Low Background Counting Facilities At SNOLAB

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2014 AARM Collaboration Meeting

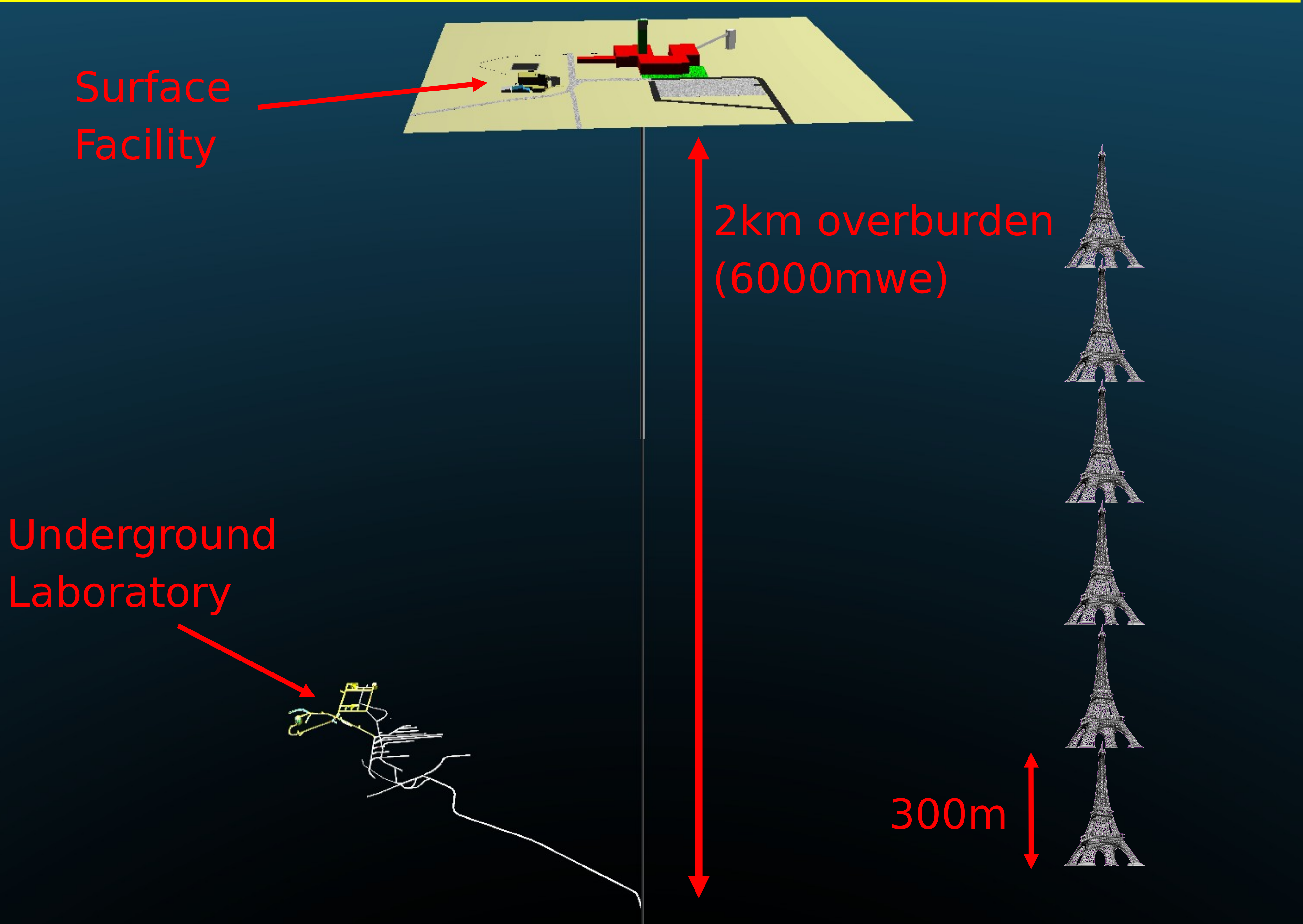
Outline

- Motivation for Low Background Counters
- Current Facilities in Operation at SNOLAB
  - PGT Ge detector
  - Canberra Well detector
- Characterizing a new Canberra Coax Detector
- Future Low Background Counters and Facilities

