

Review of Gamma-ray spectrometry for Material Radio-assay in Current and Future Generation Rare Event Search Experiments

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LRT - 20/05/2019

Introduction

- Whistle stop tour of the under- and over- ground germanium suites worldwide

whistle-stop 



ADJECTIVE

[attributive] Very fast and with only brief pauses.

‘a whistle-stop tour of Britain’

[+ More example sentences](#)

[– Synonyms](#)

quick, fast, swift, speedy, high-speed, expeditious, express, brisk, lively, prompt, flying, fleeting, lightning, meteoric, overnight, whirlwind, fast-track

[View synonyms](#)

can be relatively low cost and risk vs impact

Introduction

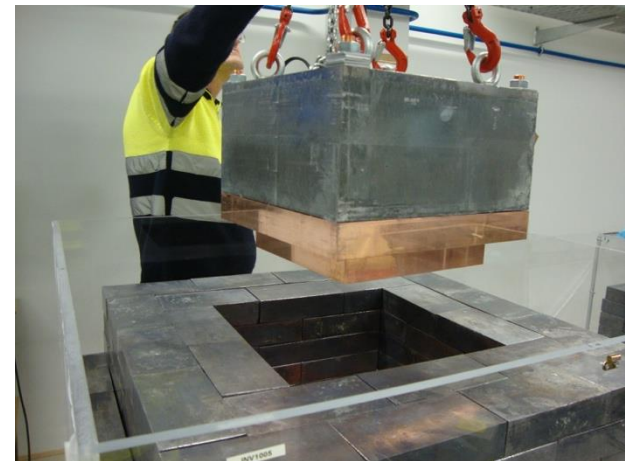
Laboratory	#Crystals	#Ge Systems
Canfranc	8	8
CJPL	3	3
CUP	16	3
Kamioka	1	1
LNGS	17	16
Modane	2	2
SNOLAB	4	4
SURF	6	5
Vue Des Alpes	1	1
LBNL	2	2
MPI-Heidelberg	1	1
U. Alabama	3	3
LAFARA	5	5
Boulby	7	7
Total	76*	61*

* Included in this talk – also not all are running!

Canfranc



- 7 HPGe p-type coaxial (2 kg)
- 1 SAGe Well model GSW275L
- (all made by Canberra)



- Facility provided with Rn reduced air at the level of approx. 1 mBq/m³
 - Reduction of 1000x

Canfranc

Name	V [cm ³]	M [kg]	FWHM @ 1332 keV [keV]	Integral (60- 2700) keV [cts/kg/day]	Tl-208 2614.5 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	420	2.31	1.85	165.3	0.4	2.9	0.1	0.4
Asterix	387	2.13	2.08	189.2	0.2	2.1	0.5	0.3
GeAnayet	410	2.26	1.96	473.3	3.2	1.9	0.1	0.6
GeLatuca	410	2.26	1.86	342.0	3.9	2.8	0.2	0.8
GeTobazo	410	2.26	2.07	491.7	3.8	2.8	0.4	0.7
GeAspe	409	2.25	1.94	477.9	3.8	2.2	0.3	0.9

Sensitivity, assuming secular equilibrium and 10% efficiency:

$^{238}\text{U} \sim 10 - 100$ ppt

$^{232}\text{Th} \sim 50 - 330$ ppt

$^{40}\text{K} \sim 10 - 100$ ppb

China Jin Ping Laboratory

- Three main screeners
 - GeTHU1: N type HPGe, 0.9kg crystal, 0.29cpm/kg_{Ge}(40~2700keV)
 - GeTHU2&2s: BEGe with glove box, compact system



