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LABORATORI NAZIONALI DEL GRAN SASSO

The underground ultra-low background laboratory STELLA (SubTerranean Low-Level Assay) at the Laboratori Nazionali del Gran Sasso (Italy) – present and future

XVIII International Conference on Topics in Astroparticle and Underground Physics

Vienna, 28 August – 1 September 2023
University of Vienna

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STELLA = SubTErranean Low Level Assay

Material screening in STELLA

- 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);

Background properties

- Rather low natural radioactivity in the surrounding calcareous rock and concrete;
- muon reduction: 10^6;
- neutron reduction: 10^3;
- Radon reduction through nitrogen flow (boil-off) in the shield;
- Graded lead shield with low ^{210}Pb content in the innermost layers and OFHC copper;

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Ultra-low background laboratory STELLA

- γ-ray spectrometry (with high purity Ge Detectors)
- 15 detectors installed

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)

Background of selected HPGe detectors

detector	total and peak background count rate [$d^{-1}\,kg^{-1}_{Ge}$]			
	40-2700 keV	352 keV	583 keV	1461 keV
GeMi	555 ± 7	4.1 ± 1.0	1.4 ± 0.5	6.1 ± 0.8
GePV	498 ± 5	2.6 ± 0.7	1.8 ± 0.4	3.2 ± 0.4
GsOr	442 ± 5	2.0 ± 0.5	0.76 ± 0.35	4.2 ± 0.5
GePaolo	222 ± 2	1.1 ± 0.3	0.31 ± 0.16	1.8 ± 0.2
GeCris	115 ± 2	0.29 ± 0.22	< 0.13	0.88 ± 0.22
GeMPI	71 ± 2	< 0.07	< 0.06	0.24 ± 0.03

Upgrade STELLA laboratory

- Planned since 2018 (EU funding through PON01_00020, FARO2030, 708 k€);;
- Will be finished by the end of 2023, 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).

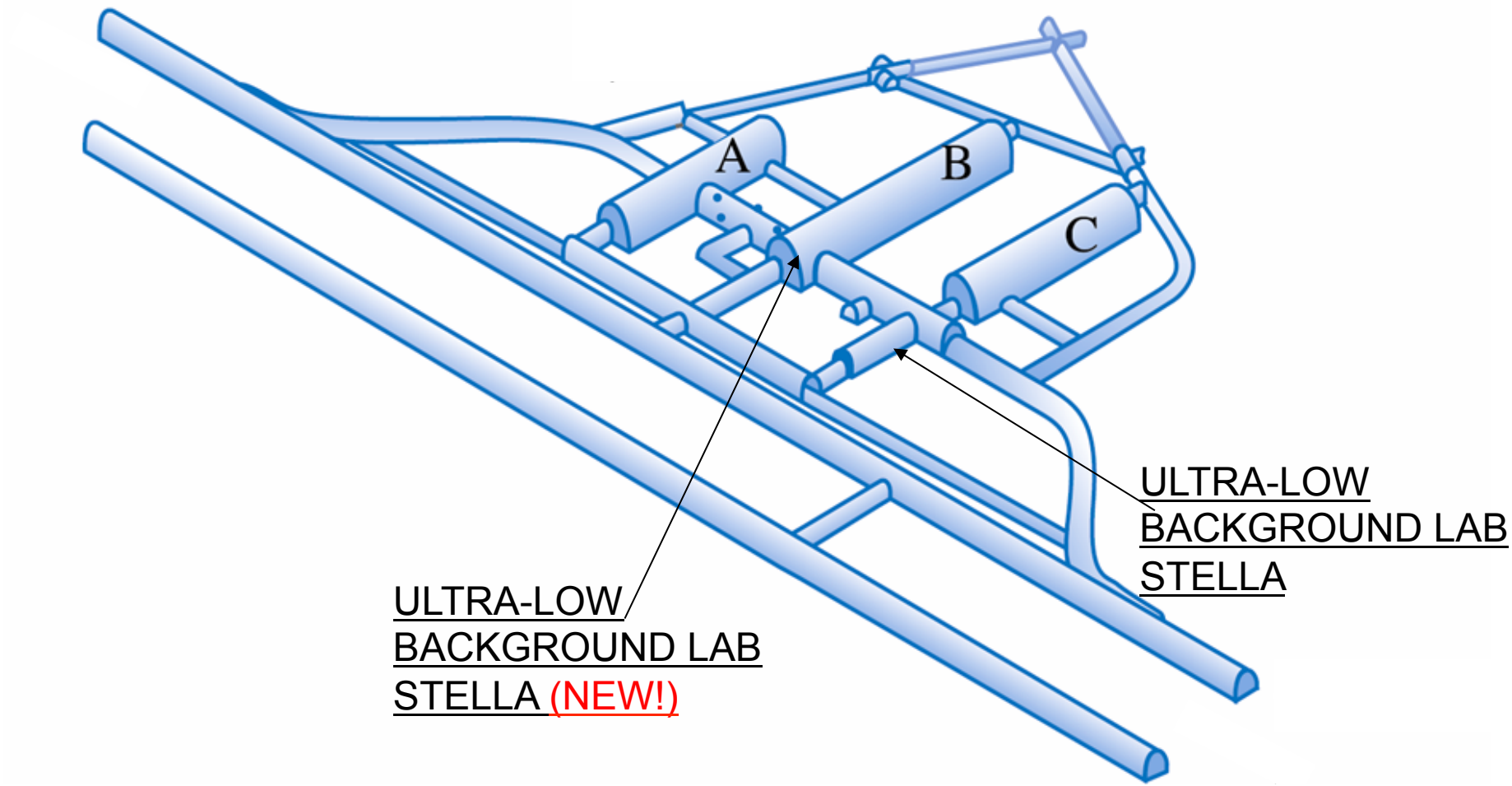
STELLA

(since 1989 until NOW)

