Istituto Nazionale di Fisica Nucleare
LABORATORI NAZIONALI DEL GRAN SASSO

The ultra-low background laboratory STELLA (SubTErranean Low Level Assay) in the Laboratori Nazionali del Gran Sasso (Italy) underground laboratories

Symposium on Science at PAUL (Paarl Africa Underground Laboratory)

Paarl, 15 – 18 January 2024
Du Kloof Lodge, Du Toitskloof Mountains

Material screening in STELLA

STELLA = SubTErranean Low Level Assay

- main task is material selection for all experiments installed in the LNGS underground laboratories (on the average about 50-100 samples per year);

if there is availability, also for experiments outside of LNGS;

- working in synergy with the ICP-MS laboratory of the LNGS Chemistry Services (check of secular equilibrium in the uranium and thorium decay chains);

- non-destructive measurements of samples ➔ Monte Carlo simulations for efficiency determination (as accurate as possible);

Ultra-low background laboratory STELLA

- γ-ray spectrometry (with high purity Ge Detectors)
- 15 detectors installed, all handled by LNGS
- 2 portable HPGe detectors with electrical cooling

Sensitivity (U/Th):

- 6 commercial LB detectors (O(mBq/kg));
- 5 commercial ULB detectors (1 well-type, 1 BEGe, combined 4 p-type coaxial) (O(0.5 mBq/kg));
- 4 custom ULB detectors (MPIK/LNGS) (O(some 10 μBq/kg));

- α spectrometry (four Silicon PIPS detectors)
- liquid scintillation counters (1 WALLAC Quantulus, 1 Hidex)

Upgrade STELLA laboratory

- Planned since 2018 (EU funding through PON01_00020, FARO2030, 708 k€);;
- Will be finished by middle of 2024, then transfer to new building;
- New laboratory space (increase flexibility);
- The detector space will be surrounded by neutron shielding (polyethylene and water) and 5 cm of steel (improve background characteristics).