GeTHU-1
0.29 cpm/kg_{Ge}
40-2700 keV

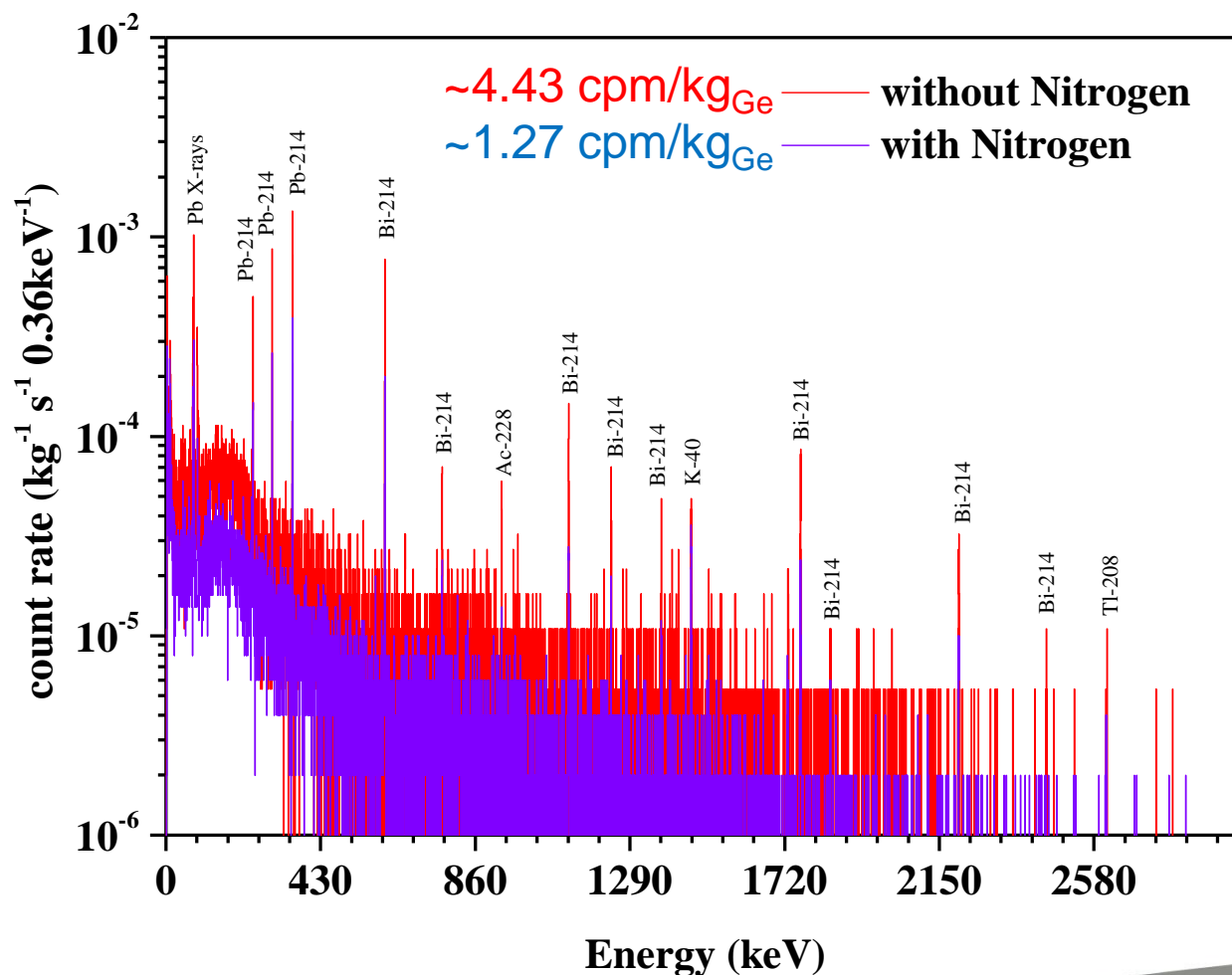


GeTHU-2



GeTHU-2s

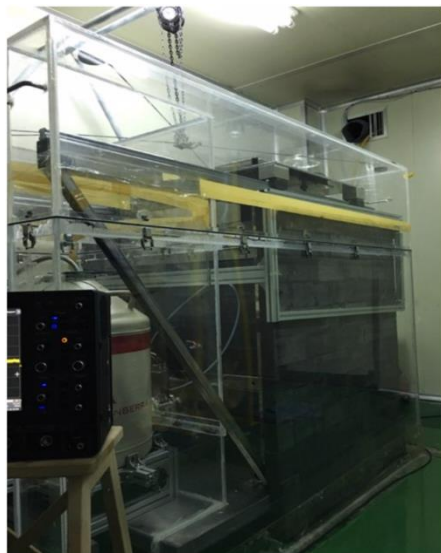
China Jin Ping Laboratory



GeTHU-II

Center for Underground Physics

- CUP has 2 detectors for material screening



← CC1
CC2 →
Both 100% rel. eff.



Dedicated shielding:

top & bottom 10 cm Pb + 10 cm Cu (inner)

side 15 cm Pb + 10 cm Cu (inner)

IMPROVED

using 5 cm thick ancient Pb closer to the detector

Total Count Rate: 6.9mHz @ 50~3200keV

Dedicated shielding:

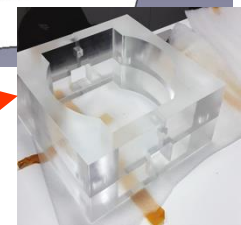
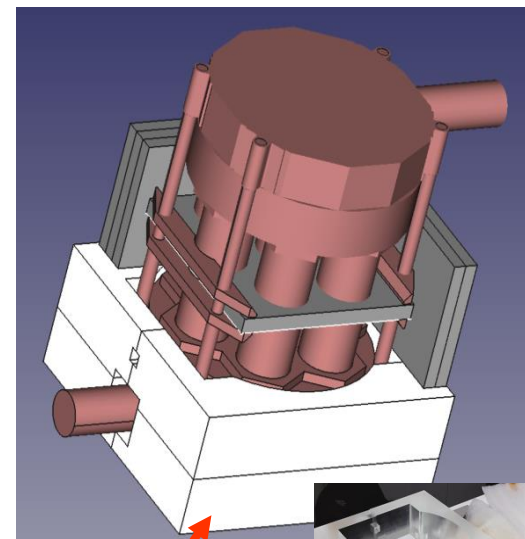
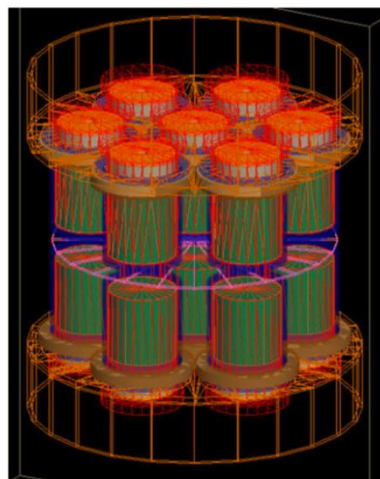
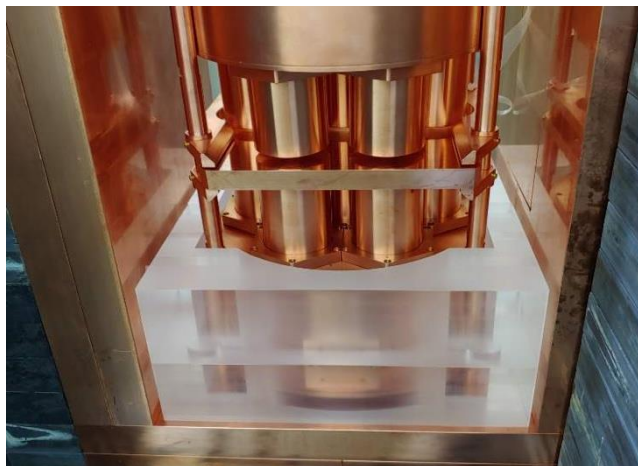
General Pb(10cm)+ Goslar Pb(10cm) +Cu(10cm)

IMPROVED

Installing acrylic globe box for protecting Rn contamination **Total Count Rate:** 8.2mHz @ 50~3200keV

Center for Underground Physics

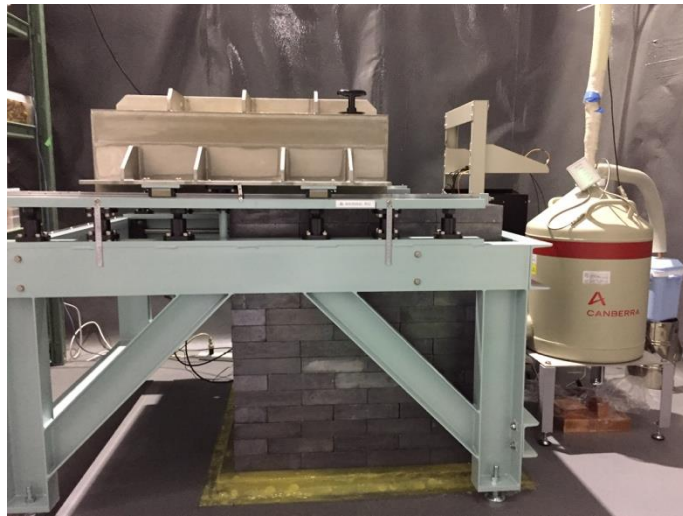
- Also Home of an amazing system!
 - Array of 14 detectors
 - 980% rel. eff. !!
 - Used for material screening but also fundamental science
 - $^{180\text{m}}\text{Ta}$ rare β -decay