STELLA

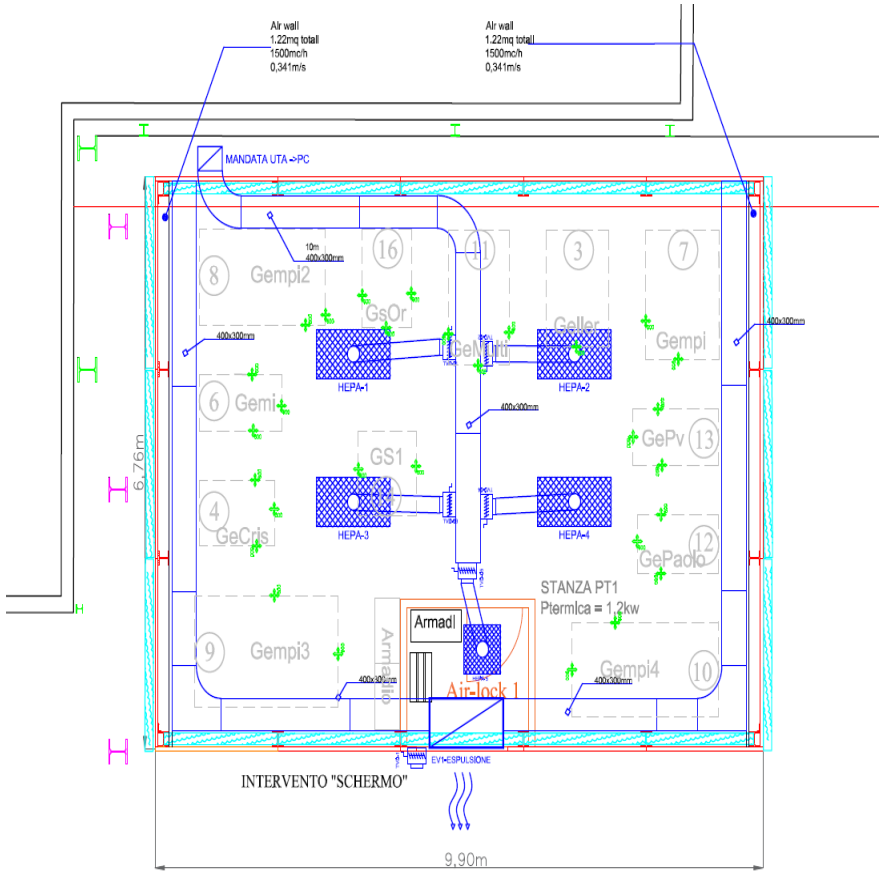
(FUTURE)

New laboratory

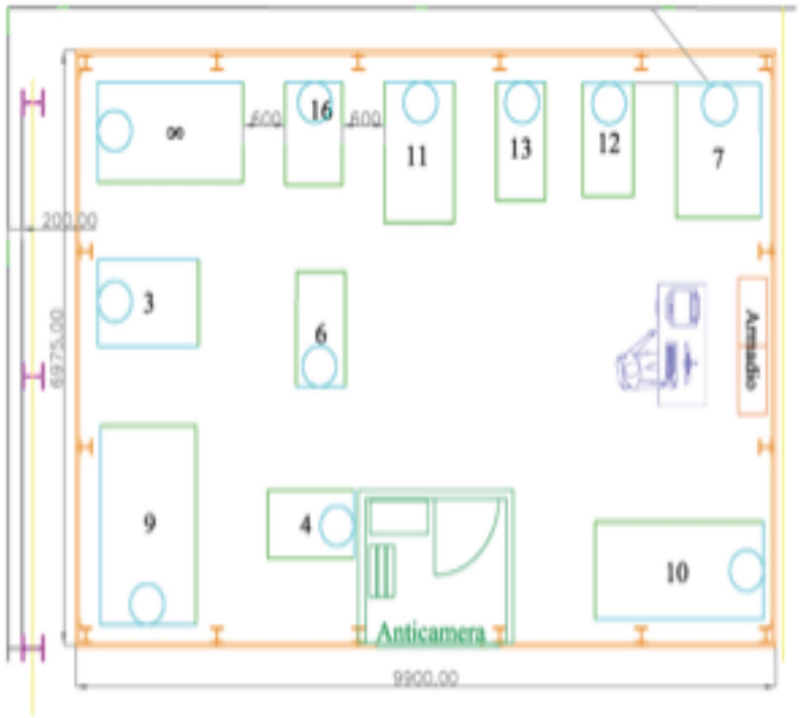


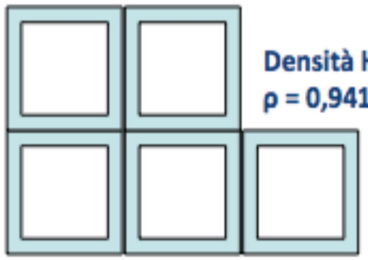
GROUND FLOOR REFURBISHMENT -1

The 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.