Motivation

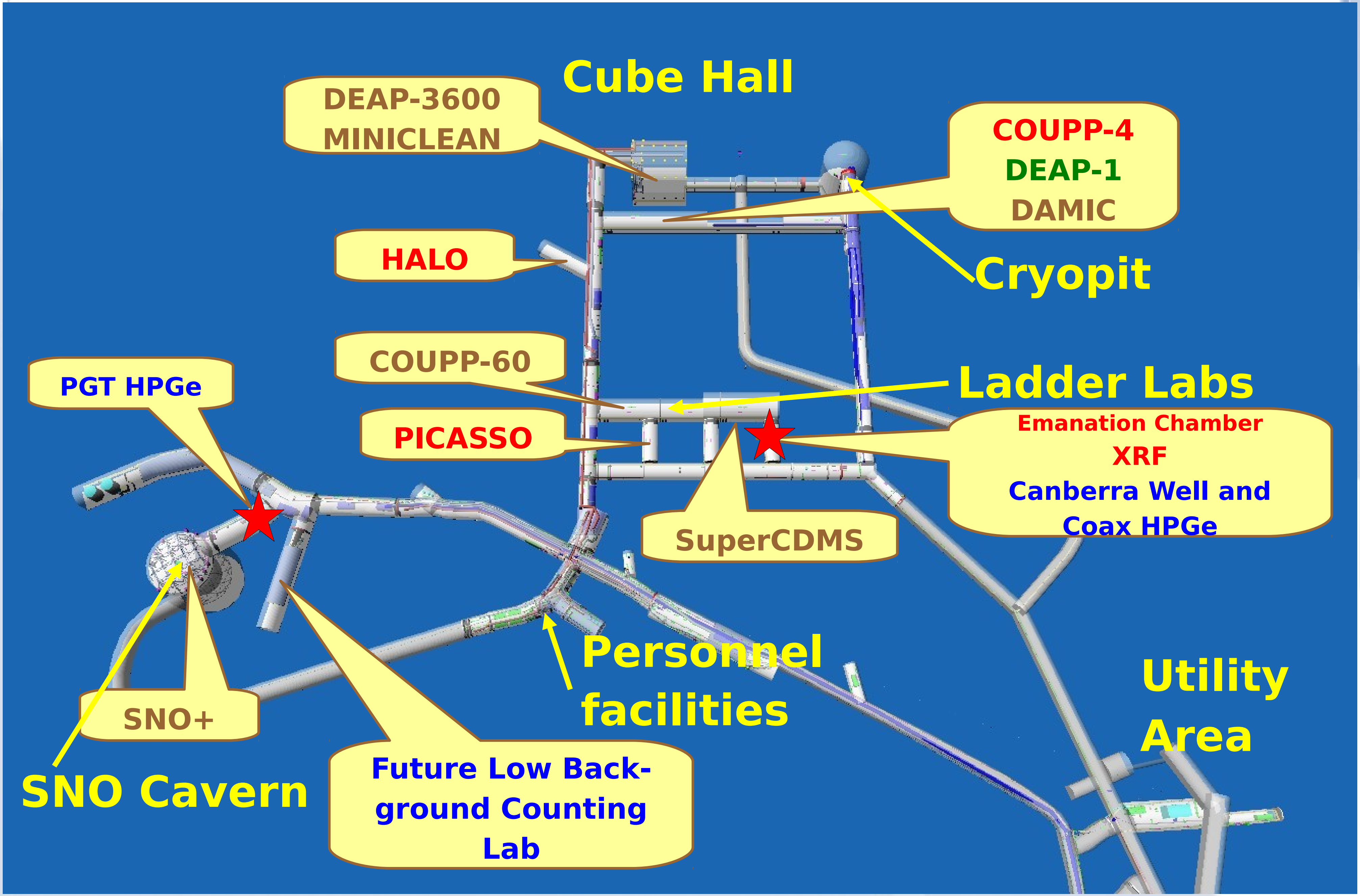
- Many of the experiments currently searching for dark matter, studying properties of neutrinos or searching for neutrinoless double-beta decay require very low levels of radioactive backgrounds both in their own construction materials and in the surrounding environment.
- These low background levels are required so that the experiments can achieve the required sensitivities for their searches.
- SNOLAB has several facilities which are used to directly measure these radioactive backgrounds.
- The backgrounds in question are on the order of 1 mBq or 1 ppb for ^{238}U, ^{232}Th and ^{235}U and 1 ppm for ^{40}K, or better, measurements down to 1 ppt are required for some components.
- The problem backgrounds can include gammas, alphas and neutrons or resulting interaction products.
- The goal is to measure these backgrounds and then to reduce them to be as low as reasonably achievable.

SNOLAB



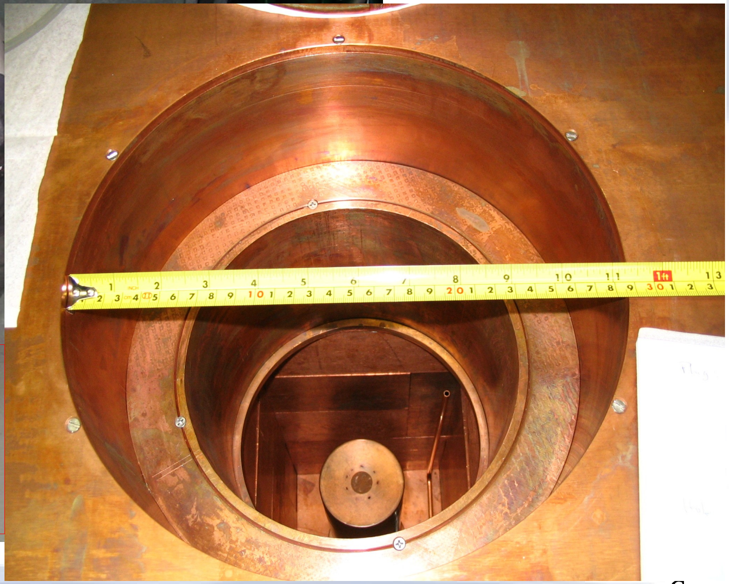
Surface Facility
2km overburden (6000mwe)
Underground Laboratory
300m

SNOLAB


Cube Hall
DEAP-3600
MINICLEAN
COUPP-4
DEAP-1
DAMIC
HALO
Cryopit
COUPP-60
Ladder Labs
PGT HPGe
PICASSO
Emanation Chamber
XRF
Canberra Well and
Coax HPGe
SuperCDMS
Personnel
facilities
Utility
Area
SNO+
SNO Cavern
Future Low Back-
ground Counting
Lab

SNOLAB PGT HPGe Counter
(The workhorse detector at SNOLAB)