Acrylic supporter

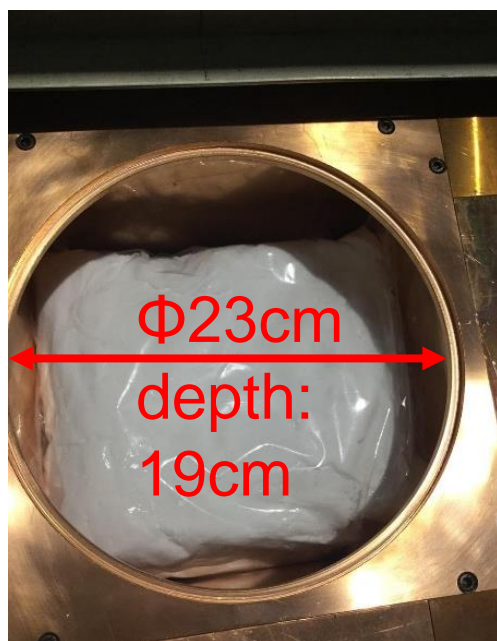
Kamioka

- Single detector use for EGADS screening
 - HPGe 80% rel. eff. from Canberra
 - 1 cm 6N grade Cu ,5 cm Cu
 - 2.5 cm low Pb(~ 5 Bq/kg) lead



Kamioka

Integral (60-2700) keV [cts/kg/day]	Tl-208 2614.5 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]
111.1	0.14	0.49	0.44	0.57



- Reaches <0.4 mBq after 12 days
- Developing new ultra low RI HPGe
 - Discussion with manufacture is ongoing

Laboratori Nazionali del Gran Sasso

- The star here is (and has been for some time) GeMPI
- However, there are 15 additional detectors
- 11 p-type
- One well-type
- One BEGe
- One n-type
- One multiple-crystal



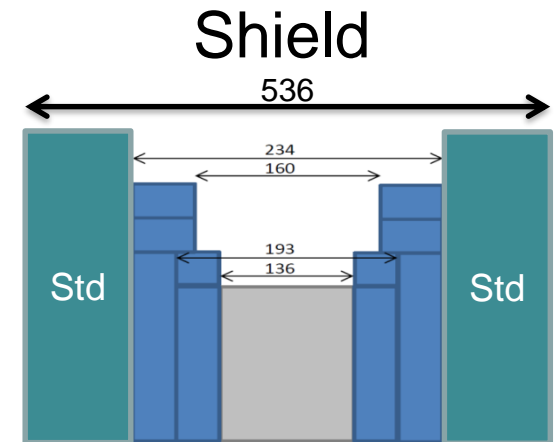
Laboratori Nazionali del Gran Sasso

detector	total and peak background count rate [$\text{d}^{-1} \text{kg}^{-1}_{\text{Ge}}$]			
	40-2700 keV	352 keV	583 keV	1461 keV
GeBer	3686	3.3	1.5	4.6
GeMi	611	5.6	2.1	5.2
GePV	482	2.8	2.1	3.2
GsOr	469	2.4	0.76	4.3
GePaolo	226	0.83	0.38	1.4
GeCris	87	<0.39	<0.29	1.0
GeMPI	30	<0.20	<0.15	0.36

O($\mu\text{Bq/kg}$)!!

Modane

- Many detectors for all purposes
 - Environmental studies and materials assay
- Malfida (Swiss army knife)
 - 150 cc, 43% Rel. Eff.



Silicon wafer measurement
700 000s 650g

Nucleide		mBq/kg
^{210}Pb	<	15.8
^{226}Ra	<	1.27
^{238}U	<	6.27
^{228}Ra	<	3.82
^{228}Th	<	0.86



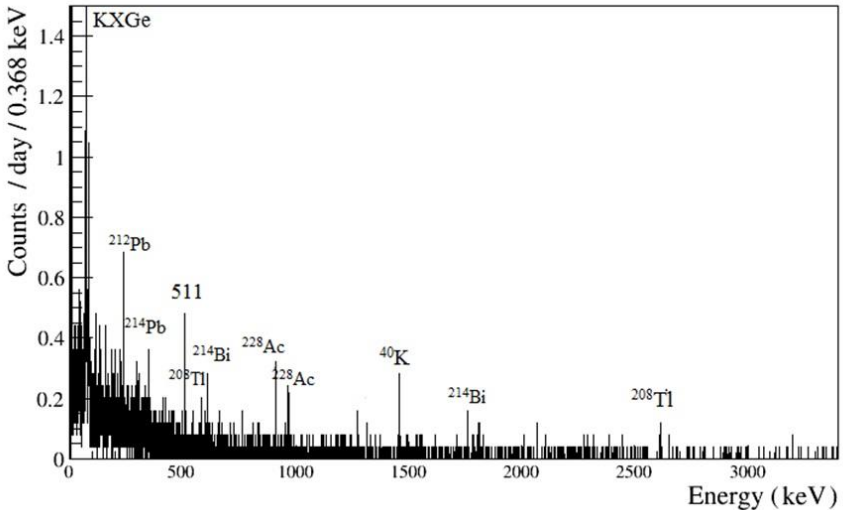
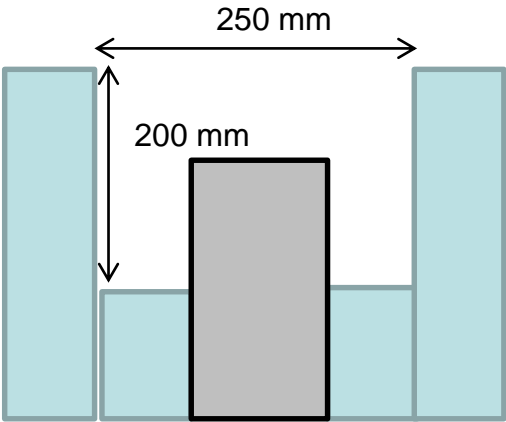
Modane

- Obélix
 - 600 cc 160% rel. eff.
 - 95 cpd background



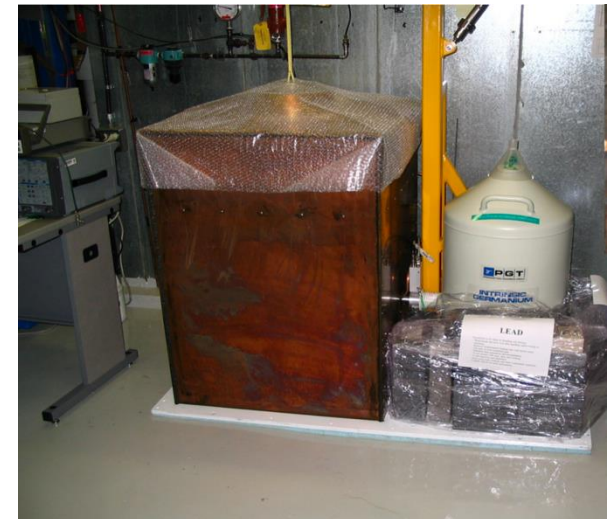
Theoretical Sample of 1kg for 500000s

Nucleide		mBq/kg
^{210}Pb	<	N/A
^{226}Ra	<	0.50
^{238}U	<	N/A
^{228}Ra	<	1.78
^{228}Th	<	0.43