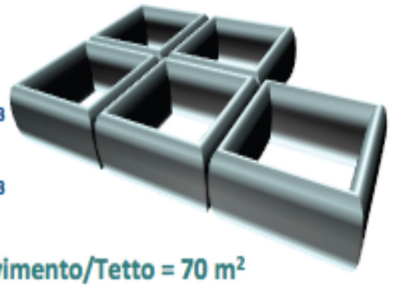


GROUND FLOOR REFURBISHMENT - 2





Densità HDPE
ρ = 0,941 – 0,965 kg / m³



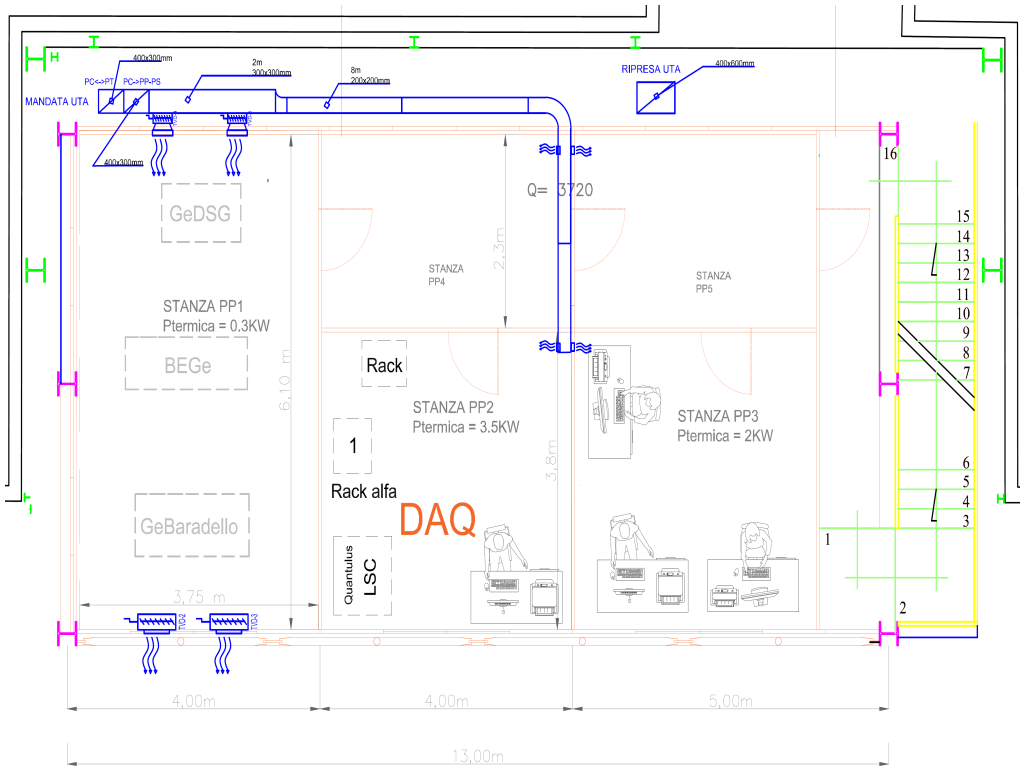
Densità HDPE
ρ = 0,950 kg / m³
ovvero
ρ = 1,000 kg / m³

Area Pavimento/Tetto = 70 m²

The ground floor will be equipped with a passive neutron shielding placed all around the external walls; it will be made with water-filled tanks. The required shielding thickness is 15 cm.
The floor shielding will be realised with HDPE slabs, possibly embedded in a steel structure that will hold the clean room floor to withstand the load of the detector shielding.