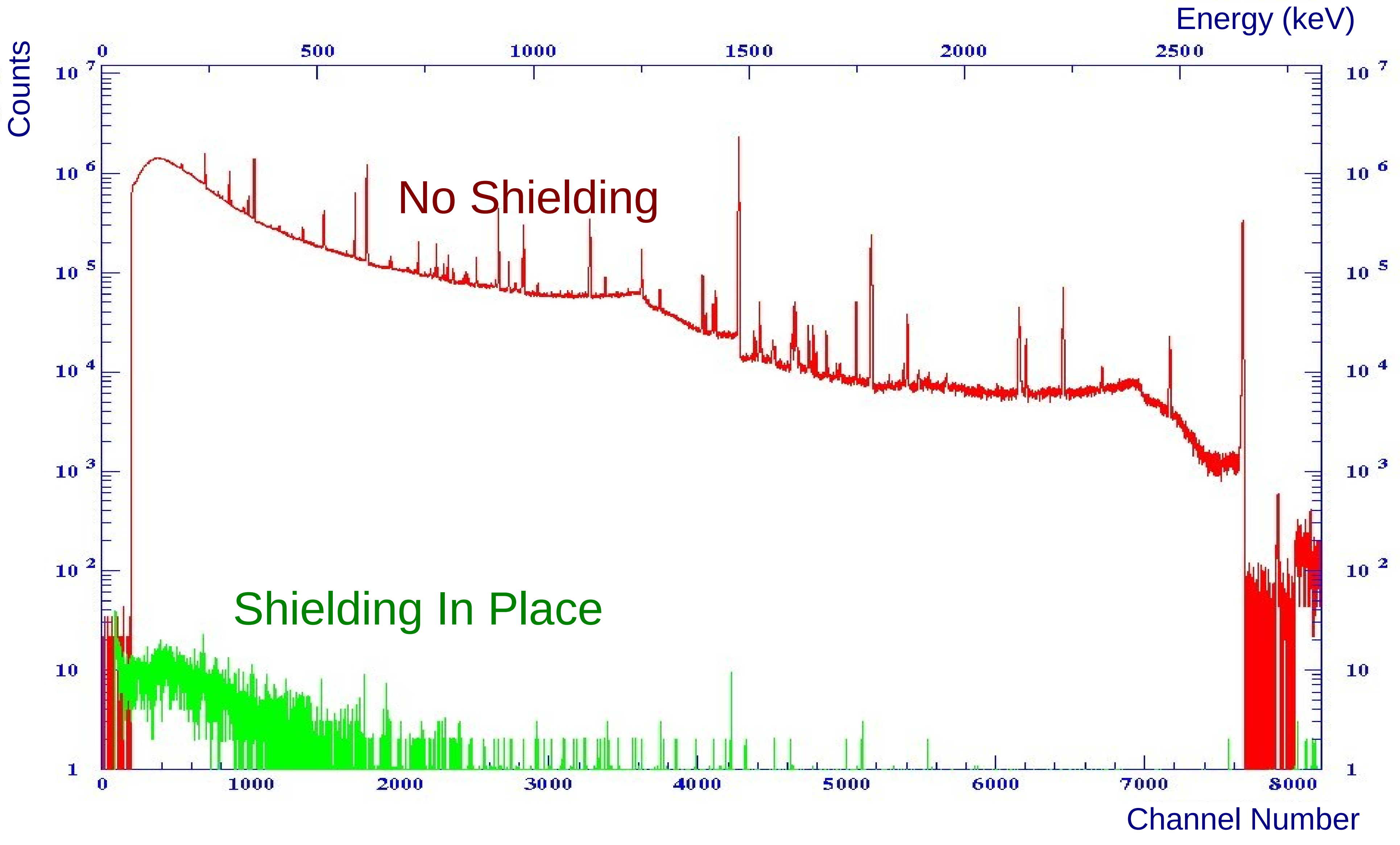
Additional lead used to dampen microseismic activity from blasting and rockbursts



SNOLAB PGT HPGe Detector Specifications

- Motivation
  - Survey materials for new, existing and proposed experiments (to be) located @ SNOLAB, such as SNO/SNO+, DEAP/CLEAN, PICASSO/COUPP/PICO, EXO, ... Also survey materials for the DM-ICE and DRIFT experiments, and Canberra.
- Constructed @ SNOLAB from a HPGe detector and its associated shielding located underground at 4600 ft level since 1997, in near continuous operation since 205
  - Counter manufactured by PGT in 1992,
  - Endcap diameter: 83 mm,
  - Crystal volume: 210 cm^3.
- Establishment of the Low Background Gamma Facility @ SNOLAB in 2005.
  - Relative Efficiency is 55% wrt a 7.62 cm dia x 7.62 cm NaI(Tl) detector,
  - Resolution 1.8 keV FWHM.
- Shielding
  - 2 inches Cu + 8 inches Pb
  - Nitrogen purge at 2L/min to keep radon out, as the lab radon levels are 150 Bq/m^3.

Unshielded and Shielded Spectra



PGT HPGe Typical Detector Sensitivity

(for a standard 1L or 1 kg sample counted for one week)

Isotope	Sensitivity for Standard Size Samples	Sensitivity for Standard Size Samples
^{238}U	0.15 mBq/kg	0.012 ppb
^{235}U	0.15 mBq/kg	0.264 ppb
^{232}Th	0.13 mBq/kg	0.032 ppb
^{40}K	1.70 mBq/kg	0.054 ppb
^{60}Co	0.06 mBq/kg	
^{137}Cs	0.17 mBq/kg	
^{54}Mn	0.06 mBq/kg	

Measurements To Date For Each Experiment

Experiment	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
SNO	2	7	0	2	0	0	0	0	0	11
SNO+	0	2	18	14	15	35	5	11	5	105
SNOLAB	7	3	0	0	9	6	17	20	0	62
EXO	1	1	0	0	2	1	0	0	0	5
MiniCLEAN	5	1	9	18	8	3	7	3	2	56
DEAP	8	8	12	10	8	15	18	18	4	101
HALO	0	0	0	2	3	1	1	0	0	7
PICASSO	1	1	4	3	0	0	0	0	0	9
DM-ICE / DRIFT	--	--	--	--	9	9	5	0	0	23
COUPP / PICO	--	--	--	--	1	15	17	10	1	44
DAMIC	--	--	--	--	--	--	1	4	2	7
Total	24	23	43	49	34	85	71	66	14	430
Calibrations &Tests	30	34	14	9	4	3	11	10	3	118
Counting time per sample averages 6 days.										