SNOLAB

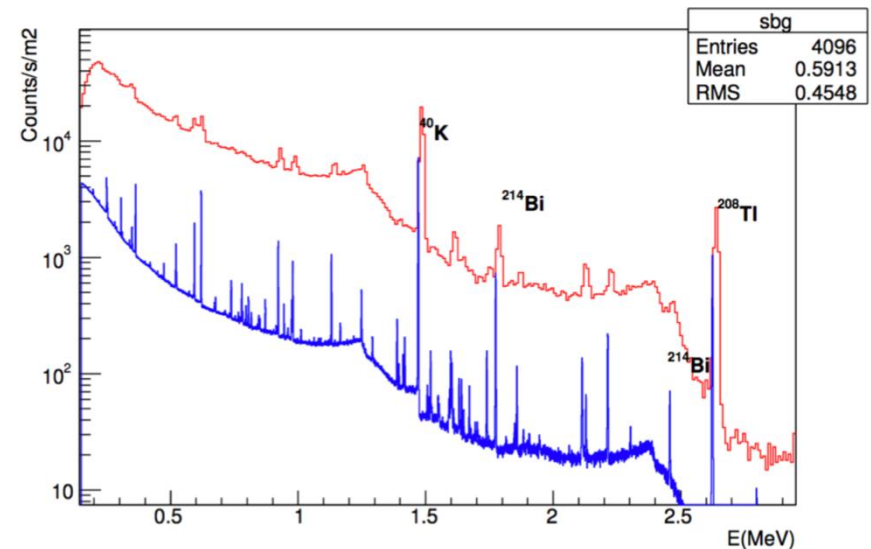
- 4x detectors in operation
 - PGT 55% p-type
 - Operational since 2005!
 - Canberra SAGe well
 - Canberra 107% p-type
 - Eurisys Measures 107% p-type



SNOLAB

Isotope (Assuming 1 kg Samples)	PGT Coaxial Detector	Canberra Well Detector	Vue Des Alpes Coaxial Detector
^{238}U	0.15 mBq/kg (12 ppt)	0.05 mBq/kg (4 ppt)	0.78 mBq/kg (64 ppt)
^{235}U	0.15 mBq/kg (264 ppt)	0.02 mBq/kg (35 ppt)	N/A
^{232}Th	0.13 mBq/kg (32 ppt)	0.26 mBq/kg (64 ppt)	0.14 mBq/kg (34 ppt)
^{40}K	1.70 mBq/kg (54 ppt)	N/A	3.72 mBq/kg (120 ppt)
^{60}Co	0.06 mBq/kg	N/A	N/A
^{137}Cs	0.17 mBq/kg	0.02 mBq/kg	
^{54}Mn	0.06 mBq/kg	1.3 mBq/kg	
^{210}Pb	4.4 Bq/kg (356 ppb)	0.11 mBq/kg (9 ppt)	

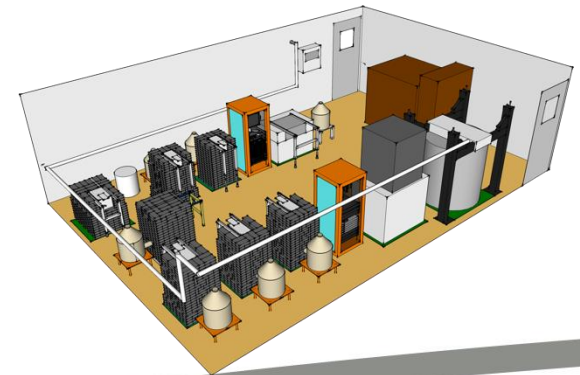
Sensitivity is normalised
to a 1kg sample



Sanford Underground Research Facility

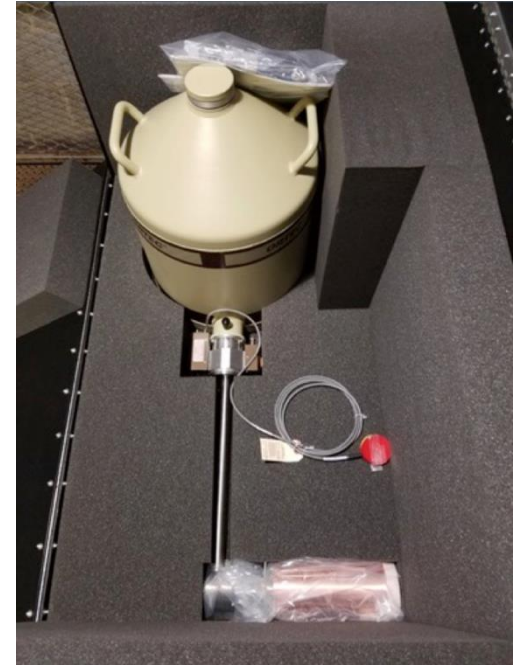
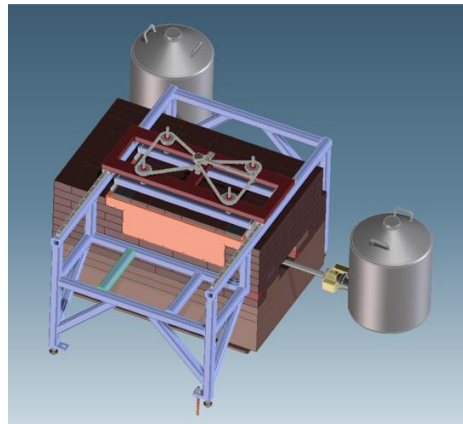
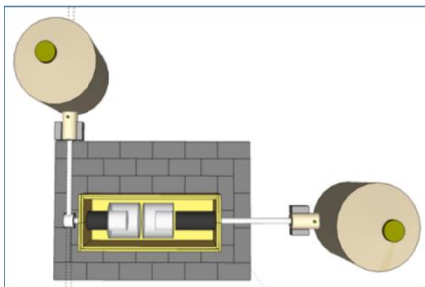
- SURF hosts 4x standalone HPGe detectors
 - MAEVE, MORGAN, MORDRED, SOLO
- Also “Twins” coincidence detectors
- Automated LN₂ Fill and Purge