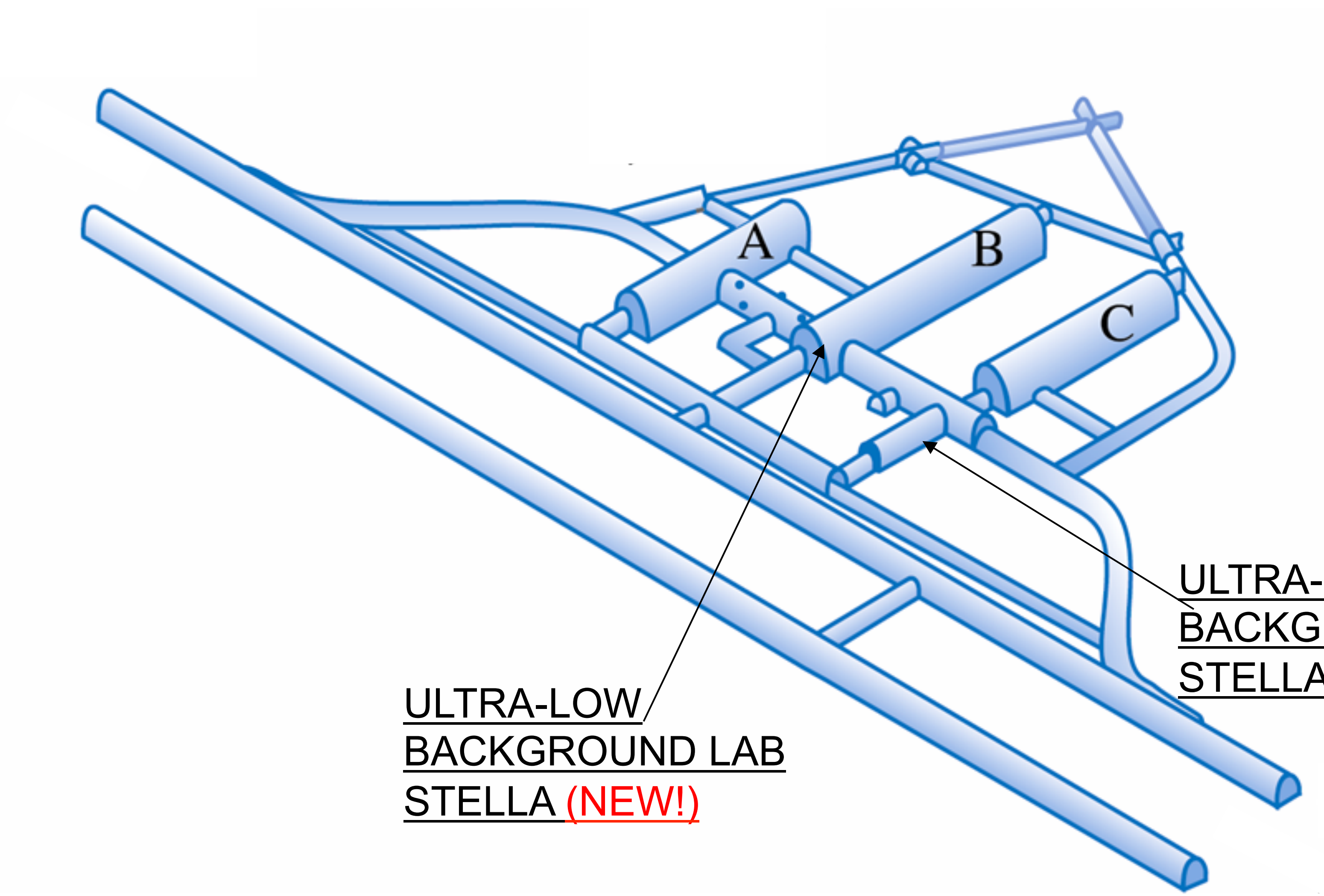
STELLA

(since 1989 until NOW)

STELLA

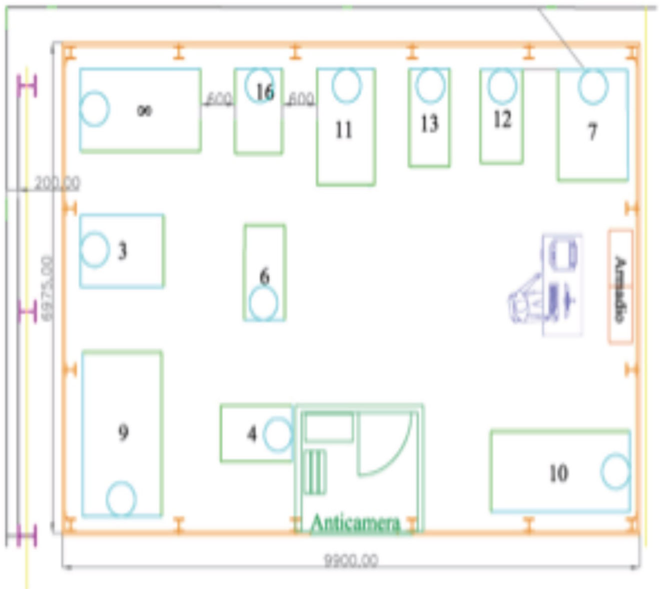
(FUTURE)

New laboratory



GROUND FLOOR REFURBISHMENT -1

Ground floor: «steel structure» with wall thickness of 5 cm (70 m^2, ca. 3 m high). This room will become a *controlled environment*, with a class close to ISO 8 standard. The walls give a background reduction of a factor of 10.