PGT HPGe Vacuum Restored After Unexpected Warm Up

Unplanned warm-up of PGT detector occurred during a prolonged period of no access to SNOLAB in summer 2013.

Following the shutdown, the detector was cooled down, however it was immediately observed that the resolution of the gamma peaks doubled, severely limiting the capabilities of distinguishing nearby peaks.

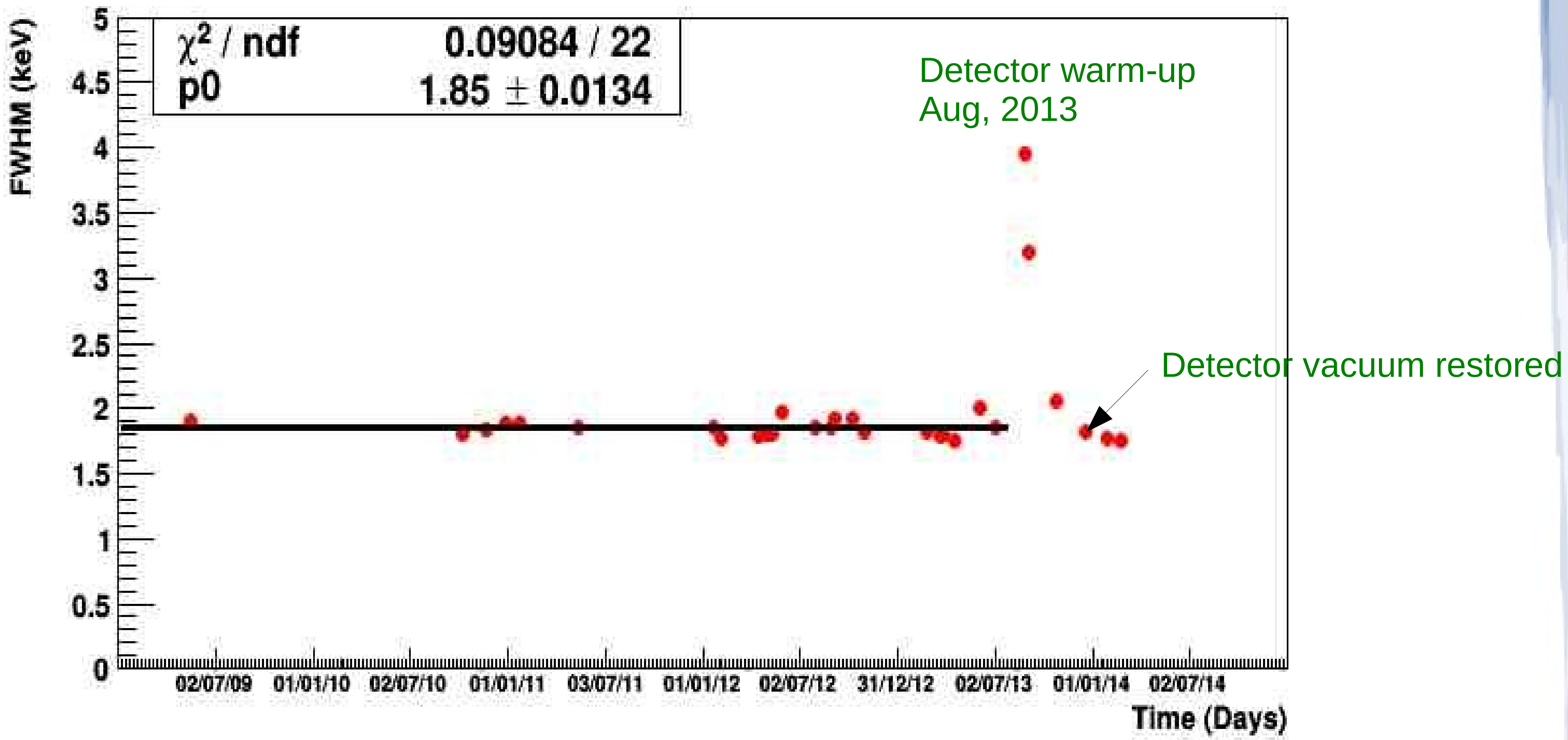
BNC (the successor to PGT) suggested that the detector resolution could be brought back down by re-establishing a good vacuum and regenerating the molecular sieve located in the nitrogen dewar. If this didn't work, then BNC would have to repair the detector.

To that end, the dewar, cold finger and detector were heated to 80 C and the vacuum was re-established over several days in December, 2013.

The resolution of the detector was subsequently measured to be similar to the historical average, so the detector is back in normal operation.