Detector	Rel. Eff.	Isotope	Best Sensitivity (mBq/kg)	Best Sensitivity (ppt)
Maeve	85% p-type	U	0.1	10
		Th	0.1	25
Morgan	85% p-type	U	0.2	20
		Th	0.2	50
Mordred	60% n-type	U	0.7	60
		Th	0.7	170
SOLO	30% p-type	U	0.6	50
		Th	0.6	75



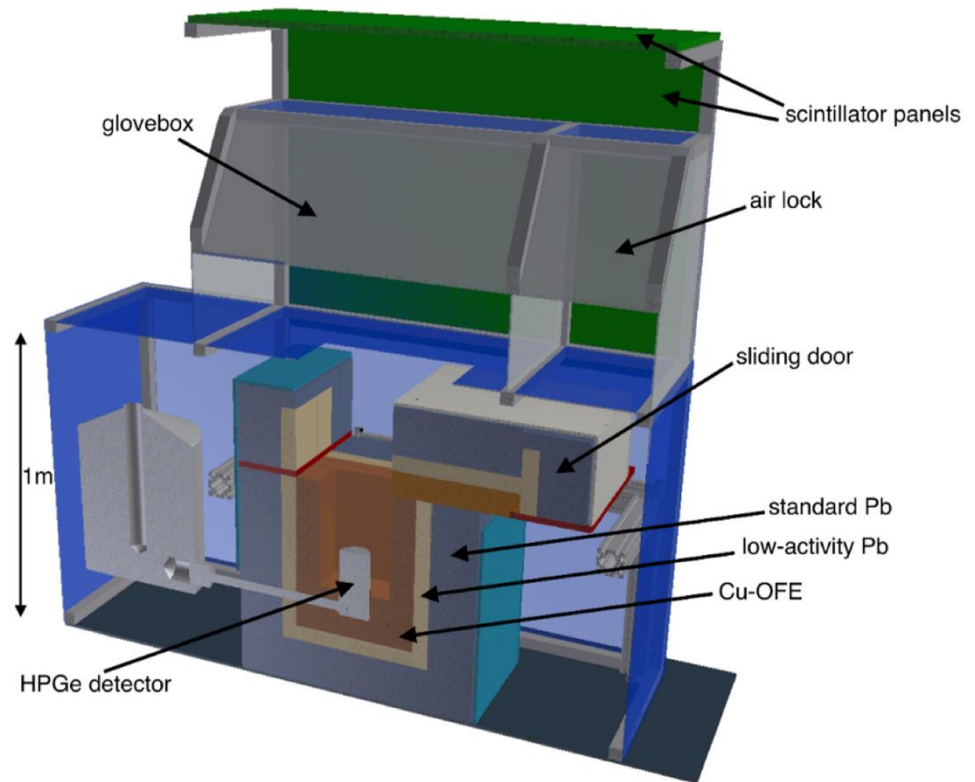
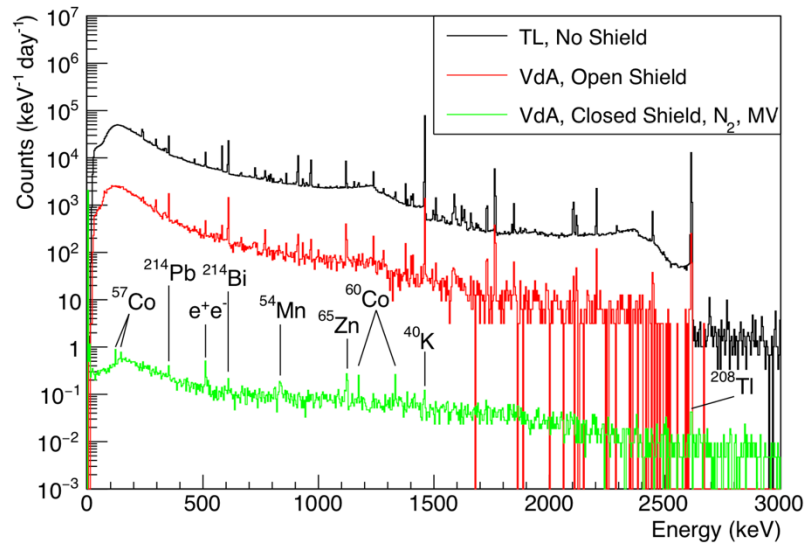
Sanford Underground Research Facility

- TWINS
 - ~4 kg of Ge total
 - Shielding removes LOS for 1 detector
 - Second detector moveable
 - Aims for approx. 5 ppt sensitivity for 1-2 week measurement