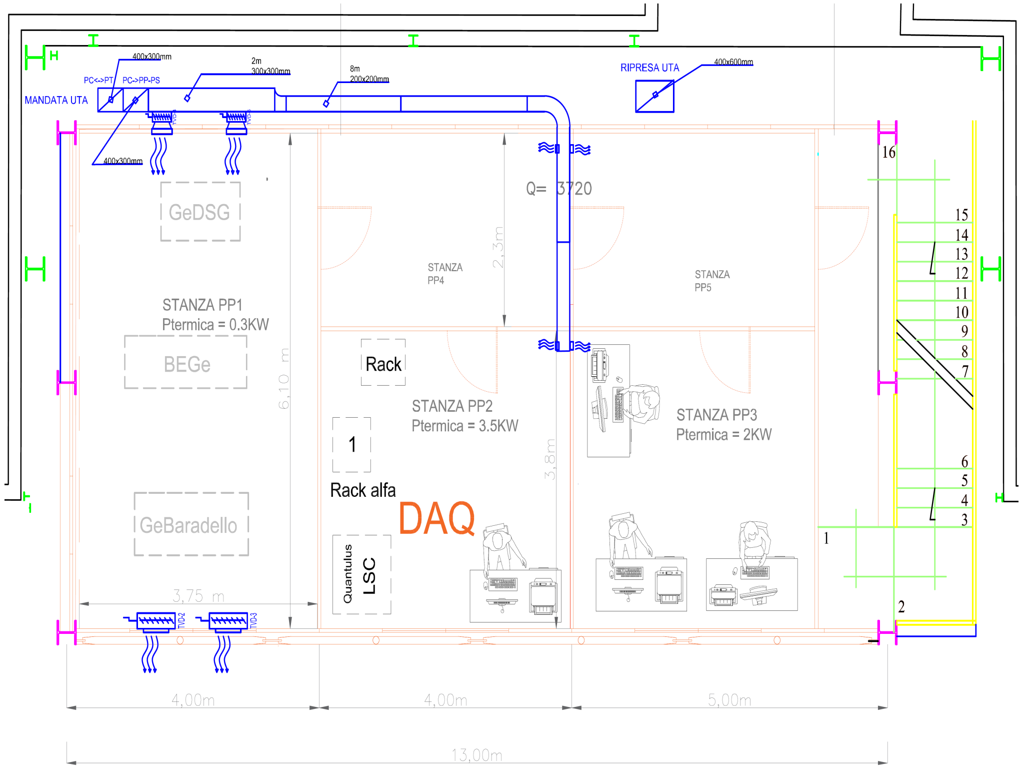


The ground floor will have a passive neutron shielding placed all around the walls; it will be made with water-filled tanks; the shielding thickness is 15 cm.

The floor shielding will be realised with HDPE slabs, enclosed in a steel structure.