PGT HPGe Vacuum Restored After Unexpected Warm Up

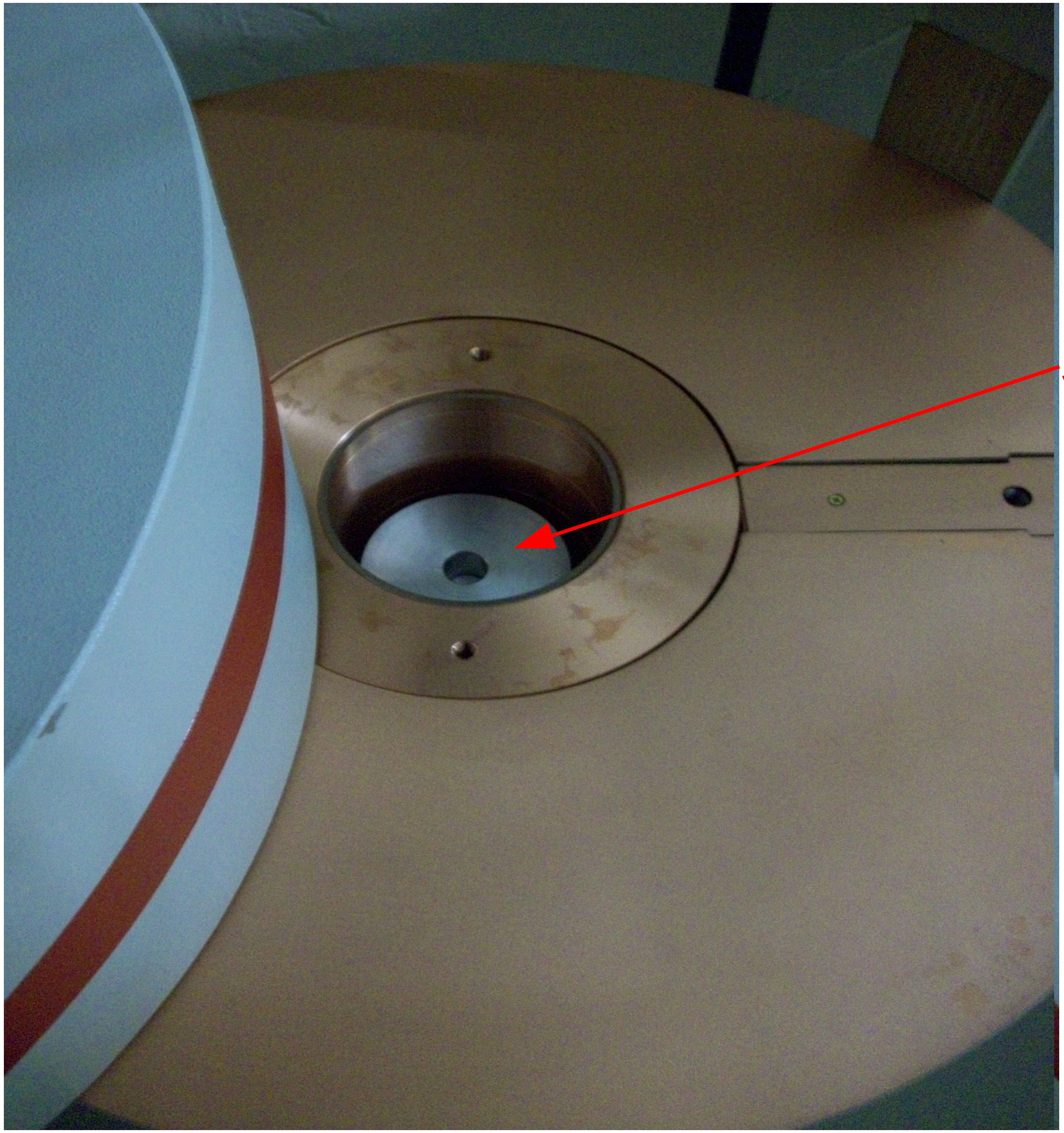
Resolution of the ^{214}Bi 609.31 keV gamma from the calibration sample



The detector resolution doubled after warming up, all peaks had this feature, after re-establishing the vacuum, the resolution the displayed peak was 1.76 keV FWHM, the long-term average was 1.85 keV FWHM.

Canberra Well Detector at SNOLAB

Canberra Well Detector at SNOLAB



Detector Volume: 300 cm^3

Sample Bottle
Volume is 3 ml

SNOLAB Canberra Well Detector Specifications

- Motivation
  - Survey very small quantities of materials, concentrated samples or very expensive materials. Used by DAMIC, DEAP, PICO & SNO+ so far.
- Constructed by Canberra using low activity materials and shielding.
  - Counter manufactured by Canberra in 2011 and refurbished in 2012, the cold finger was lengthened as it was too short to fit the shielding and the tail end and crystal holder were replaced to reduce radioactivity levels.
  - Crystal volume: 300 cm^3.
- Installed and operational in 2013.

- Shielding
  - Cylindrical shielding of 2 inches Cu + 8 inches Pb
  - Nitrogen purge at 2L/min to keep radon out, as the lab radon levels are 150 Bq/m^3.

Canberra Well Detector Background
(is the detector an ultra-low counter)

- Background run completed, 86.2 days.