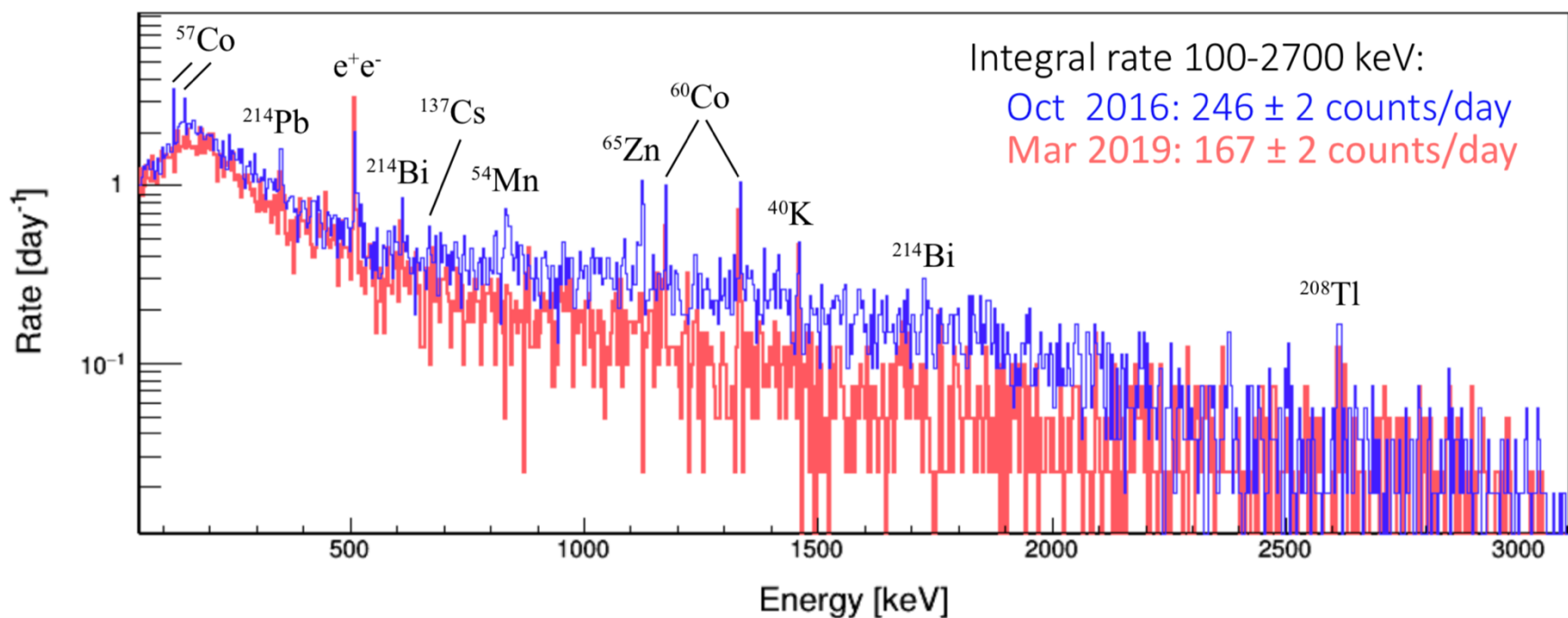


Vue Des Alpes - GeMSE

- Operates at 620 mwe
- Shielded with both standard and low activity lead and copper



Vue Des Alpes - GeMSE

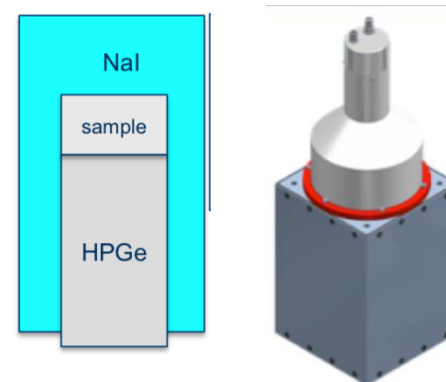
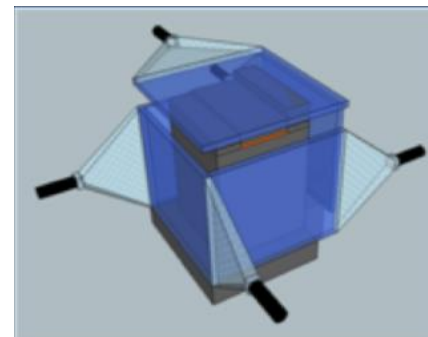


1 / 03	<ul style="list-style-type: none">Factor 1.5 reduction after 2.5 yearsOptimisation of shielding and location using GEANT4Agrees with expectation in reduction of cosmogenics
100-2700	

Journal of Instrumentation. 11(12) 2016

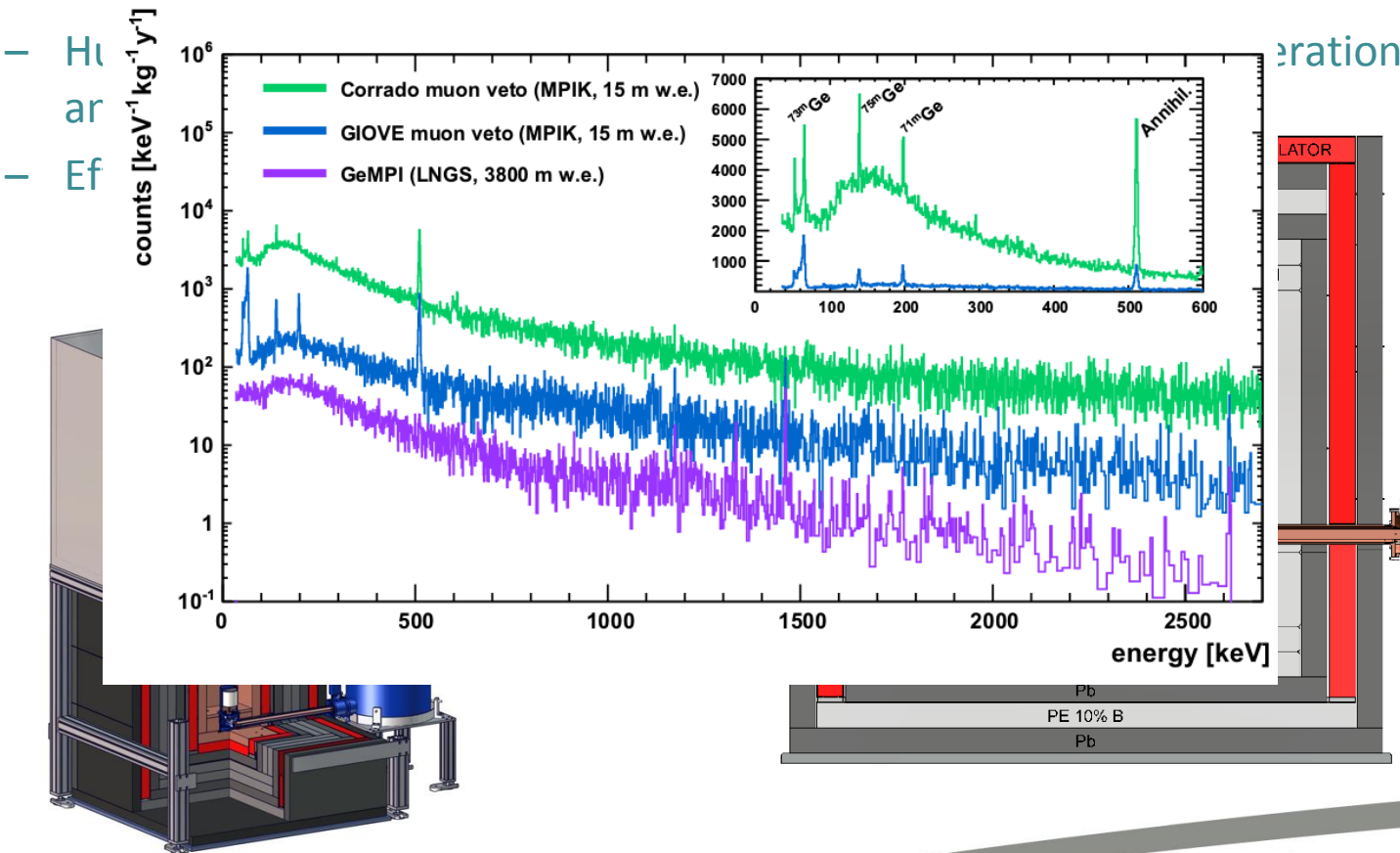
Lawrence Berkley National Laboratory

- LBNL
 - Surface facility
 - Concrete Bunker
- MERLIN
 - 115% n-type
 - CR veto on 5 sides
 - U/Th/K – 0.5 ppb/2 ppb/1 ppm
- Big-8
 - 85% p-type
 - 10 kg annular NaI
 - U/Th/K – 0.8 ppb/2.5 ppb/1.5 ppm



GIOVE – MPI Heidelberg

- Surface facility looking at what can be done to bring surface detectors close to UG detectors.



