Science and Technology Facilities Council

Boulby Underground Laboratory

WP5.3 – New Assay Technologies

Paul Scovell – 28/04/22

Introduction

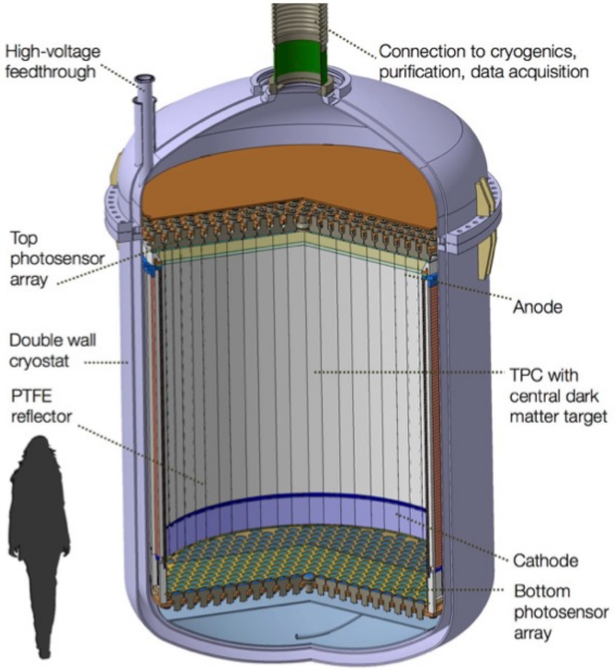
- *A problem on the horizon!*
- *Introduction to facilities*
- *What are we aiming to achieve?*
- *Deliverables*

- With budgetary constraints, this WP is relatively low on equipment costs.
  - Substantial improvements can still be realized
- Coordinate efforts among existing laboratories to build and consolidate expertise ready to “hit the ground running” for future large scale experiments

A Problem on the Horizon

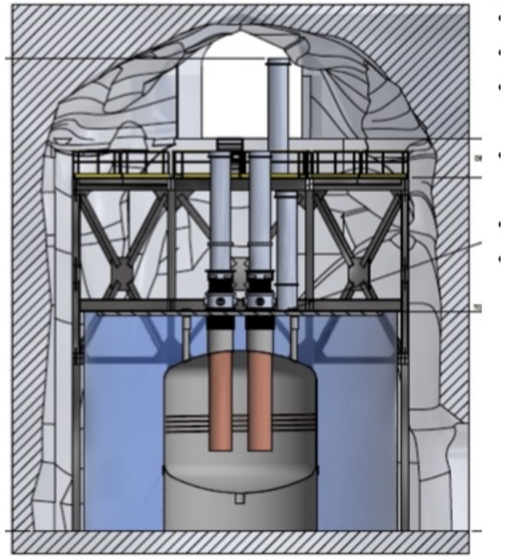
- The next generation of low background physics experiments are going to be huge

LZ/XENON/DARWIN



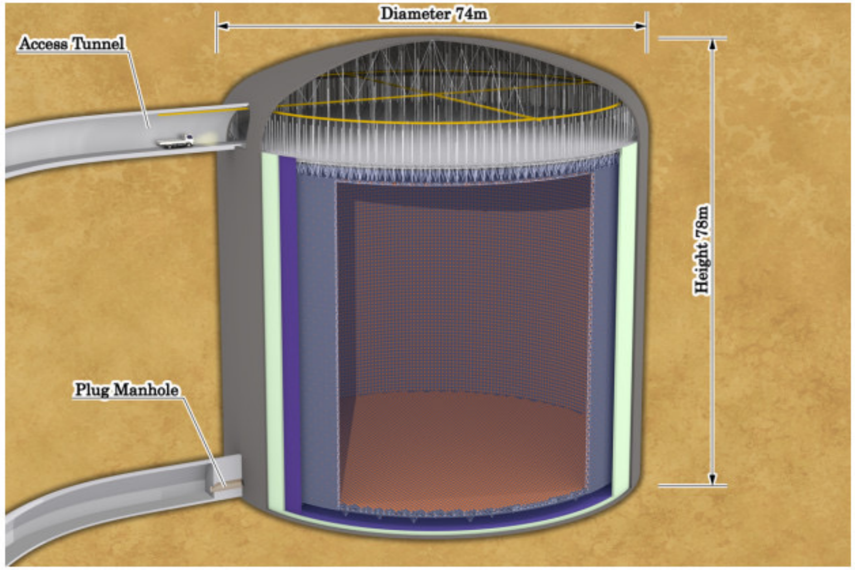
Credit: [arXiv:1606.07001v1]