^{238}U 1.16 counts per day

^{232}Th 0.51 counts per day

^{228}Ac 0.39 counts per day

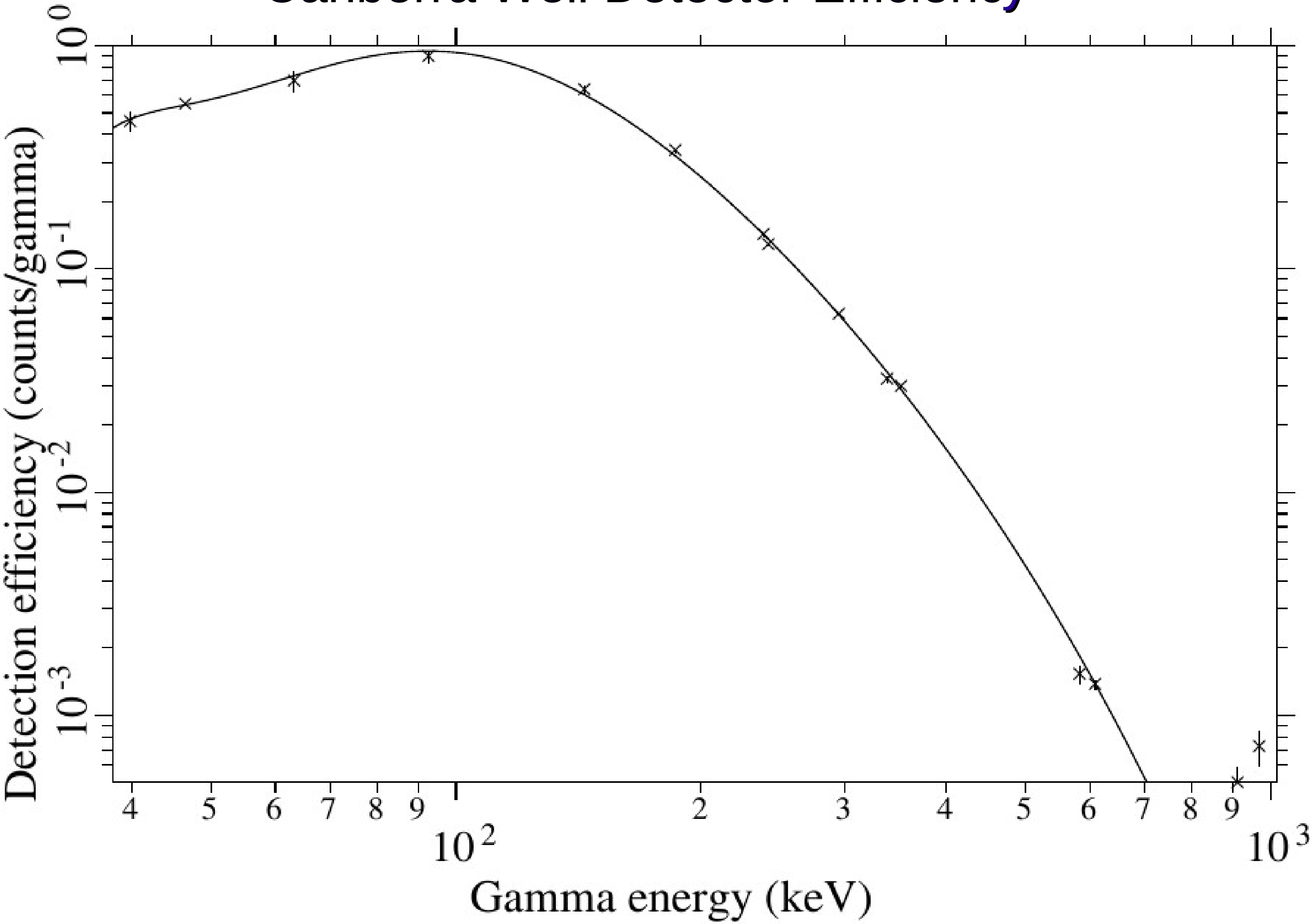
^{235}U 0.48 counts per day

^{40}K 0 counts per day

^{210}Pb 0 counts per day

- Total backgrounds at the level of ~2.54 counts / day in regions of interest.
- Calibration sources approved by SNOLAB and efficiency measurements up to ~900 keV have been completed.
- Samples for DAMIC, DEAP, PICO and SNO+ have been counted or are in progress.

Canberra Well Detector Efficiency



-Effective survey region is between ~35 and 700 keV.

-Very large statistic run has recently been completed to better estimate the efficiency above 700 keV.

Canberra Well Detector Sensitivity

Isotope	Sensitivity for Standard Size Samples	Sensitivity for Standard Size Samples
^{238}U (↑ ^{226}Ra)	0.05 mBq/kg	4 ppt
^{238}U (↓ ^{226}Ra)	0.08 mBq/kg	6 ppt
^{228}Ac	0.2 mBq/kg	49 ppt
^{232}Th	0.4 mBq/kg	98 ppt
^{235}U	0.02 mBq/kg	35 ppt
^{210}Pb	0.15 mBq/kg	

Canberra Coax Detector at SNOLAB

The coax detector was ran inside the well detector shielding to characterize the backgrounds in the hope the detector had backgrounds less than or similar to the PGT detector.

However, it was determined that the coax detector had extremely high background levels. It had substantial amounts of ^{232}Th, ^{235}U and the top part of the ^{238}U chain, the other backgrounds are similar to those observed from the PGT counter.

Canberra Coax Detector at SNOLAB

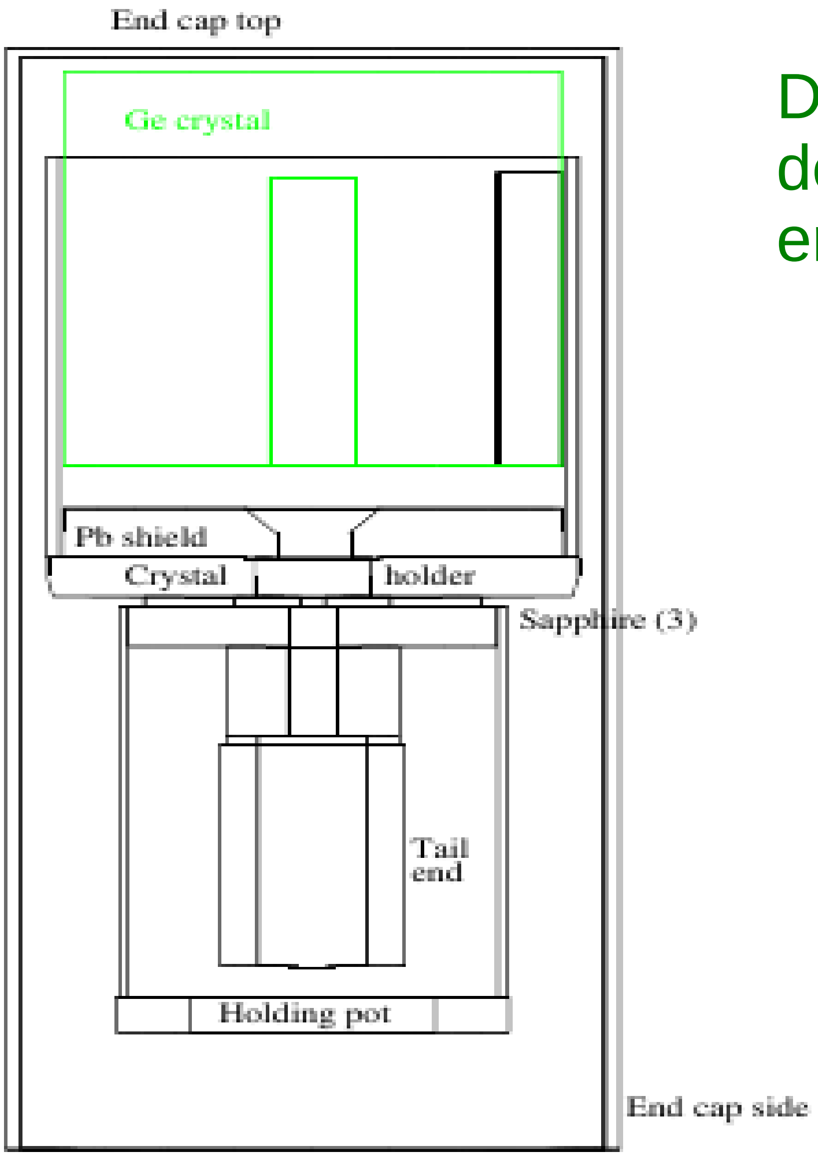
The background levels for a low background detector should be no more than 100 counts/year in each detectable gamma region.