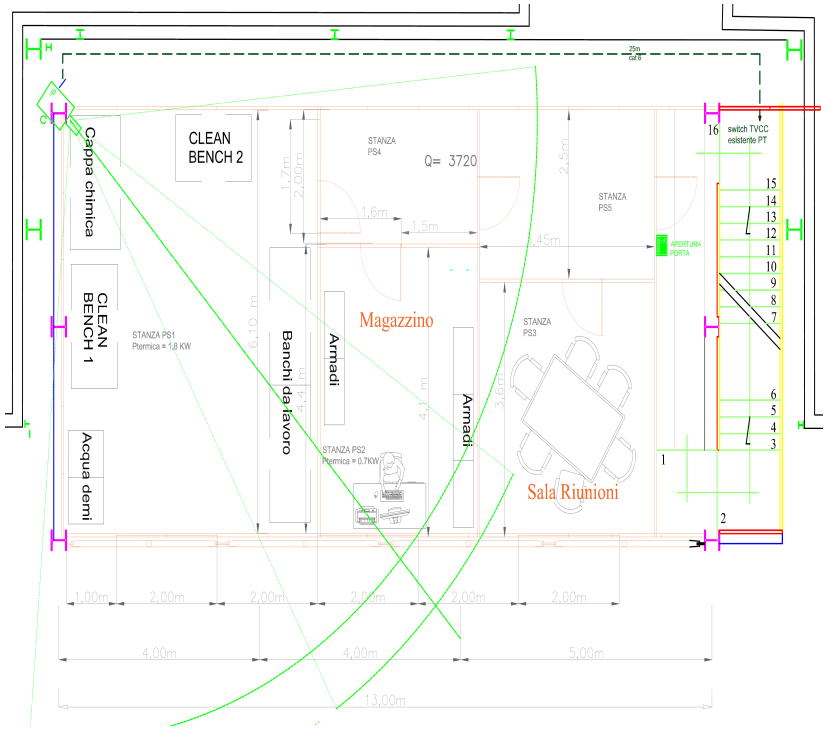
FIRST FLOOR REFURBISHMENT

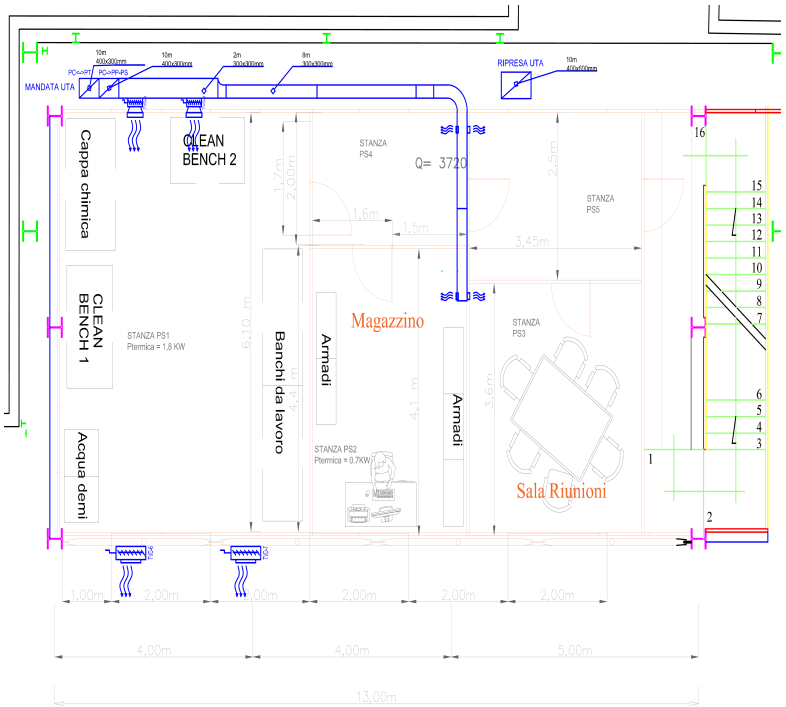
The first floor of the ex-OPERA building will be rearranged to host on the a controlled environment volume with similar characteristics to the ground floor, and offices and the DAQ room in the remaining part.



SECOND FLOOR REFURBISHMENT

The second floor of the ex-OPERA building will be rearranged to host a small laboratory, offices and 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.

Meteorites

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Meteorite measurements (*King et al., «The Winchcombe meteorite, a unique and pristine witness from the outer solar system» Science Advances, 8, eabq3925, 16/11/2022; Shober P.M. et al., «Arpu Kuilpu: An H5 from the outer main belt», Meteoritics and Planetary Science, 57, Issue 6 (2022) pp. 1146-1157*);

Rare decay search

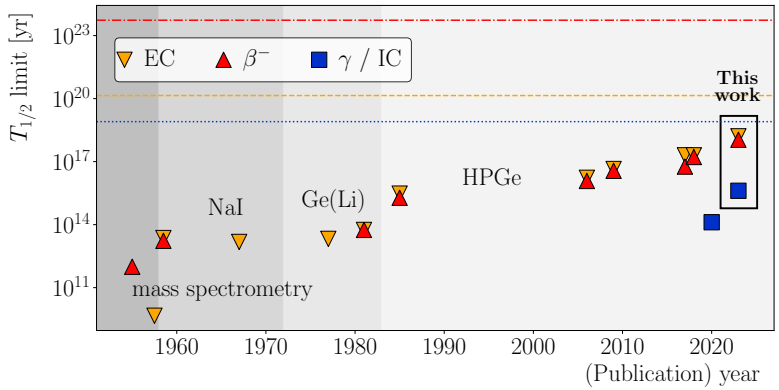

Fig. 2 Lower limits on the decay half-life of ^{180m}Ta on the EC, β^- and γ / IC channels [9, 18–28]; the box encloses the new results presented in this work. The labels and corresponding shadowed areas refer to the different techniques used for the measurements. The horizontal lines indicate the theoretical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

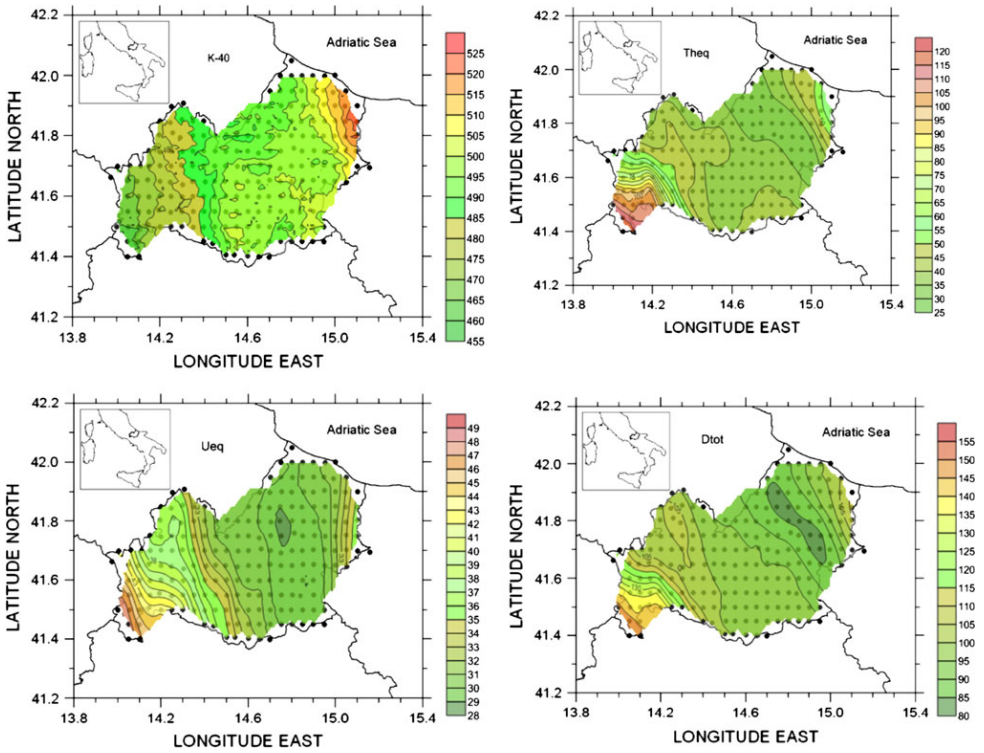
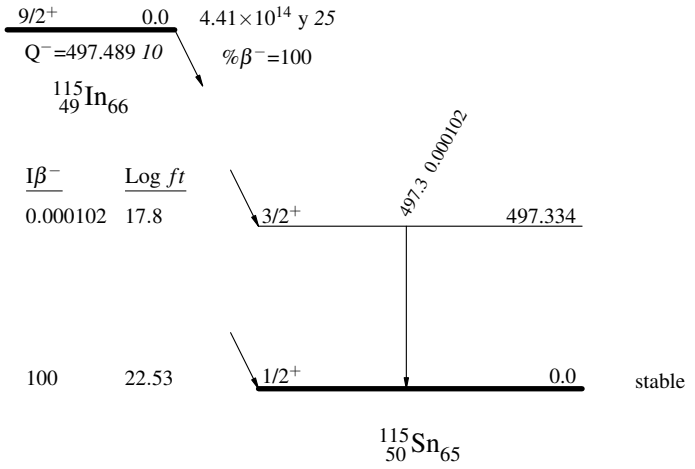


