Introduction

• Many fundamental experiments aim to detect very weak signals. They have to fight against background of different origin.
  - cosmic radiation
  - particles of nuclear decays
  - intrinsic natural radioactivity
  ⇒ low background α and γ spectroscopy @ L.N.G.S.
In 1979 A. Zichichi makes a proposal to the Italian Parliament for building a large underground laboratory inside the highway tunnel underneath the Gran Sasso, at that time under construction. In 1982 the Parliament approves the construction, then completed in 1987. In 1989 the first underground experiment, MACRO, is starting data taking. The EAS-TOP experiment, on Campo Imperatore, already started working from 1987 on.
Some very deep underground laboratories

1. Canfranc, Spain
2. Boulby, UK
3. Modane, France
4. Superkamiokande, Kamioka, Japan
5. Laboratori Nazionali del Gran Sasso, Italy

July 25th, 2005
LNGS and the ILIAS EU initiative

ILIAS = Integrated Large Infrastructures for Astroparticle Science

ILIAS is an initiative supported by the EU VI Framework Programme with the aim to support the EU Large infrastructures operating in the astroparticle physics sector.

Participants:
- France: Commissariat à l’Energie Atomique, CNRS
- Italy: Istituto Nazionale di Fisica Nucleare, Istituto di Fotonica e Nanotecnologie Trento, European Gravitational Observatory
- Germany: Max-Planck-Institut für Kernphysik Heidelberg, Technische Universität München, Max-Planck-Institut für Physik München, Eberhard-Karls-Universität Tübingen
- Spain: Zaragoza University
- UK: Universities of Sheffield, Glasgow, and London
- Czech Rep.: Czech Technical Univ. in Prague
- Denmark: University of Southern Denmark
- Netherland: Leiden University
- Finland: University of Jyväskylä
- Slovakia: Comenius University Bratislava
- Greece: Aristotle University of Thessaloniki

ILIAS was proposed under the coordination and review of APPEC (AstroParticle Physics European Coordination)
The ILIAS project is based on three main groups of activities

- **Networking activities**
  aim: foster the contacts/collaborations among researchers working on the same fields in different EU countries
  support: organisation of workshops, visits, specific activities

- **Transnational Access activities**
  aim: support access of EU researchers to major research infrastructures
  support: subsistence and travel costs for host researchers
  costs of technical support for the hosting institution

- **Joint research activities**
  aim: support specific R&D activities conducted jointly
  support: travel costs
  personnel
  equipment and consumables
Activities of the Deep Underground Laboratories in ILIAS

Activity

**J1 : LBT-DUS**  
Low Background Techniques for Deep Underground Science  
Joint R&D for the improvement of the strengthening of the low background facilities and know-how of the UG labs

**A1 : TARI-DUSL**  
Transnational Access to the EU Deep Underground Science Laboratories  
Support for the transnational access of research teams to the EU underground labs with priority to researchers from less favoured countries

**N2 : EUNet-DUSL**  
European Network of the Deep Underground Science Laboratories  
Coordination and networking to support the management of common issues relevant in the operation of the UG Labs

**J1 : Low background techniques for deep Underground science**

**Motivations :**

Extremely low-level background techniques and instrumentation are an essential requirement for a number of topics in astroparticle physics, f.i.:

- Search for bb decay
- Search for Dark matter
- Detection of low-energy neutrinos (solar, geo)

Fundamental topics common to most experiments are:

- Selection of radiopure materials
- Techniques for shielding against environmental backgrounds
- Purification techniques

This is the main motivation to carry on a Joint Research Activity on Low Background Techniques coordinated by the 4 UG Labs within ILIAS.
Key R&D topics:

- Development and strengthening of the ultra-low background facilities and instrumentation in the UG labs
- Measurement and monitoring of the background components in the underground Labs - Development of background simulation codes
- Application of low background techniques to interdisciplinary fields
- R&D on radiopurity of materials and purification techniques.

EU Support to LNGS:

- Personnel (2 post-docs + 1 technician)
- Travel money
- Contribution to equipment and consumables for selected specific activities

A1 : Transnational Access

The key objective of the Transnational Access is to offer free access to the deep Underground labs for EU research teams to carry out short or medium-term projects using the underground environment and facilities offered by the labs. Projects are selected by a User Selection Panel (USP) which meets periodically.

