific Committee, assist the director in the guidance of the laboratory.

- The Laboratory Coucil meets once per month and decides planning of the laboratory activity and funding needs to be presented to the directive offices of the INFN; evaluation of the problems connected with the laboratory activity and the actuation locally of the dispositions of the INFN Consiglio Direttivo; evaluation and annual report of the internal activity.
- The goal of the scientific committee is to express opinions and proposals to the Director about the scientific directions of the Laboratory, on the experiments and on their approval, taking into consideration the available resources, underground spaces and the proposed lasting according to the Director´s dispositions. The Committee is composed by scientific personalities chosen among the national and international community, it is appointed by the I.N.F.N. President on a proposal of the L.N.G.S. Director and after a disposition of the Consiglio Direttivo. The Committee members are in charge for three years and generally can be consecutively re-appointed for a second term only once.

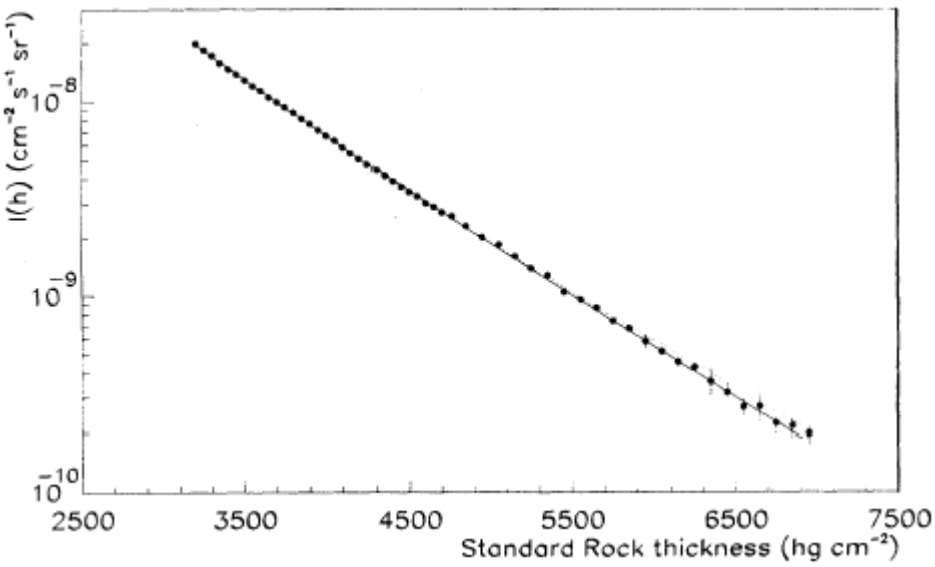

Figure 4: Vertical muon intensity versus standard rock depth at LNGS as measured by MACRO [Amb99]

B Scientific experiments : current status and prospects

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 [Rep03] [Betxx] 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 □, geophysics □, and to test □ 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 □□ 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 □□ 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,□)^{3}He (relevant for the pp chain and reaction rates in proto-stars), ^{14}N(p,□)^{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.

C Future perspectives

Extensive works in the underground area started in september 2004 for imrovement of safety in the underground areas, and minimization ov the environmental impact of the experimental activities. The works are coordinated by a commissioner nominated by the italian government and include:

- complete sealing of all the experimental area from the water system
- construction of basins and canalizations able to contain all potential leaks of liquids from the experiments located in the Halls

A new buiding is under costruction in the outside facilities; it will host offices for new groups of researchers, and special labs dedicated to OPERA (emulsion development and scanning)

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