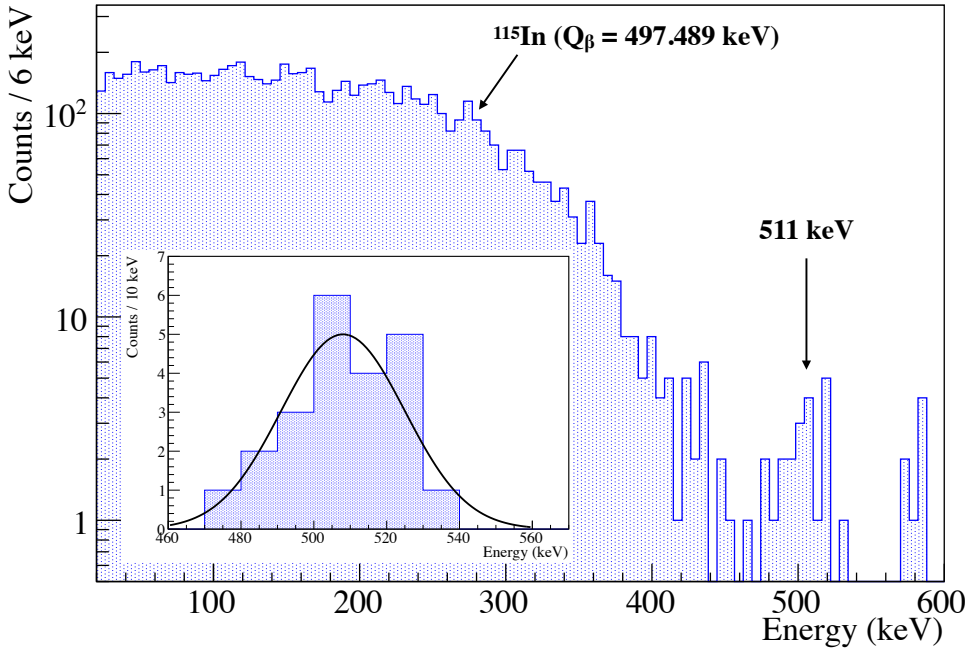
Fig. 1 Radioactivity maps of the Molise region showing massic activities (in Bq kg^{-1}) of ^{40}K, U_{eq} (represented by ^{226}Ra), Th_{eq}, and the total dose rate due to natural radioactivity and cosmic radiation (in nGy h^{-1})

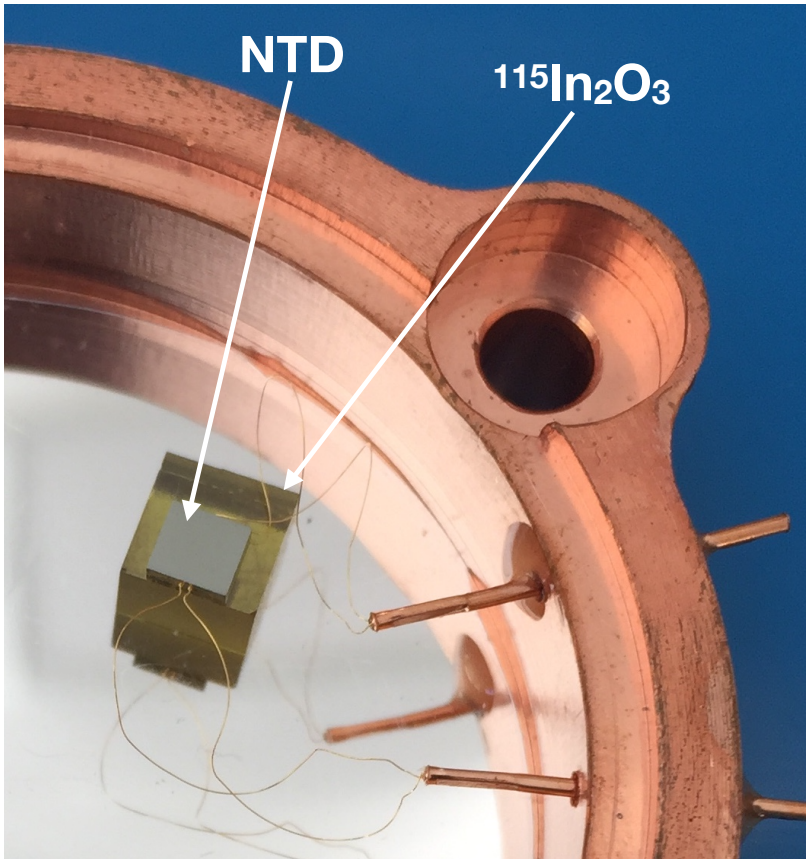
New detector design

- **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;*

  Nagorny, S. et al., «Measurement of Pt-190 alpha decay modes with gamma emission using a novel approach with an ultra-low-background high purity germanium detector», Journal of Instrumentation, 16, Issue 3 (2021) P03027).