EU Support to LNGS:

- Travel and subsistence money for the host researchers
- Contribution to management costs

LNGS was already supported for Transnational Access since December 2001 within contract HPRI-CT-2001-00149 (to be competed in December 2004)
N2: Network of the EU Deep Undergr. Labs

Objectives:

- Scientific coordination and public communication
  - several specific activities ongoing (R. Antolini)
    - open days at the underground labs
    - preparation of booklet on underground science for general public
    - dedicated web pages

- Safety problems and accident prevention
  - Exchange of information, visits of experts, ...

- Service Improvement, coordination and extension of deep underground laboratories

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Rock properties

- composition:
  
  Ca 26 %, Si 1 %, Mg 9 %, O 51.5 %, C 12.5 %

  \[ \langle p \rangle = (2.71 \pm 0.05) \text{ g cm}^{-3} \]
  \[ \langle Z \rangle = 11.4 \]
  \[ \langle Z^2/A \rangle = 5.7 \]
## Rock properties

radioactivity (in Bq kg\(^{-1}\)):

<table>
<thead>
<tr>
<th></th>
<th>Gran Sasso</th>
<th>M(^{+}) Blanc</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{232})Th</td>
<td>0.25-0.5</td>
<td>(\approx) 90</td>
</tr>
<tr>
<td>(^{238})U</td>
<td>5</td>
<td>80-500</td>
</tr>
<tr>
<td>(^{226})Ra</td>
<td>4.5</td>
<td>30-300</td>
</tr>
<tr>
<td>(^{40})K</td>
<td>5-50</td>
<td>100-2000</td>
</tr>
</tbody>
</table>

## Characteristics

lat. 42° 27’ N  
long. 13° 34’ E

mean depth:  
3800 m.w.e.  
min. depth:  
3000 m.w.e.
**Muons**

*muon fluence:*

\[ \approx 1 \mu/(m^2\cdot h), \ E_\mu > 1 \text{ TeV} \]

(10^6 reduction with respect to surface)

---

**Neutrons**

*neutron flux:*

e.g. @ L.N.G.S.

fission and \((\alpha,n)\)

\[ \Phi_{th} = 3\times10^{-6} \text{ cm}^{-2} \text{ s}^{-1} \]

\[ \Phi_{fc} < 0.3\times10^{-6} \text{ cm}^{-2} \text{ s}^{-1} \]

(10^3 reduction)
Low background counting laboratory

8 (+3) HPGe detectors working

<table>
<thead>
<tr>
<th>type</th>
<th>volume [cm$^3$]</th>
<th>rel. efficiency</th>
<th>FWHM [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>GeBer n-type</td>
<td>235</td>
<td>56%</td>
<td>2.0</td>
</tr>
<tr>
<td>GeMi p-type</td>
<td>403</td>
<td>86%</td>
<td>1.9</td>
</tr>
<tr>
<td>GePV p-type</td>
<td>363</td>
<td>91%</td>
<td>1.8</td>
</tr>
<tr>
<td>GsOr p-type</td>
<td>414</td>
<td>96%</td>
<td>1.9</td>
</tr>
<tr>
<td>GeMPI p-type</td>
<td>413</td>
<td>102%</td>
<td>1.9</td>
</tr>
<tr>
<td>GePaolo p-type</td>
<td>518</td>
<td>113%</td>
<td>2.0</td>
</tr>
<tr>
<td>GeCris p-type</td>
<td>465</td>
<td>120%</td>
<td>2.0</td>
</tr>
<tr>
<td>GeMulti p-type</td>
<td>$4 \times 225$</td>
<td>$4 \times 96%$</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Collaboration of European Low-Level Underground Laboratories
Mission

To promote higher quality and sensitivity in ultra low-level radioactivity measurements for the improvement of crisis management, environment, health and consumer protection standards of Europe.
What is ULGS?