U. Alabama

- 3x detectors – Ge I, II, III



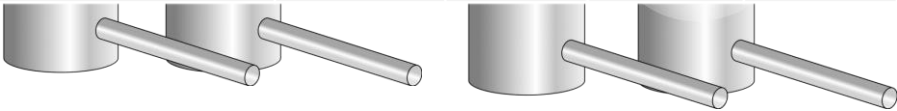
	GeII	GeIII
Ge Crystal		
Diameter	70.5	80
Length	68	82
Dead layer thickness (nominal)	0.9	0.7
Dead layer thickness (adjusted)	1.42	0.7
Crystal Holder		
Material	Cu	Cu
Thickness	1.0	0.8
End Cap		
Material	Cu	Al
Diameter	89	95.25
Length	140	159
Entrance thickness	1.0	1.5
Side thickness	1.5	1.5
Ge front to endcap distance	4.5	5.5
Shielding		
Inner Cu thickness	50.8 (2")	50.8 (2")
Outer Pb thickness	203.2 (8")	203.2 (8")
Performance		
Relative Efficiency at 1.33 MeV	60%	100%

Used e.g. for NAA in LZ

LAFARA

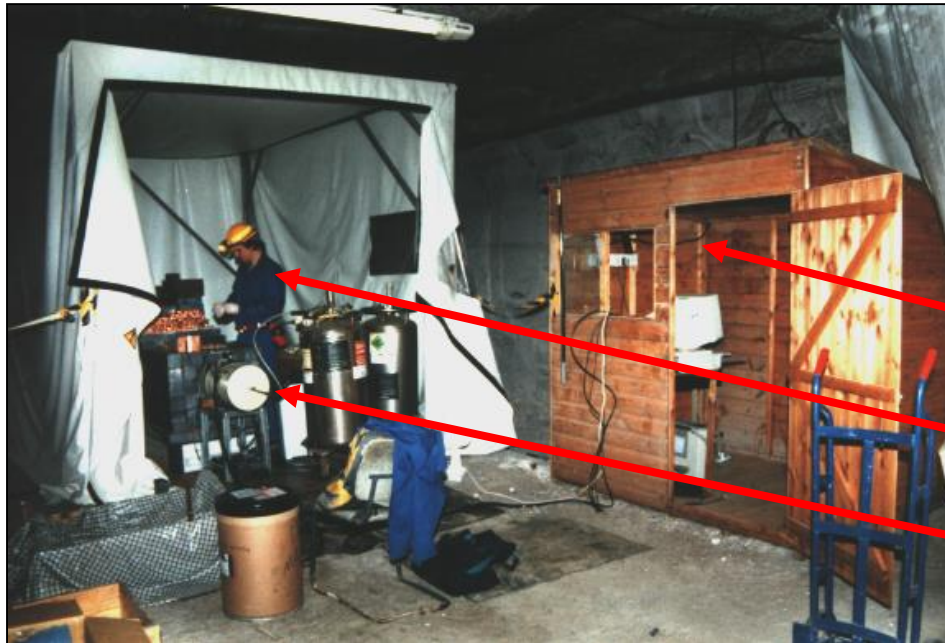
- 30 m² laboratory with 5 germanium detectors
 - 2x planar detectors (Canberra, Ortec)
 - 3 SAGe-well detectors

Détecteur	Type	Capot	Fabricant	Refroidissement	Volume Germanium	Efficacité relative	Résolution 122 keV	Résolution 1332 keV
SP	Semi-planaire	Fenêtre carbone	Ortec-Ametek (modifié)	Mirion CryoPulse® 5+	183 cc	54 %	0,72 KeV	1,72 keV
CX	Planaire Co-axial	Aluminium	Mirion Canberra	Mirion CryoPulse® 5+	230 cc	53 %	0,95 KeV	1,97 keV
P21-1	SAGe-well, Puits 21 mm	Aluminium	Mirion Canberra	Mirion CryoPulse® 5+	430 cc	105 %	0,75 KeV	1,85 keV
P21-2	SAGe-well, Puits 21 mm	Aluminium	Mirion Canberra	Mirion CryoPulse® 5+	430 cc	107 %	0,75KeV	1,8 keV
P32	SAGe-well, Puits 32 mm	Aluminium	Mirion Canberra	Mirion CryoPulse® 5+	450 cc	114 %	0,86 KeV	2,35 keV



<https://lafara.obs-mip.fr/detecteurs/>

Boulby Underground Germanium Suite



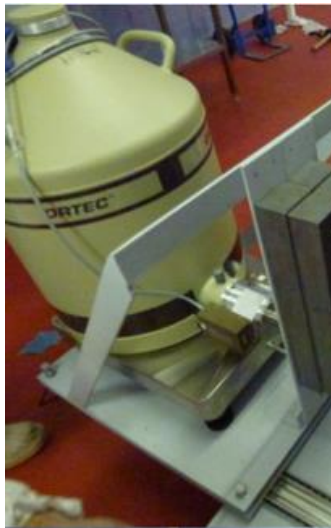
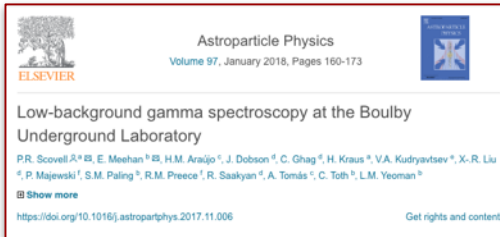
Germanium detector
operational @Boulby in
1990