The activities present are:

- ^{228}Th progeny at 30 counts/day
- ^{228}Ra progeny at 30 counts/day
- ^{238}U progeny at 500-600 counts/day, although below ^{226}Ra the rate is only about 5 counts/day.
- ^{40}K at 18 counts/day

The detector was dismantled by Canberra and the pieces were counted at SNOLAB to determine if there is a smoking gun causing the high background rate.

Simulation of Coax Detector



Detector simulated in GEANT4 to determine and verify background emitters.

Simulation of Coax Detector

^{40}K signal most likely due to inadequate shielding thickness

TABLE IV. Calculated count rates *R* for various components. For comparison to these calculated rates, the measured count rate is given on the first line. Two entries are given for the bottom of the Th chain - the separate rates of the γ rays at 583 keV and 2615 keV. γ energies for the other entries are 911 keV (Th-chain top), 1001 keV (U-chain top), 609 keV (U-chain bottom), and 1461 keV (^{40}K).

		Count rate *R* (counts/day)					
		Th chain			U chain		
Line	Component	Top	Bottom (583)	Bottom(2615)	Top	Bottom	^{40}K
1	Measured count rate of coaxial detector	11±1	8.3±1.8	11±1	4.8±0.7	4.5±1.8	5.4±0.7
2	Tail end (old)	10.4±1.0	8.4±0.6	8.7±0.7	5.2±1.0	0.6±0.3	<0.76
3	Tail end (new)	<0.09	<0.15	<0.16	<0.05	<0.17	<0.37
4	Crystal holder (new-Al)	0.90±0.80	<1.10	<0.55	<1.95	<1.04	<4.1
5	Crystal holder (old-Mg)	<1.05	<1.21	<0.61	<1.63	<1.64	<2.4
6	4 screws in crystal holder	<0.03	<0.08	<0.04	<0.06	<0.05	<0.1
7	Lead shield	<0.53	<0.83	<0.52	<1.04	<0.85	<2.5
8	3 screws in Pb shield	<0.04	<0.09	<0.06	<0.11	<0.06	<0.1
9	Lead foil next to crystal	0.53±0.50	0.60±0.64	0.25±0.27	<0.51	<0.75	1.0±1.2
10	Contact set	<0.81	<1.35	<0.53	<2.89	<1.66	<1.8
11	3 sapphire discs	<0.39	<0.43	<0.42	<0.33	<0.35	<1.9
12	Heat-sink compound	<0.02	<0.02	<0.02	<0.03	<0.02	0.14±0.07
13	FET (in packing)	0.09±0.05	0.06±0.04	0.08±0.04	<0.22	0.09±0.05	<0.01
14	Screw set 1	<0.11	0.38±0.08	0.45±0.09	<0.14	<0.12	<0.23
15	Holding pot	0.06±0.05	<0.04	<0.05	<0.08	<0.04	<0.26

Canberra Coax Returned too SNOLAB

- Canberra returned refurbished detector to SNOLAB in December 2013.
- Backgrounds measured using well detector shielding, preliminary results look promising with ^{235}U, ^{238}U levels similar to the PGT counter, ^{40}K results are lower, however, ^{232}Th results appear to be slightly higher.
- Engineering design drawings are now in progress for the detector shielding.

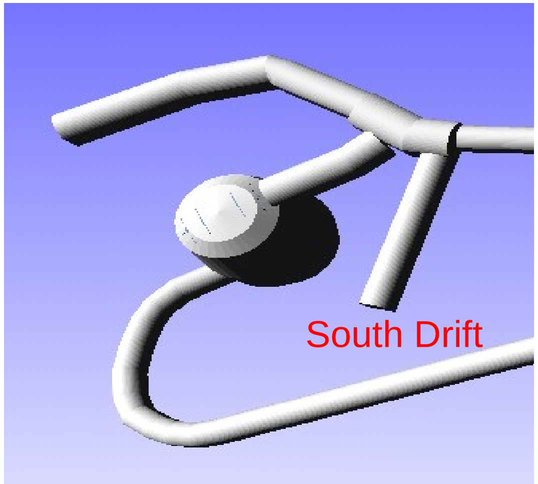
  - 8" Pb for outer shielding (from same batch as used by the PGT det.)