**Ultra Low-level Gamma Spectrometry**

i.e. low-level γ-spectrometry with additional background reduction by using active shields, material selection and/or underground laboratories
### Sensitivity

<table>
<thead>
<tr>
<th>Method</th>
<th>Detection limit for U and Th [Bq/kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULGS (non-destructive)</td>
<td>$10^{-8} - 10^{-7}$</td>
</tr>
<tr>
<td></td>
<td>$\gamma$ emitters</td>
</tr>
<tr>
<td>ICP-MS (destructive)</td>
<td>$10^{-10} - 10^{-7}$</td>
</tr>
<tr>
<td></td>
<td>primordial parents</td>
</tr>
<tr>
<td>ULGS + NAA</td>
<td>$10^{-11}$</td>
</tr>
<tr>
<td></td>
<td>primordial parents</td>
</tr>
</tbody>
</table>

\[
\begin{align*}
1 \text{ Bq} \ 238\text{U/kg} & \equiv 81 \times 10^{-9} \text{ g/g} \\
1 \text{ Bq} \ 232\text{Th/kg} & \equiv 246 \times 10^{-9} \text{ g/g} \\
1 \text{ Bq} \ 40\text{K/kg} & \equiv 32 \times 10^{-6} \text{ g/g}
\end{align*}
\]

\[
\gamma_{\text{ext}}
\]

High energy muons are not stopped

e.m. showers are only partially attenuated

---

Neutron thermalization produces photons through $(n,\gamma)$ capture

Interaction of high energy particles with shielding induces secondary background
Neutron thermalization produces photons through \((n,\gamma)\) capture.

Interaction of high energy particles with shielding induces secondary background.

High energy muons are reduced by overburden and/or active shield.

Electromagnetic showers are attenuated.
Normalised counting rate [d⁻¹ kg⁻¹]

Depth [m w.e.]

Muon fluence rate [a.u.]

above ground

ARC Seibersdorf
MPI-K-HD
VKTA Rossendorf
IAEA-MEL
JRC-IRMM

- active + passive shield
- only passive shield

July 25th, 2005
SiLBRT - Minneapolis

[Diagram showing normalised counting rate and muon fluence rate as a function of depth.]

Rn

γ<sub>ext</sub>

gas radon becomes important

high energy muons are reduced further deep underground (factor >10⁻⁶ reduction @ LSCE & LNGS)

Neutrons now induced from natural radioactivity ((α,n) & fission) (factor 10⁻³ reduction @ LNGS)

γ's now from natural radioactivity inside shielding and detector components
BUT ... !!!

Normalised counting rate [d⁻¹ kg⁻¹]

Depth [m w.e.]

Muon fluence rate [a.u.]

above ground

VKTA Rossendorf

PTB

JRC-IRMM

LNGS

LSCE

0 1000 2000 3000 4000 5000

10⁻² 10⁻¹ 10⁰ 10¹ 10² 10³ 10⁴ 10⁵ 10⁶
Normalised counting rate \([\text{d}^{-1} \text{keV}^{-1} \text{kg}^{-1}]\)

Depth \([\text{m w.e.}]\)

Muon fluence rate \([\text{a.u.}]\)

LNGS

1993

1996

1997

July 25th, 2005

SLBRT - Minneapolis
**HPGe detectors**

**shielding:**
- 20 cm low activity lead ($^{210}$Pb < 20 Bq kg$^{-1}$)
- 5 cm OFHC copper
- 5 cm acrylic and Cd foil on the bottom

**Rn-suppression:**
- 1 cm acrylic cover with continuous N$_2$ flow

**Material selection:**
- highly radiopure, (almost) no activation

---

Energy, keV

Counts [kg.yeV]

$^{137}$Cs, $^{60}$Co, $^{207}$Bi, $^{0}$νββ

plus continuous contribution of Ge intrinsic cosmogenics

ANG2 LNGS, no shield
Heidelberg Moscow
plot from O. Chkvorets
### HPGe detectors

<table>
<thead>
<tr>
<th>detector</th>
<th>total and peak background count rate ([d^{-1} kg^{-1} Ge])</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40-2700 keV</td>
</tr>
<tr>
<td>GeMi</td>
<td>555 ± 7</td>
</tr>
<tr>
<td>GePV</td>
<td>498 ± 5</td>
</tr>
<tr>
<td>GsOr</td>
<td>442 ± 5</td>
</tr>
<tr>
<td>GePaolo</td>
<td>222 ± 2</td>
</tr>
<tr>
<td>GeCris</td>
<td>77 ± 2</td>
</tr>
<tr>
<td>GeMPI</td>
<td>30 ± 2</td>
</tr>
</tbody>
</table>