LEGEND



Credit: [W. Pettus, PANIC 2021]

HYPER K



Credit: [U. Warwick Hyper-K Group Website]

A Problem on the Horizon

- Each project will require *O*(10,000) individual components
  - Scales from individual surface mount electronic components to whole cryostats and assemblies
- In the UK, we have a wide and mature array of assay techniques
  - HPGe
  - Surface Alpha
  - Radon Emanation (warm and cold)
  - ICP-MS
  - Cleanliness studies
- But this isn't going to be enough

Introduction

- The world of low-background material assay spans many fields
  - Particle Physics – eg Dark Matter, 0vBB
  - Geophysics
  - Environmental Science
  - Aviation
  - Etc
- An array of techniques are used to determine various parts of the NORM decay chains
  - E.g. U238

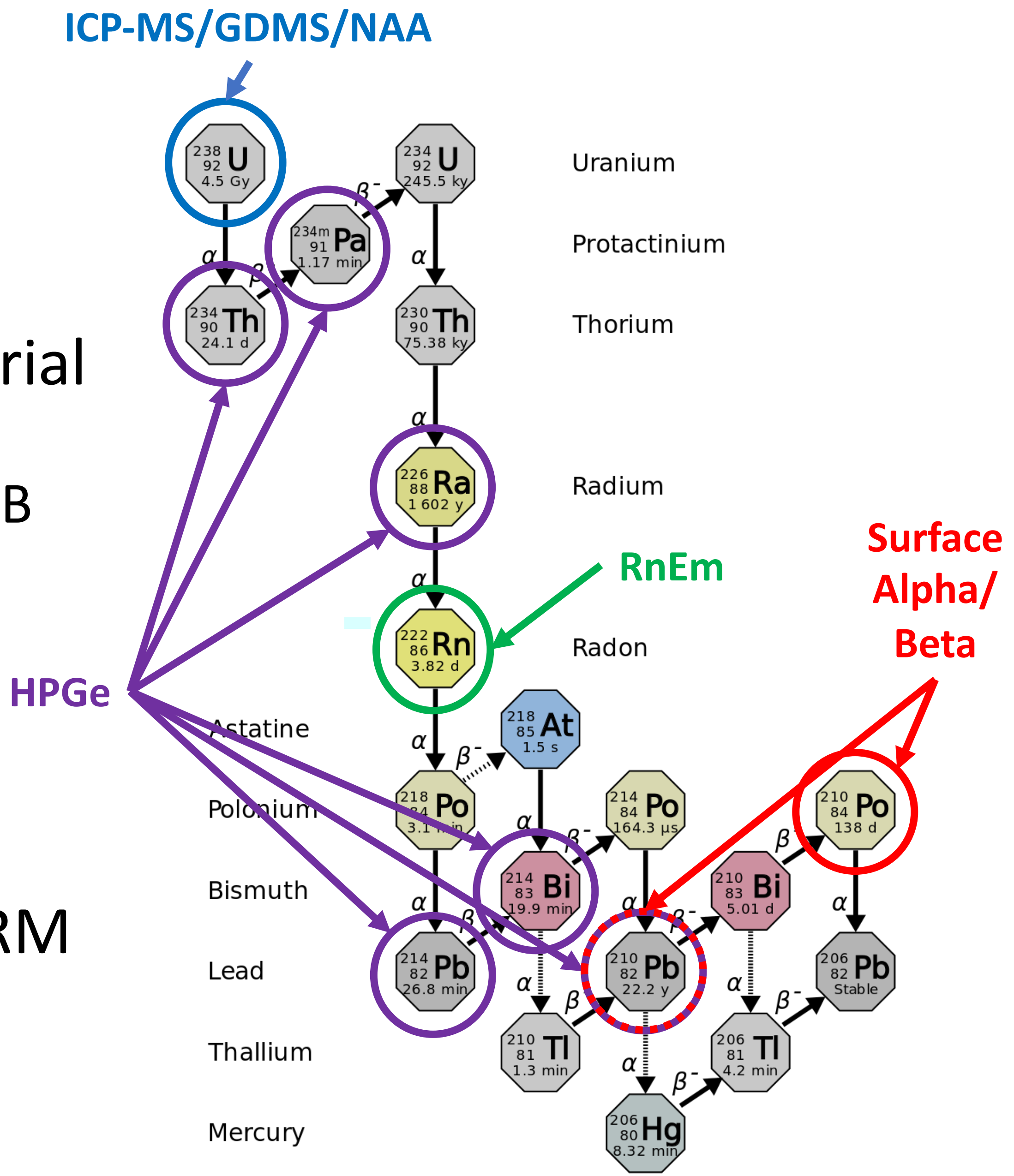


Image taken from Wikipedia – User: Tosaka

How to Maximise Sensitivity