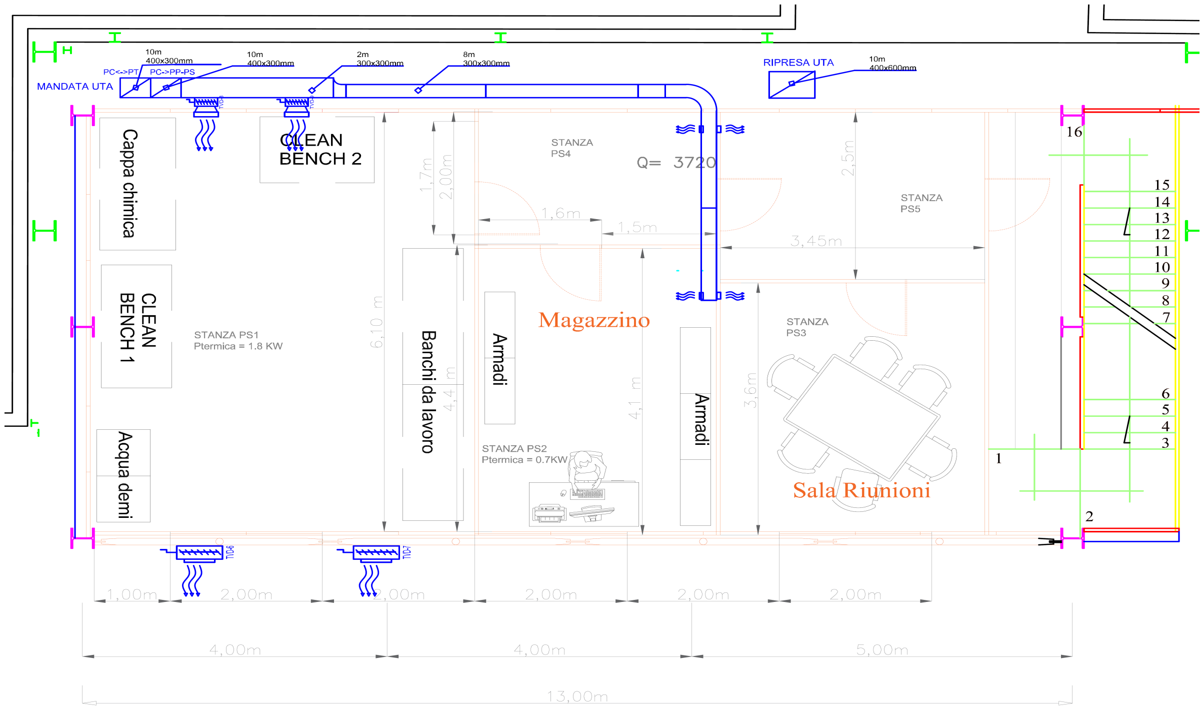
FIRST FLOOR REFURBISHMENT

The first floor of the building will be host a controlled environment with similar characteristics to the ground floor, office space, and the DAQ room.



SECOND FLOOR REFURBISHMENT

The second floor of the building will host a small laboratory space, office space, and a warehouse.



Collaboration MPI-K-HD & LNGS

New HPGe detector made by MPI-K-HD (group Prof. Manfred Lindner):

- Based on GeMPI design;
- Improved shielding;
- Increased efficiency;
- Location in new STELLA laboratory.

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Thanks to:

Chiara Ghiano and Roberto Cerroni, for running the STELLA laboratory together with me;

Aldo Ianni, Antonio Iannuzzo, Franca Masciulli and collaborators, Lidio Pietrofaccia, Maria Teresa Ranalli, Graziano Panella, Roberto Tartaglia and the LNGS Administrative Service for the excellent collaboration on the STELLA Upgrade;

LNGS Director & LNGS Staff for their constant support.

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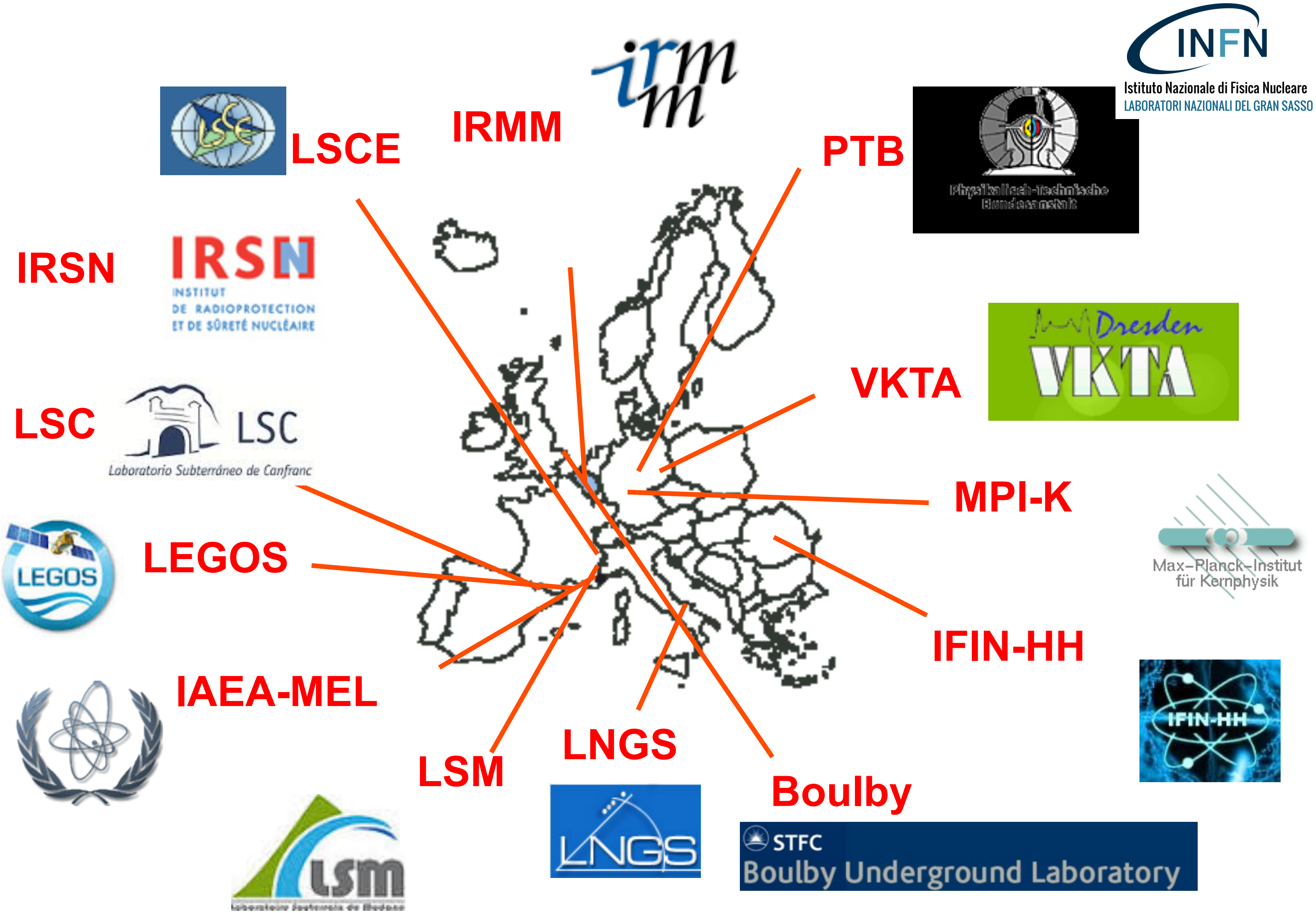
CELLAR