*July 25th, 2005*  
SiLBRT - Minneapolis
effective volume of sample chamber ~ 15 l
(e.g. 125 kg Cu or 157 kg Pb)

High purity copper directly placed underground after electrolysis

OUTLOOK

further improvements possible:
- neutron shield
- material selection improved
- active shield
- going deeper underground
- storage of construction material underground
- multisegmented crystals or multiple crystals
- collaboration with producers
GERDA

The GERmanium Detector Array for the search of neutrinoless double beta decay of $^{76}$Ge

71 physicists / 12 institutions / 4 countries  Spokesperson: Stefan Schönert, MPIK Heidelberg

**Institutions and Members**

- **INFN LNGS, Assergi, Italy**

- **JINR Dubna, Russia**

- **MPIK, Heidelberg, Germany**

- **Univ. Köln, Germany**
  - J. Eberth, D. Weiszhaar

- **Jagiellonian University, Krakow, Poland**
  - M. Wojcik

- **Univ. di Milano Bicocca e INFN, Milano, Italy**
  - E. Bellotti, C. Cattadori

- **INR, Moscow, Russia**
  - I. Barabanov, L. Beznukov, A. Gangapshev, V. Gurentsov, V. Kusminov, E. Yanovich

- **ITEP Physics, Moscow, Russia**
  - V.P. Bolotsky, E. Demidova, I.V. Kirpichnikov, A.A. Vasenkov, V.N. Komoukhov

- **Kurchatov Institute, Moscow, Russia**

- **MPI Physik, München, Germany**

- **Univ. di Padova e INFN, Padova, Italy**
  - A. Bettini, E. Famea, C. Rossi-Alvarez, C.A. Ur

- **Univ. Tübingen, Germany**
  - M. Bauer, H. Clement, J. Jochum, S. Scholl, K. Rottler

**Technical Specifications**

- **Dimensions**
  - Ø 3.8 m (inner radius)
  - 4.0 m (outer radius)

- **Materials**
  - 10 cm Pb
  - 1.5 m stainless steel
  - Vespel or similar
  - 8x10$^5$ Ra-226
  - 1x10$^5$ Th-228
  - 9x10$^7$ K-40

- **Radioactivity**
  - Ge $< 1 \times 10^{-3}$
  - $< 1 \times 10^{-4}$
  - $< 1 \times 10^{-2}$
  - Copper $< 20$
  - $< 26$
  - $< 88$

- **Water Shield**
  - Instrumented with PMTs as cosmic veto

**Spokesperson**

Stefan Schönert, MPIK Heidelberg
### Backgrounds in GERDA

<table>
<thead>
<tr>
<th>Source</th>
<th>$B \times 10^9$ cts/(keV kg y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ext. $\gamma$ from $^{208}$Tl ($^{232}$Th)</td>
<td>$&lt;1$</td>
</tr>
<tr>
<td>Ext. neutrons</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>Ext. muons (veto)</td>
<td>$&lt;0.03$</td>
</tr>
<tr>
<td>Int. $^{60}$Ge ($t_{1/2}$ = 270 d)</td>
<td>12</td>
</tr>
<tr>
<td>Int. $^{60}$Co ($t_{1/2}$ = 5.27 y)</td>
<td>2.5</td>
</tr>
<tr>
<td>$^{222}$Re in LN/LAr</td>
<td>$&lt;0.2$</td>
</tr>
<tr>
<td>$^{209}$Tl, $^{233}$U in holder</td>
<td>$&lt;1$</td>
</tr>
<tr>
<td>Surface contam.</td>
<td>$&lt;0.6$</td>
</tr>
</tbody>
</table>

*derived from measurements and MC simulations*

**Target for phase II:** $B \leq 10^{-3}$ cts/(keV kg y)

⇒ additional bgd. reduction techniques
Background reduction techniques

- Muon veto
- Anti-coincidence between detectors
- Segmentation of readout electrodes (Phase II)
- Pulse shape analysis (Phase I+II)
- Coincidence in decay chain (Ge-68)
- Scintillation light detection (LArGe)

Also next step for screening at nBq/kg level.
Exiting to see what comes up at this level.
Measurements

measurements of direct physics interest:

- $^{42}$Ar in natural liquid argon: $^{42}$Ar/$^{40}$Ar $\leq 10^{-18}$
- double beta decay of $^{96}$Zr and $^{150}$Nd:
  $T_{1/2}(^{96}$Zr$) > 3 \times 10^{19}$ a
  $T_{1/2}(^{150}$Nd$) > 1 \times 10^{20}$ a
- Roman Pb (age $> 2000$ a): $^{210}$Pb $< 1.3$ Bq/kg
- $\beta$-decay of $^{115}$In to $^{115}$Sn$^*$: $(3.73 \pm 0.98) \times 10^{20}$ a

Cu of Norddeutsche Affinerie (Hamburg, Germany)

<table>
<thead>
<tr>
<th>anodes</th>
<th>NOSV quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>97-99% + 2000 ppm O$_2$</td>
<td>99.9975% (1-4 ppm O$_2$)</td>
</tr>
</tbody>
</table>

+...

<table>
<thead>
<tr>
<th>Element</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni: % IN ORE</td>
<td>&lt; 1-2 ppm</td>
</tr>
<tr>
<td>Co:</td>
<td>&lt; 1 ppm</td>
</tr>
<tr>
<td>$^{40}$K:</td>
<td>$7.5 \pm 1.0$ mBq/kg</td>
</tr>
<tr>
<td>$^{226}$Ra:</td>
<td>$1.8 \pm 0.4$ mBq/kg</td>
</tr>
<tr>
<td>$^{228}$Th:</td>
<td>$&lt; 0.44$ mBq/kg</td>
</tr>
<tr>
<td>radionuclide</td>
<td>cosmogenic</td>
</tr>
<tr>
<td>-------------</td>
<td>------------</td>
</tr>
<tr>
<td>$^{56}$Co</td>
<td></td>
</tr>
<tr>
<td>$^{57}$Co</td>
<td></td>
</tr>
<tr>
<td>$^{58}$Co</td>
<td></td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td></td>
</tr>
<tr>
<td>$^{54}$Mn</td>
<td></td>
</tr>
<tr>
<td>$^{59}$Fe</td>
<td></td>
</tr>
<tr>
<td>$^{46}$Sc</td>
<td></td>
</tr>
<tr>
<td>$^{48}$V</td>
<td></td>
</tr>
</tbody>
</table>

**Cosmogenic** and primordial radioactivity concentrations in Cu

<table>
<thead>
<tr>
<th>radionuclide</th>
<th>halflife</th>
<th>activity [µg/kg]</th>
<th>exposed (270 d)</th>
<th>unexposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{228}$Ra (U)</td>
<td>1600 a</td>
<td>&lt; 35</td>
<td>&lt; 16</td>
<td></td>
</tr>
<tr>
<td>$^{228}$Th (Th)</td>
<td>1.91 a</td>
<td>&lt; 20</td>
<td>&lt; 19</td>
<td></td>
</tr>
<tr>
<td>$^{40}$K</td>
<td>$1.277 \times 10^9$ a</td>
<td>&lt; 120</td>
<td>&lt; 88</td>
<td></td>
</tr>
</tbody>
</table>

**Other activities**

- Development and strengthening of the ultra low-level background facilities (LNGS)
- Extension of the Low Level Laboratory at LNGS
- Development of new generation of HP-Ge detectors for Ultra-low level applications
- Set-up of ultra low-level scintillation counter systems
- Ultra low-level gas counting (GNO low counting lab)

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GNO Ultra low-level gas counting  
Ultra low-level HPGe detector @ LNGS
Measurement and monitoring of the background components underground
- Development of detectors for determination of neutron and gamma flux and spectrum
- Coordinated measurement and comparison of neutron and gamma spectra in all 4 UG labs
- Set-up of Rn monitoring systems in air and water inside all 4 UG labs

New measurement and monitoring of n spectrum (INFN Pw)

γ-ray mapping in the LNGS

Application of low background techniques to interdisciplinary fields
- low-level environmental radioactivity measurement and monitoring
- Radiodating laboratory
- Geophysics

Radiopurity of materials and purification techniques
- Set-up a database containing relevant information on radiopurity of materials commonly used for low background applications. Setting up an efficient database is not a trivial job.
- Measurement of poorly known radiopurity of materials with possible applications within ultra-low background experiments
- Cross-check of measuring methods available at the different labs.