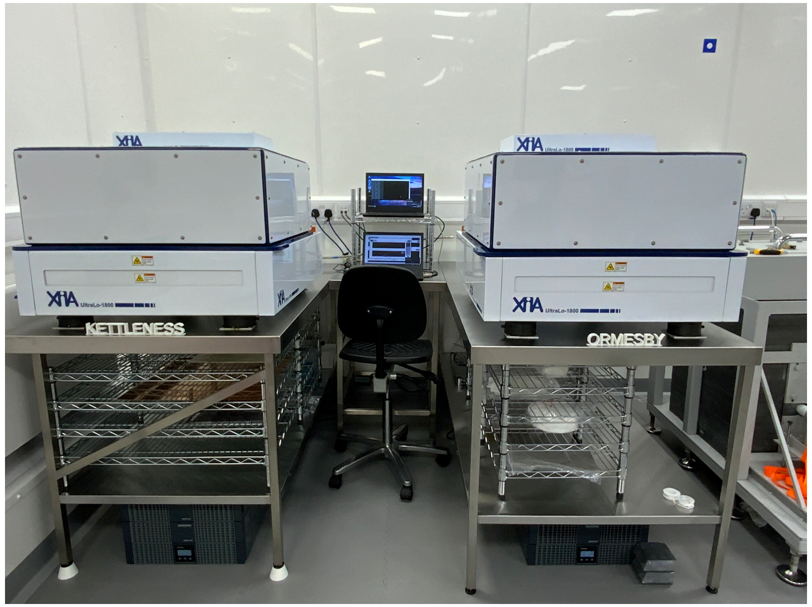
- Assay detectors constructed from low background materials
- Reduce ambient radon (can be challenging!)
- Low background shielding
- Large active detector volume – also maximises throughput
- Low energy capabilities

- And keep it all clean, background stable, aim for 100% duty cycle!

Our Facilities

Boulby

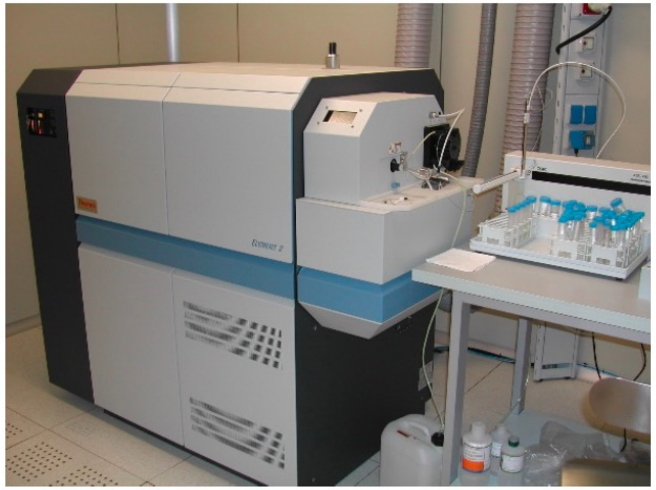
Boulby Underground Screening (BUGS) Facility – hosts six HPGe systems with two considered low background and four of the ultra-low background (ULB) standard. In the ULB standard there are 600 cc and 375 cc p-type detectors and BEGe BE6530 and ULB SAGe well type detectors which allow the study of material background down to a few keV energy and with almost 4-pi coverage in the case of the SAGe-well. BUGS also hosts two XIA ultralo 1800 surface-alpha counters and a dual detector radon emanation assay system.