Garden Shed

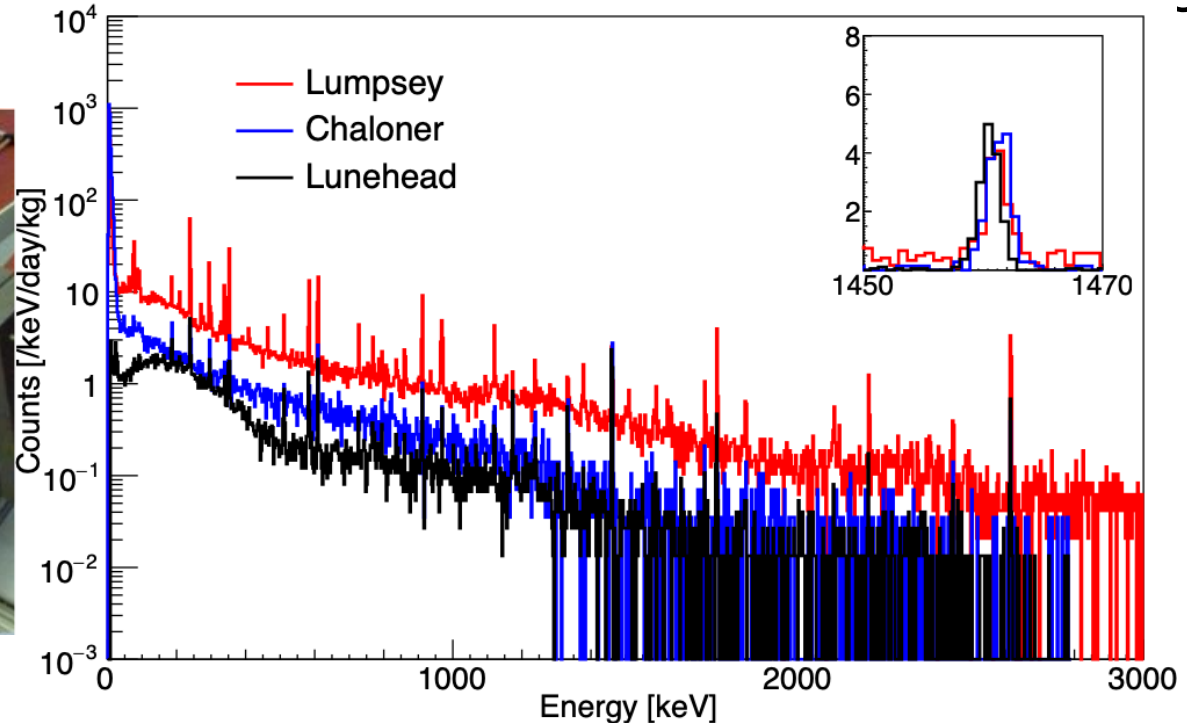
Director of SNOLAB

Still in use, although...

Boulby Underground Germanium Suite



- Lunehead refurbished with CF endcap
- Added Chaloner (BE5020) & Lumpsey (SA Ge)



Boulby Underground Germanium Suite



S-ULB detectors added in 2017 – ask and ye shall receive

- 160% p-type – Belmont
- 100% p-type – Merrybent
- BE6530 – Roseberry

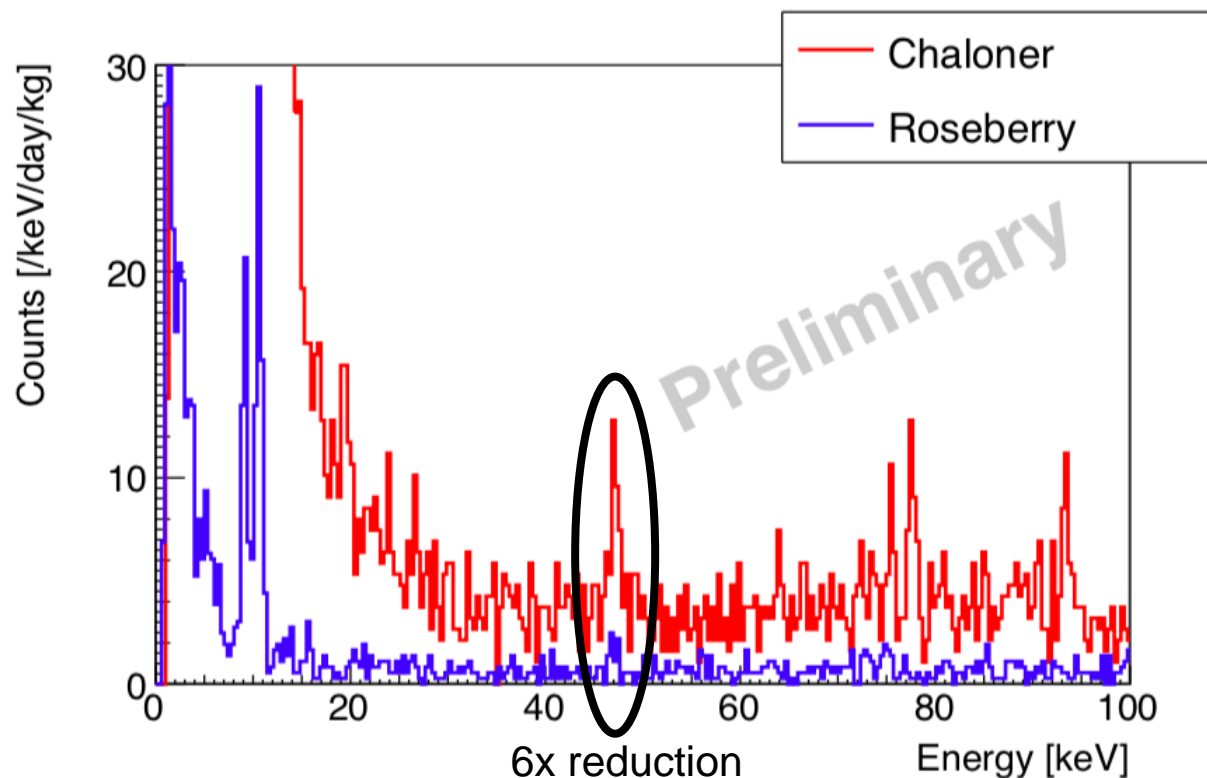
Purged using dry N₂ generator – Noblegen NG5/NG6

Boulby Underground Germanium Suite

- In 2016 moved to a new purpose built lab
 - Class 1k cleanroom (ISO-6)



Boulby Underground Germanium Suite



Boulby Underground Germanium Suite

Name	V [cm ³]	M [kg]	FWHM @ 1332 keV [keV]	Integral (60- 2700) keV [cts/kg/day]	Tl-208 2614.5 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]
Belmont	600	3.2	1.92	150.0	0.3	1.8	1.1	0.9
Merrybent	375	2.0	1.87	255.5	0.4	7.1	1.0	1.3
Lunehead	375	2.0	1.86	674.6	2.8	8.5	2.0	8.8
Roseberry	170	0.9	1.58	Pb210 – 1.1 cts/day		2.9	0.4	0.8
Chaloner	150	0.8	1.56	6.9 cts/day		12.7	2.0	12.7
Wilton*	131	0.4	1.88			counts (due to small shield)		
Lumpsey**	263	1.4	1.66	17.1 cts/day		64.3	1.6	7.4

* Used For pre-screening

** Out of service for refurbishment to S-ULB

Best of 0.6 cts/day/kg

- Substantial reduction in Rn backgrounds expected post installation of Rn reduction system
 - Although Boulby has 2.5 Bq/m³ Rn, improvement still required!