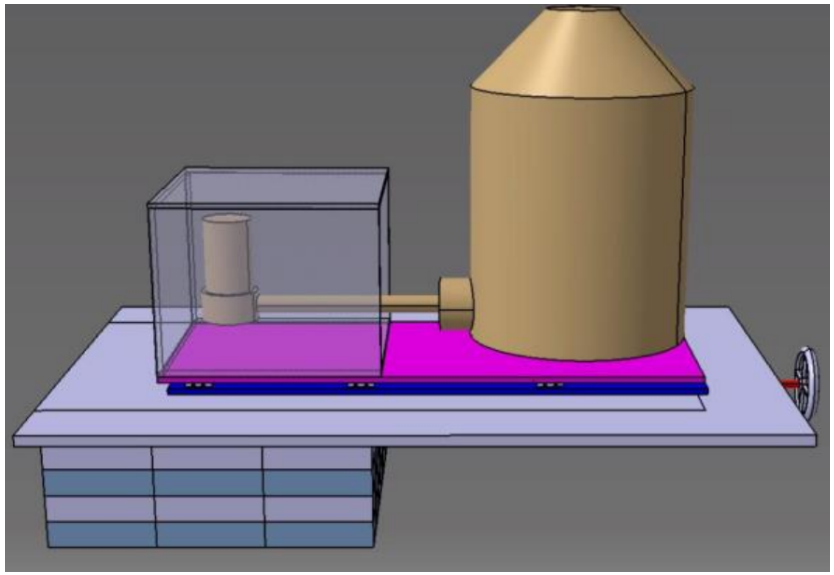






In_2O_3

4th forbidden non-unique β decay

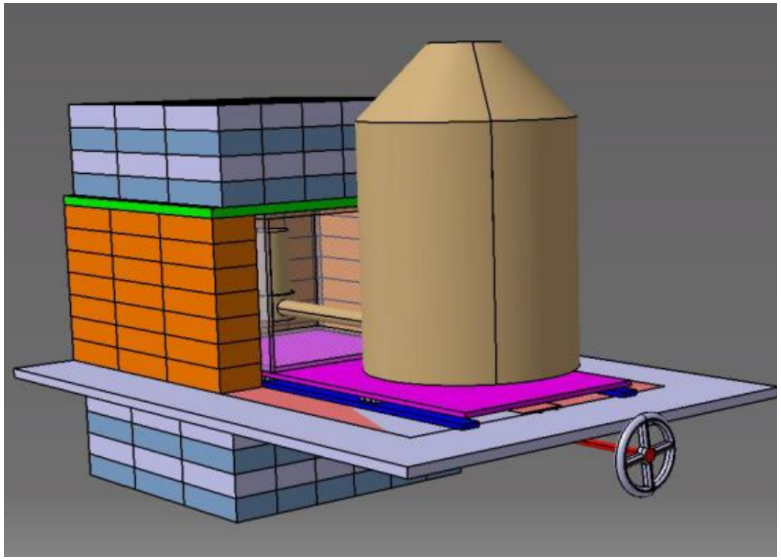


GS1

Operated al

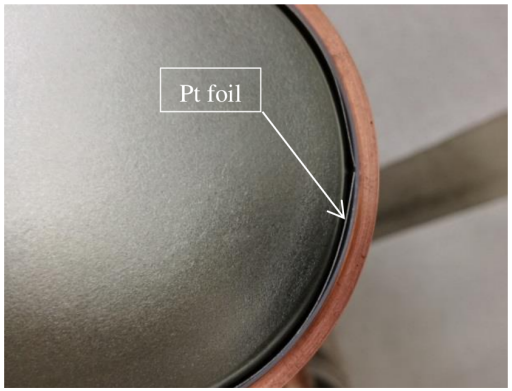
LNGS

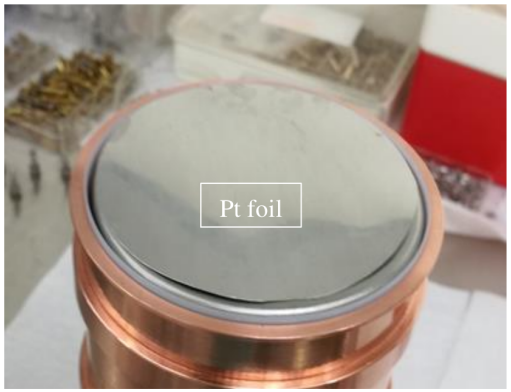
(3800 m w.e.)