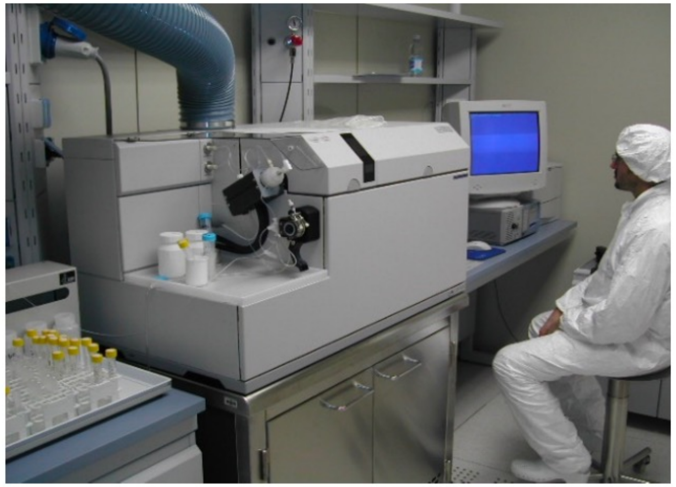


Credit: STFC Trev Palin

LNGS

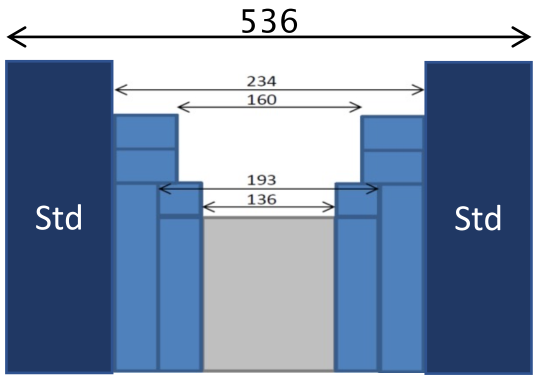
LNGS has been operating a **mass spectrometry facility** for 20 years. It is located inside an ISO5 clean room, and it consists of two Inductively Coupled Plasma- Mass Spectrometers (ICP-MS). The former is equipped with double focusing mass analyser, the latter is a quadrupole-based mass spectrometer. Several instruments for sample treatment, water and reagent purification are available. The **SubTerranean Low Level Assay (STELLA) laboratory** at LNGS hosts currently fourteen HPGe systems, all of them considered ULB standard. They are mainly p-type detectors, but there are also two detector systems available that allow to measure down to few tens of keV energy (one, BEGe, one well-type detector). Moreover, there are four small α-particle detectors, and two low background liquid scintillation counters available (WALLAC Quantulus, HIDEX TDCR (Triple-to-Double Coincidence Ratio)).