Collaboration of European Low-level underground LAboRatories



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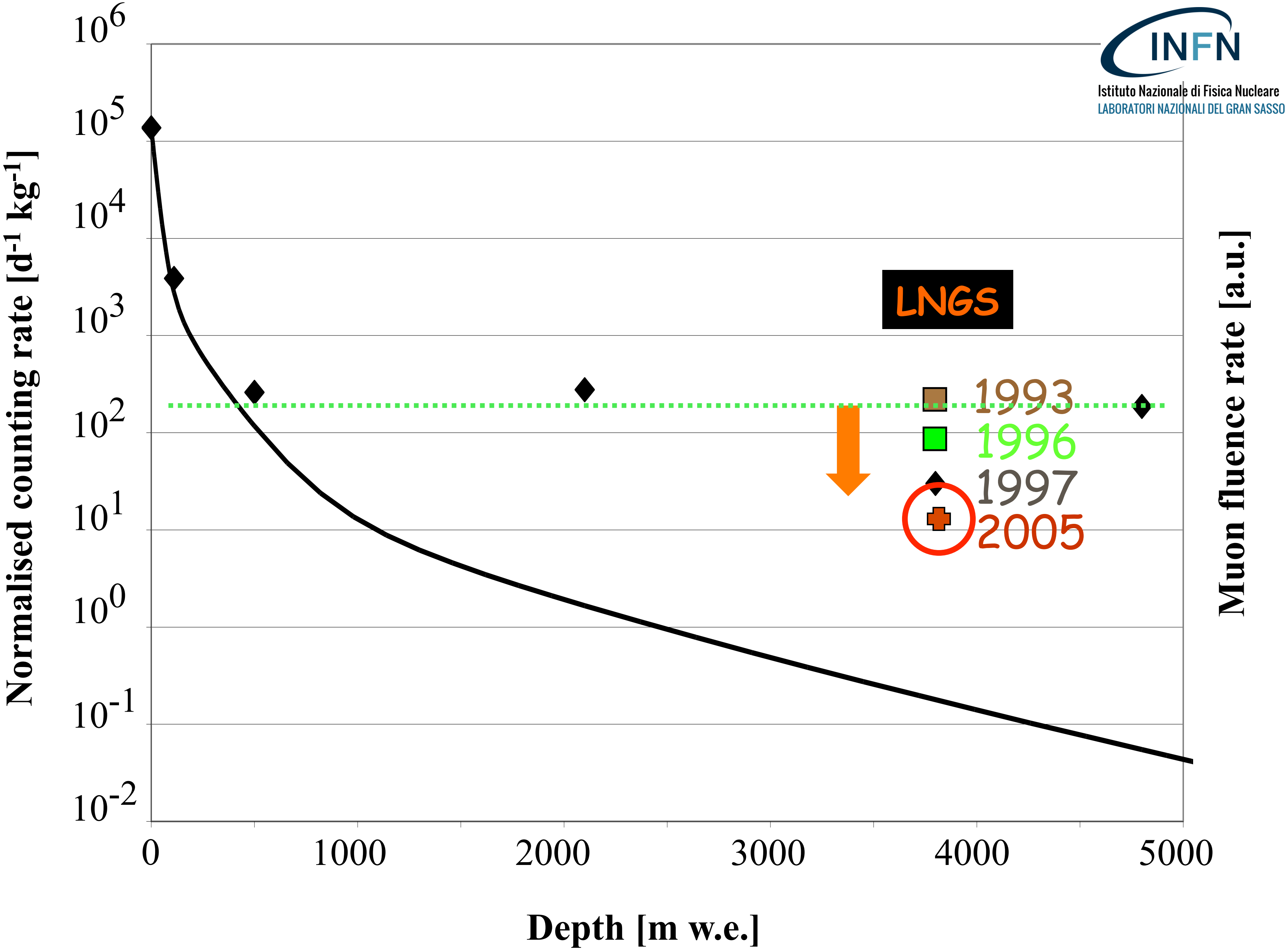