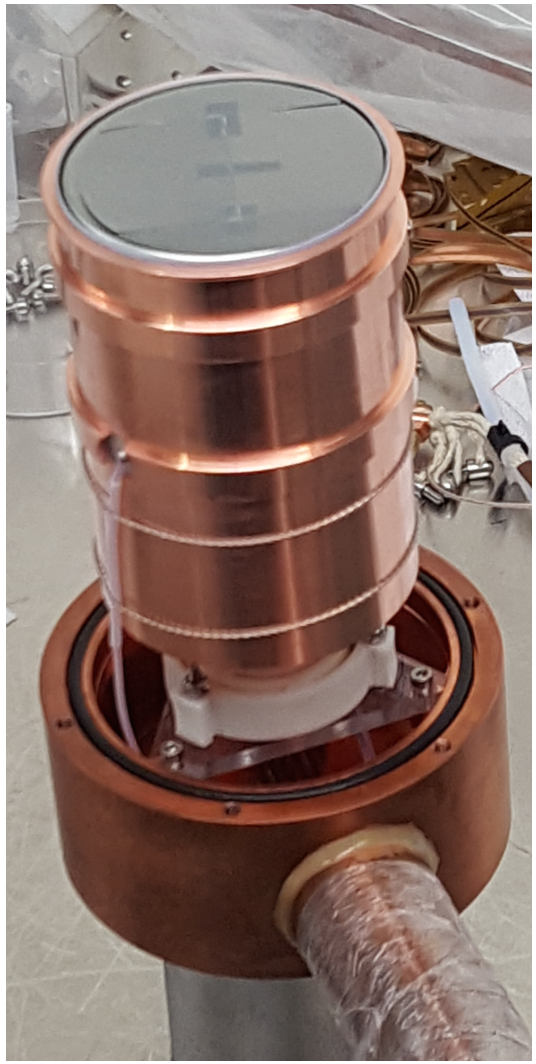


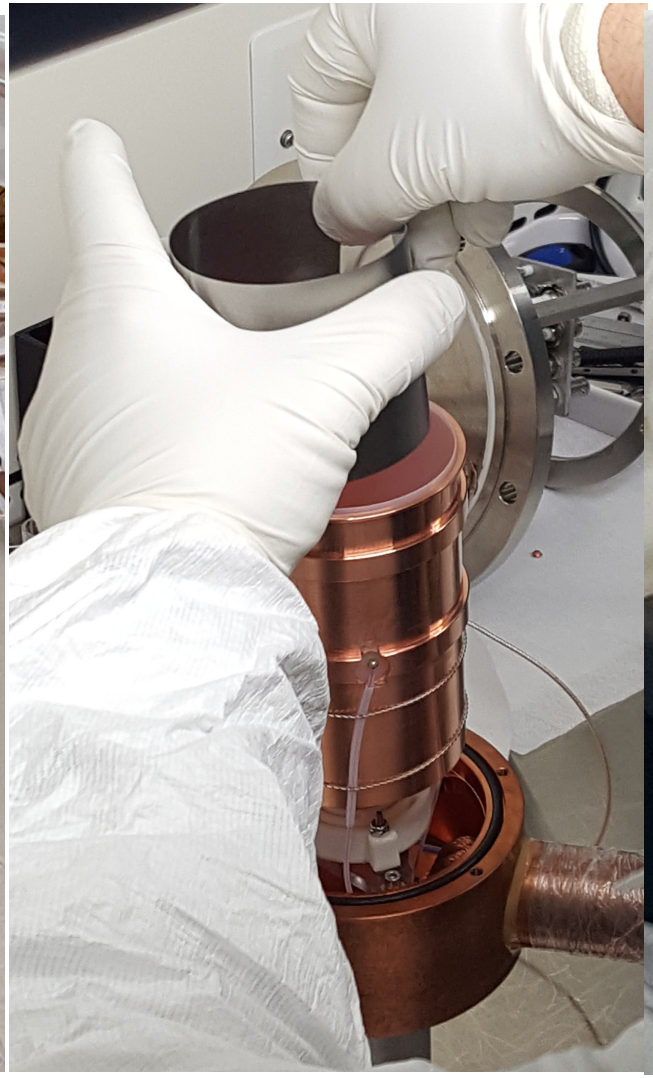
S.S. Nagorny

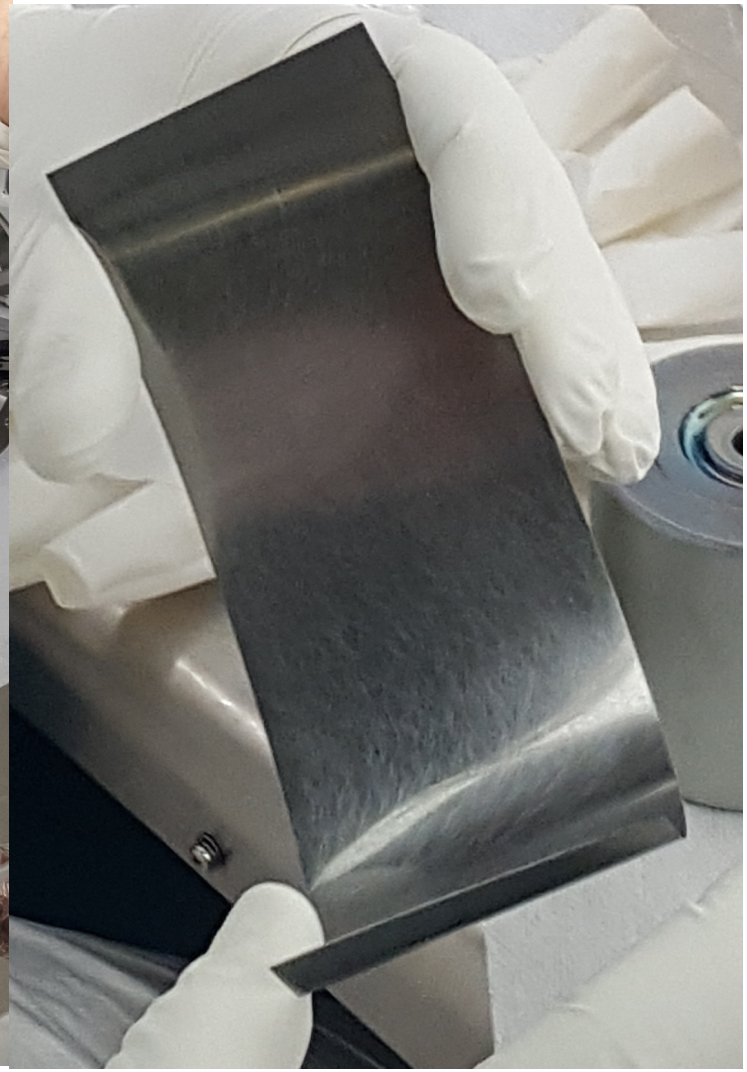
M. Laubenstein











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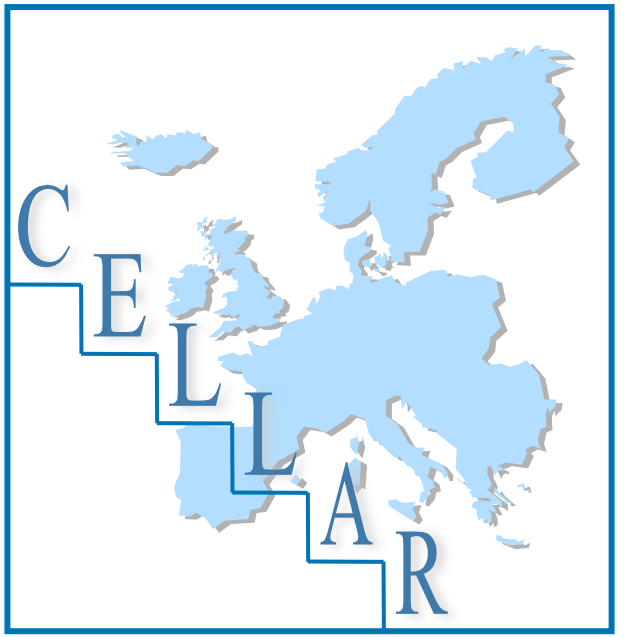
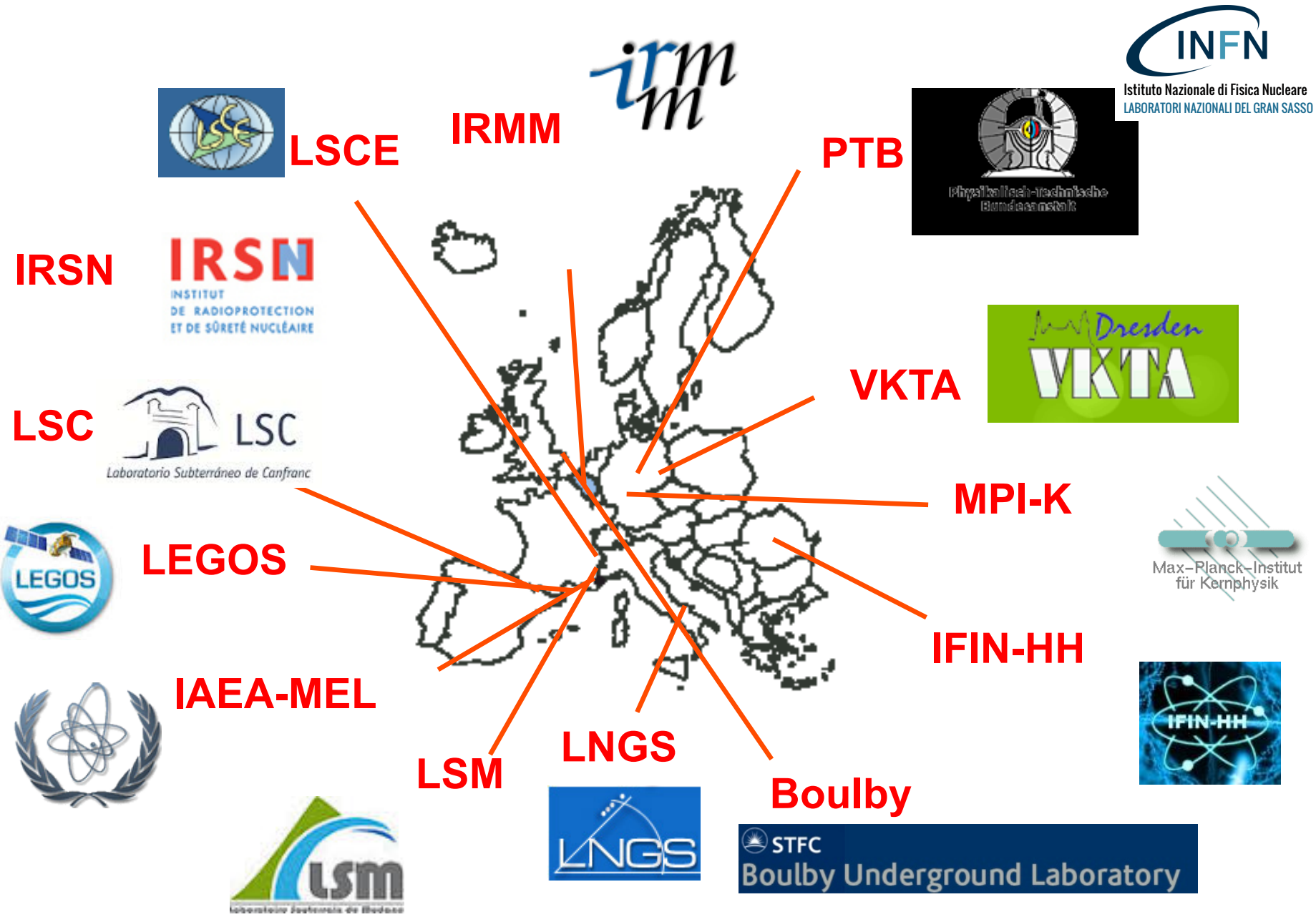
CELLAR

Collaboration of **E**uropean **L**ow-level **underground** **LA**bo**R**atories




LSCE
IRMM
PTB
IRSN
VKTA
LSC
MPI-K
LEGOS
IFIN-HH
IAEA-MEL
LSM
LNGS
Boulby
INFN
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LSC
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LEGOS
Max-Planck-Institut für Kernphysik
IFIN-HH
LSM
LNGS
STFC
Boulby Underground Laboratory

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);

Collaboration with IAEA & ENEA

- 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;

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Conclusions

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

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.) The upgrade of the STELLA laboratory will open new opportunities for detector upgrades and will improve further the background characteristics.

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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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Thank you for your attention !