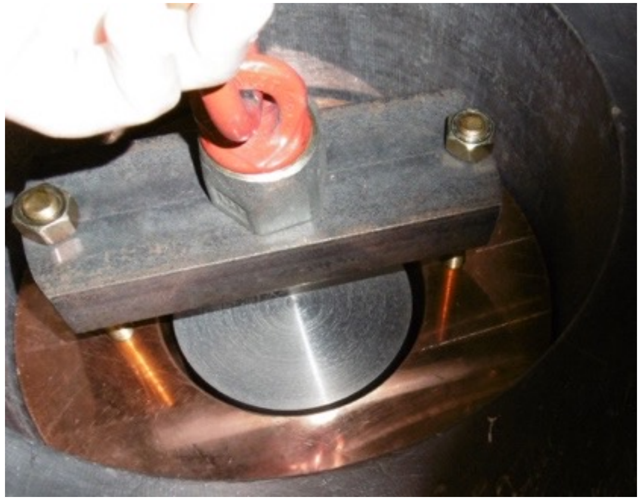


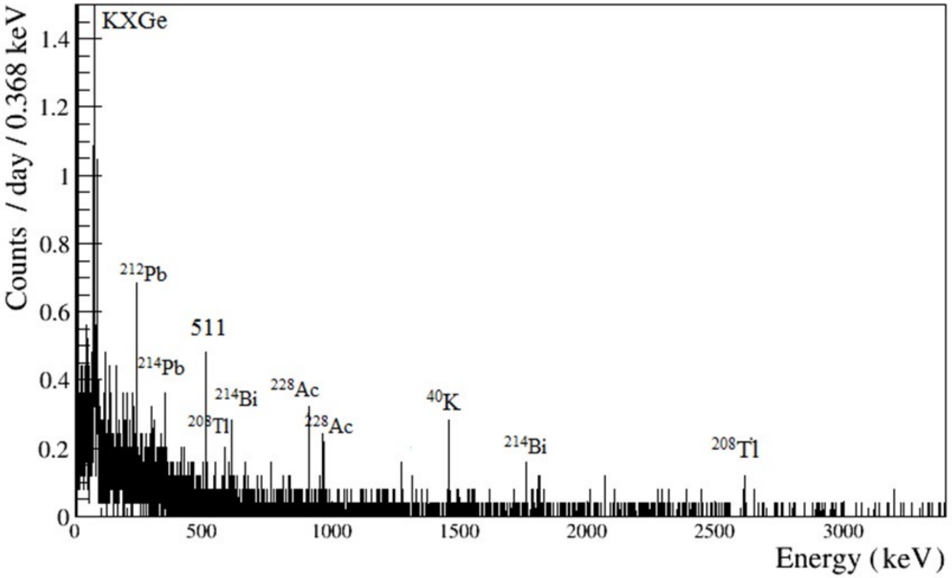


LSM

LSM hosts 22 HPGe spectrometers for low and ultra-low background measurements. The detector volume ranges from 80 cm^3 up to 980 cm^3 with different types of germanium (coaxial, planar and well-type detectors) allowing the measurement of various samples from few g to several kg. Moreover, low background alpha and radon detectors are available in the laboratory. Finally, the LSM is in close contact with ENS Lyon for low level ICP-MS measurements