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LNGS
1993
1996
1997
2005
Normalised counting rate [d-1 kg-1]
Muon fluence rate [a.u.]
Depth [m w.e.]
0
1000
2000
3000
4000
5000
10-2
10-1
100
101
102
103
104
105
106

CELLAR publications

- Metal samples from Tokai Mura (M. Hult et al., «Measurements of ^{60}Co in spoons activated by neutrons during the JCO criticality accident at Tokai-Mura in 1999», J. Environ. Radioact. 73 (3) (2004) p. 307-321);

- Metal samples from Hiroshima (J. Gasparro et al., «Measurements of Co-60 in massive steel samples exposed to the Hiroshima atomic bomb explosion», Health Phys., Vol. 102 (2012) pp. 400-409);

Meteorites

Meteorite measurements (*Gibson et al., «An investigation of the 27 July 2018 bolide and meteorite fall over Benenitra, southwestern Madagascar», South African Journal of Science, 117, Issue 3-4 (2021) pp. 91-99; Jenniskens P. et al., «The impact and recovery of asteroid 2018 LA», Meteoritics and Planetary Science, 56, Issue 4 (2021) pp. 844-893*);

Rare decay search

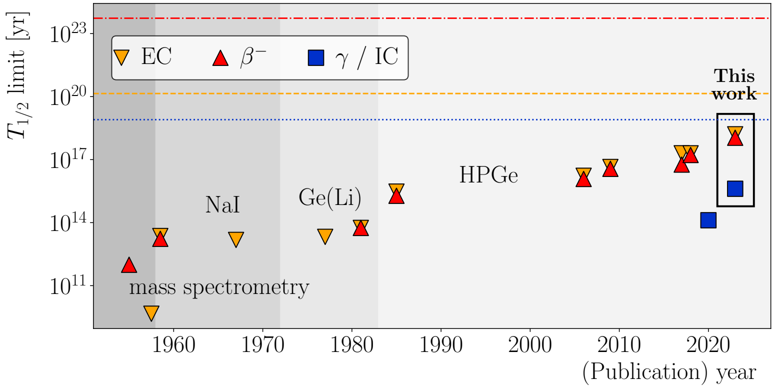

Fig. 2 Lower limits on the decay half-life of ^{180m}Ta on the EC, β^- and γ / IC channels [9, 18–28]; the box encloses the new results presented in this work. The labels and corresponding shadowed areas refer to the different techniques used for the measurements. The horizontal lines indicate the theoretical half-lives from the calculations of the nuclear matrix elements [7]: EC (dashed), β^- (dash-dotted) and γ / IC (dotted).

Rare decay search (*Cerroni, C. et al., «Deep-underground search for the decay of ^{180m}Ta with an ultra-low-background HPGe detector», arXiv: 2305.17238v2 [nucl-ex] (2023);*

Celi, E. et al. «New limit on ^{94}Zr double beta decay to the 1st excited state of ^{94}Mo», European Physical Journal C, 83(5) (2023), 396;

Broerman, B. et al. «Updated and novel limits on double beta decay and dark matter-induced processes in platinum», European Physical Journal C, 83(5) (2023), 396);

Environmental radioactivity

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Environmental measurements (*M. Laubenstein et al., «Radionuclide mapping of the Molise region (Central Italy) via gamma-ray spectroscopy of soil samples: relationship with geological and pedological parameters», J. Radioanal. Nucl. Ch., 298 (2013) pp. 317-323*).

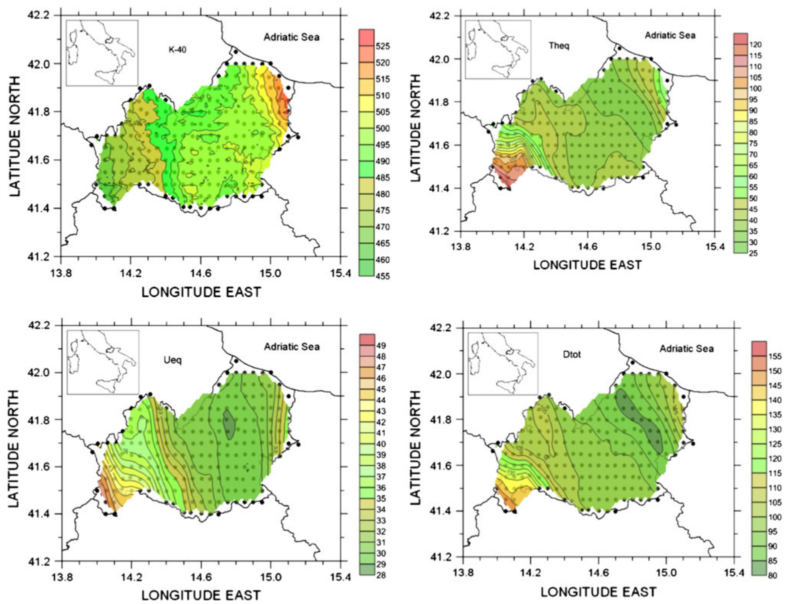

Fig. 1 Radioactivity maps of the Molise region showing massic activities (in Bq kg^{-1}) of ^{40}K, U_{eq} (represented by ^{226}Ra), Th_{eq}, and the total dose rate due to natural radioactivity and cosmic radiation (in nGy h^{-1})

F. Di Paolo et al., «Ground gamma-ray survey of the Solforata gas discharge area, Alban Hills-Italy: a comparison between field and laboratory measurements», J. Environ. Radioact. 115 (2013) pp. 175-182;

M. Laubenstein, D. Magaldi, «Natural radioactivity of some red Mediterranean soils», Catena, Vol. 76, Issue 1, (2008) pp. 22-26;

C. Tsabaris et al., «Determination of Cs-137 activities in surface sediments and derived sediment accumulation rates in Thessaloniki Gulf, Greece», Environ. Earth. Sci., Vol. 67 (2012) pp. 883-843;

EyeRAD

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INFN Environmental RADioactivity monitoring network

- The INFN network is set up to support national institutional monitoring networks, with a view to a synergistic effort aimed at safeguarding public exposures, especially in the event of anomalous or accidental events.
- Step One: rapid and cost-effective activation of an environmental radioactivity monitoring network
- Step Two: inclusion of any other initiatives on environmental monitoring and radiation protection