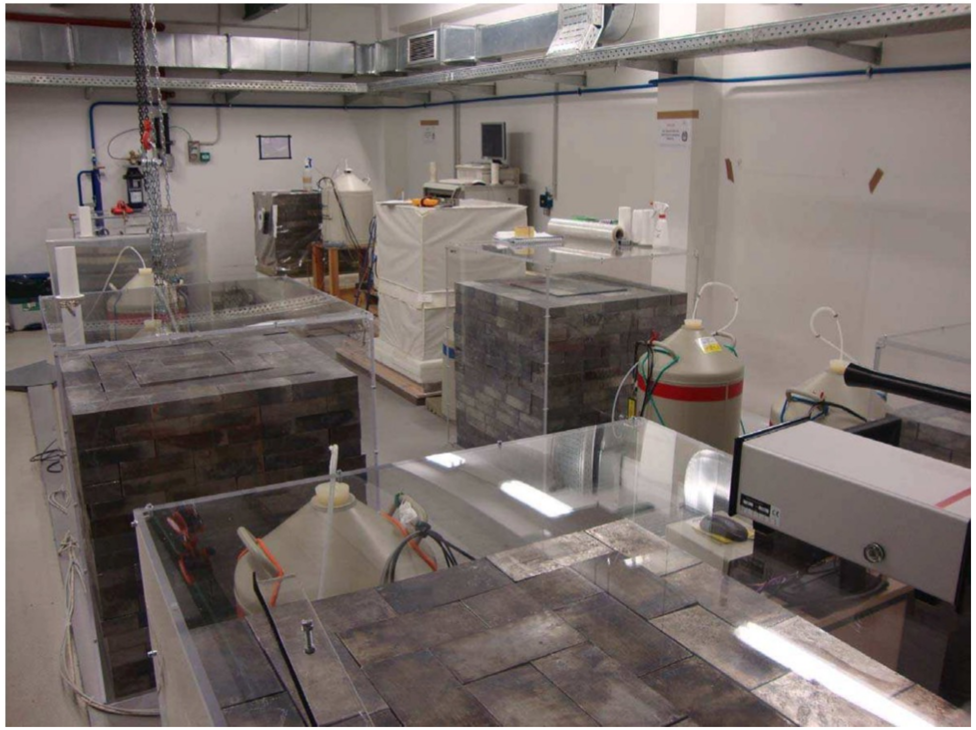






LSC

LSC LSC hosts eight HPGe detectors for ultra-low background measurements. They are 7 p-type closed-end coaxial 2.2-kg High Purity germanium detectors, aluminum or copper cryostats and relative efficiencies in the range from 100 to 110%. The shielding of each detector is made of 20 cm of lead with ^{210}Pb activity less than 29 Bq kg^{-1}. An internal shield of 10 cm of oxygen-free high thermal conductivity (OFHC) copper for 6 detectors and 5 cm for the remaining one is added to reduce the bremsstrahlung produced by the remaining ^{210}Pb activity. In addition, there is 1 SAGe well type detector which 19.7 cm3 well capacity. Finally, a quadrupole ICP-MS is available for U and Th quantification as well as the corresponding laboratory facilities for sample treatment. Moreover, a new ICP-MS will be hosted in the clean room equipped with an automation system for extraction/preconcentration purposes. This new service will be available during the second half of 2022.



Name	V [cm3]	M [kg]	FWHM @ 1332 keV [keV]	Integral (60-2700) keV [cts/kg/day]	Tl-208 583.19 keV [cts/kg/day]	Bi-214 609.3 keV [cts/kg/day]	Co-60 1332.5 keV [cts/kg/day]	K-40 1460.8 keV [cts/kg/day]
GeOroel (p-type)	420	2.31	2.22	128.7	1.29+/-0.16	1.13+/-0.15	0.06+/-0.03	0.68+/-0.11
Asterix (p-type)	387	2.13	1.92	171.3	0.48 +/-0.08	0.73+/-0.14	0.28+/-0.06	0.62+/-0.09
GeAnayet (p-type)	410	2.26	1.99	461.2	3.68+/-0.33	0.71+/-0.14	0.16+/-0.04	0.74+/-0.08
GeLatuca (p-type)	410	2.26	1.86	305.3	3.57+/-0.33	1.16+/-0.16	0.23+/-0.05	0.56+/-0.15
GeTobazo (p-type)	410	2.26	2.02	453.8	3.35+/-0.33	0.93+/-0.16	0.23+/-0.05	0.98+/-0.15
GeAspe (p-type)	409	2.25	1.96	455.7	3.79+/-0.35	1.20+/-0.16	0.56+/-0.11	1.01+/-0.19
GeRysy* (SAGE-Well)	427	2.35	2.04	587.1	0.44+/-0.01	1.23+/-0.17	0.22+/-0.02	0.41+/-0.07

Work Package Aims and Objectives

1. Collaborate

- Foster and improve inter-laboratory collaboration
- Data analysis techniques
- Unify Quality assurance and Quality control

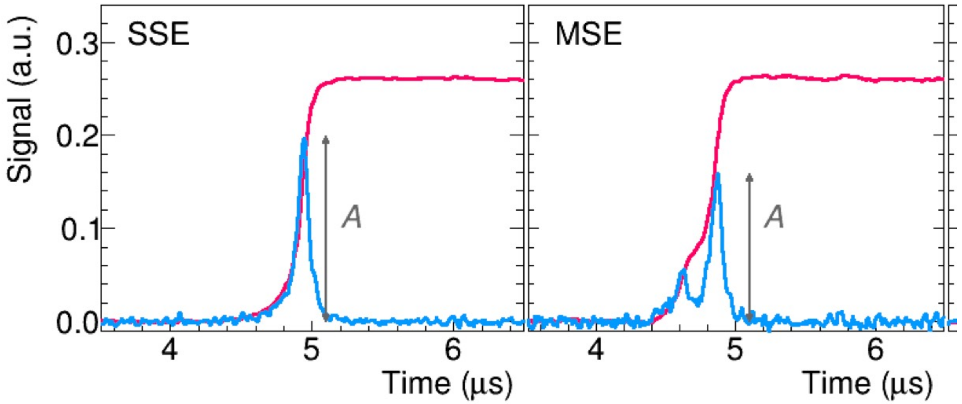
- Ensure that the European underground radio-assay community is prepared for future demand from the low-background particle physics community
- Comprehensive cross-calibration effort across all facilities using all techniques