New detector design

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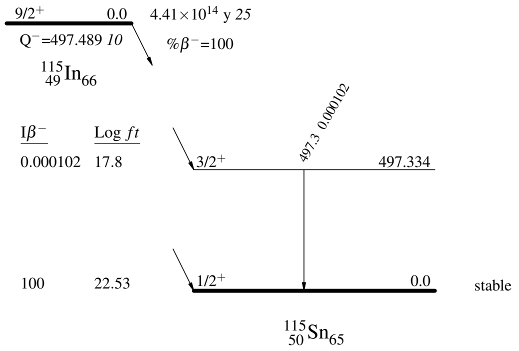
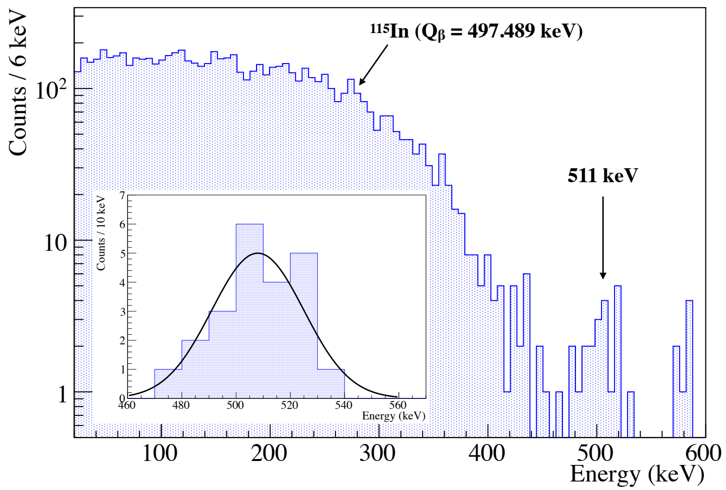
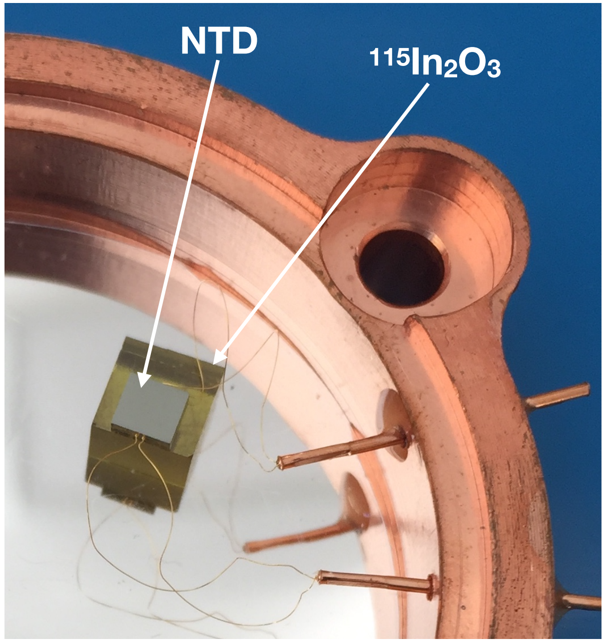
- **New detector design** (*Celi, E. et al., «Development of a cryogenic In_2O_3 calorimeter to measure the spectral shape of ^{115}In β-decay», Nuclear Instruments and Methods in Physics Research A, 1033 (2022) 166682*).







In_2O_3

4^{th} forbidden non-unique β decay

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Collaboration with IAEA

- Standard reference materials (M.K.Pham et al.,«Certified reference materials for radionuclides in Bikini Atoll sediment (IAEA-410) and Pacific Ocean sediment (IAEA-412)», Applied Radiation and Isotopes 109 (2016) pp. 101-104;

- Annual participation to international intercomparison exercises for gamma-ray spectrometry;

... and much more ...

- **Fundamental Physics** (*Donadi, S.. et al., « Underground test of gravity-related wave function collapse», Nature Physics, 17 (2020) 74-78;*

  Derakhshani, M. et al., «At the crossroad of the search for spontaneous radiation and the Orch OR consciousness theory», Physics of Life Reviews, 42 (2022) pp. 8-14);
- **Quantum Computing** (*Cardani, L et al., «Disentangling the sources of ionizing radiation in superconducting qubits», European Phys. J. C, 83(1) (2023) 94);*
- **Biology** (*Morciano, P. et al, «Overview of DISCOVER22 experiment in the framework of INFN-LNGS Cosmic Silence activity: challenges and improvements in underground radiobiology», Frontiers in Physics, 11 (2023) 1263338;*

  Ampollini, M. et al, «Sub-background radiation exposure at the LNGS underground laboratory: dosimetry characterization of the external and underground facilities», Frontiers in Physics, 11 (2023) 1274110).

Conclusions

1.) The exceptional sensitivity and high resolution of high purity germanium detectors in gamma-ray spectrometry and their use in underground laboratories has an increasing number of applications.

2.) A growing number of measurements is done underground in fields such as environmental monitoring, surveillance of nuclear activities, benchmarking besides the material selection for experiments, which require materials with extremely low levels of radioactivity.

3.) Strongly recommend the installation of a(n) (ultra-)low background laboratory working in synergy with above-ground installations.

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Thank you for your attention !