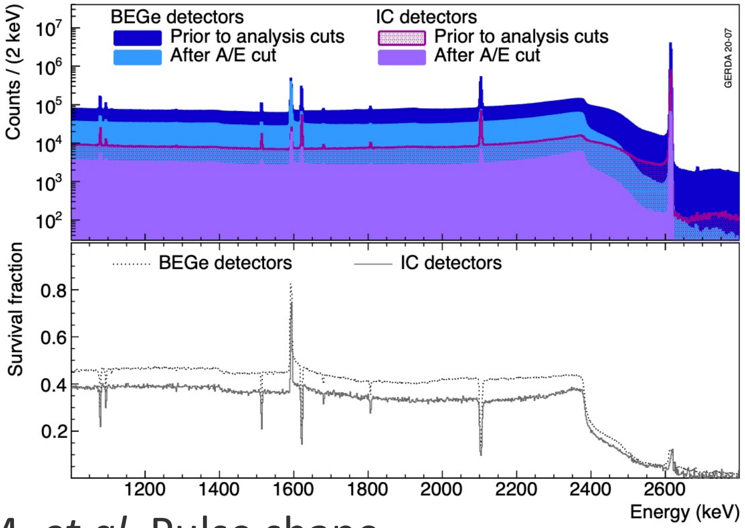
2. Identification of Clean Materials

- Use existing relationships with HPGe and related manufacturers to characterise and develop a catalogue of suitable materials for construction of future high purity germanium (HPGe) systems.
- Work in partnership with HPGe and related manufacturers to develop a catalogue of approved materials for use in the construction of future HPGe systems. This will include electronic components and cryostat components including the assay of electroformed copper that will be produced as part of the work of the additive manufacturing group

3. Improve Data

- Investigate potential improvements in HPGe data quality with a particular concentration on pulse shape discrimination and baseline noise reduction.
- Pulse shape and timing analysis will be done on point contact germanium detectors





Agostini, M., Araujo, G., Bakalyarov, A.M. *et al.* Pulse shape analysis in GERDA Phase II. *Eur. Phys. J. C* **82,** 284 (2022)

4. Destructive HPGe Assay

- Investigate any improvements in sensitivity and throughput that can be gained through sample preparation including chemically separated assay using HPGe detectors.
- Leverage techniques developed for ICP-MS in HPGe assay
- Dissolve sample
- Chemically extract radioactive isotopes of interest (U, Th, Ra, Pb)
- Chemical extraction techniques will be developed through this project

5. ICP-MS Automation

- The limit of detection (DL) for the ICP-MS technique is often limited by the background level of the analytical method rather than the instrumental sensitivity.
- Typically, the operator adopts complex and time-consuming chemical procedures to separate the matrix and pre-concentrate the analytes prior to the ICP-MS measurement.
- Develop fully automated system for inline sample processing of different materials widely used in low background particle physics detectors

6. Build External Partnerships

- Build relationships with partners from outside the field of underground physics who require ultra-low background measurements.
- Fexample, surface-alpha assay to the electronics industry to demonstrate the sensitivity gains that are possible when assaying samples underground.
- This will help to characterise the risk of single event failures in electronics to complement gains being made in software redundancy to tackle the effects of such failures.

7. Detection of α- and β-particles

- Enhance α- and β-particle detection capabilities and improve their sensitivities in the light of the new challenging demands in future experiments.
- New techniques have to be developed to meet these requirements, which consist of:
  - Development of dedicated sample preparation techniques
  - Background improvement of detectors capable to measure a- and b-particles (e.g. ultra-low background liquid or plastic scintillation counters).

8. Help improve HPGe construction Techniques

- Develops on Aim 2
- Looks more to the construction techniques, cosmogenic activation
- Minimising time on surface
- Minimising material around detectors
- Will require additional collaboration with detector manufacturers (Mirion, Ametek, BSI, Caen, etc)

Deliverables

Deliverables

1. Hire personnel that will develop the assay techniques
2. Delivery of comprehensive cross-calibration for low background material assay**.**
3. Delivery of result on sensitivity gains for destructive HPGe assay
4. Delivery of results of pulse-shape discrimination and baseline noise reduction for point contact germanium detectors
5. Report on identification of suitably radiopure materials that may be used for future HPGe detector systems
6. Develop database for distributing future samples between participating laboratories
7. New protocols for sample treatment and automation prior to ICP-MS measurement in order to enhance the sensitivity.
8. Design report for a new ULB detector measuring a- and b-particles.
9. Design report for a new ULB HPGe detector which will lower background whilst increasing counting efficiency