  - 2" low background Pb from Plombum

  - 2" low background Cu

  - (1/4" acrylic, inner layer primarily to maintain cleanliness of the chamber)
- Detector chamber to be designed to hold samples up to 20 litres
- Entire detector will be enclosed in an airtight copper or stainless steel box and the chamber will be purged with nitrogen.

SNOLAB Low Background Laboratory
(To be built)



A new dedicated space will be constructed at SNOLAB for a low background lab located in the South Drift (former refuge station).

This drift is isolated from other drifts and is inaccessible to large equipment. This will help reduce micro-seismic noise which can effect Ge detectors.

Increased air flow and perhaps other radon reduction techniques will be used. It is known that the compressed air from surface has substantially less radon than the lab air and can be used to reduce radon levels from 135-150 Bq/m^3 to 1-5 Bq/m^3.

Space can accommodate up to 5 Ge detectors, XRF, radon emanation chamber and have room for other types of counters which would benefit from low-cosmic ray background.

Engineering design drawings are now in progress.

Future Low Background Counting Lab

Electrostatic Counting System

Originally built for SNO, now used primarily by EXO. However, these counters are owned by SNOLAB so samples can be measured for other experiments.

Measures ^{222}Rn, ^{224}Ra and ^{226}Ra levels.

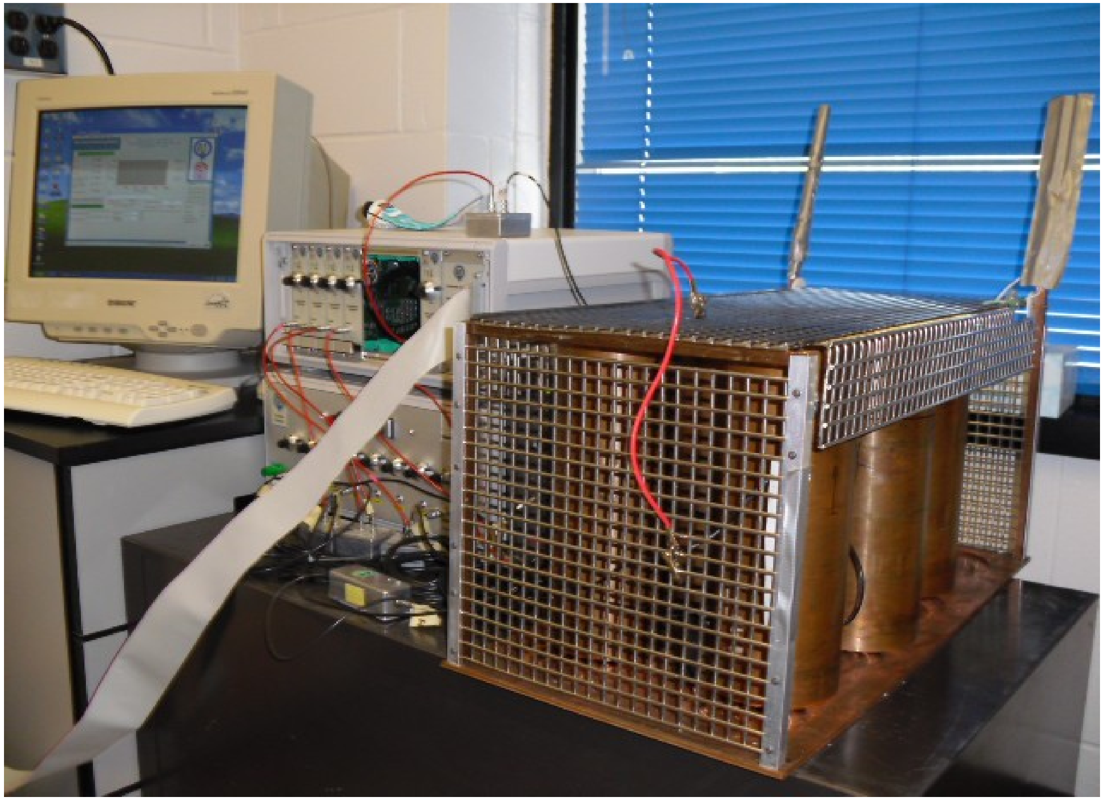
Sensitivity Levels are:

- ^{222}Rn: 10^{-14} gU/g
- ^{224}Ra: 10^{-15} gTh/g
- ^{226}Ra: 10^{-16} gU/g

Work is ongoing to improve sensitivity even further.

9 counters located at SNOLAB,
1 on loan to LBL (EXO),
1 on loan to U of A (DEAP).

Alpha Beta Counting System



Currently located at the SNOLAB hot lab at LU so that radioactive spike sources can be measured for SNO+.

Sensitivity for ^{238}U and ^{232}Th is ~ 1 mBq assuming that the chains are in equilibrium.

SNOLAB Data Repository

SNOLAB maintains a database in a spreadsheet format for each experiment.
https://www.snolab.ca/users/services/gamma-assay/index.html

The data is shown in units of mBq/kg and pp(b or m).

The table shows data from the standard gamma searches:
^{238}U, ^{235}U, ^{232}Th, ^{40}K ^{137}Cs, ^{60}Co.

While searching for the above gammas, we also search for any other peaks in the spectrum between 100 keV and 2800 keV, For example, ^{54}Mn is usually observed in steel. These are also included in the spreadsheet for each sample.

The database is available to all SNOLAB users and can be made available to others upon request as it is password protected, contact Ian.Lawson@snolab.ca or Bruce.Cleveland@snolab.ca.

Summary

- SNOLAB PGT HPGe low background counting system has run continuously for the past since 2005 and has counted 430 samples so far.

  Counting queue is usually long.

  The counter is available for all SNOLAB experiments and can be made available to non-SNOLAB experiments upon request (eg. DM-ICE, DRIFT).

- Two Canberra Ge detectors were delivered to SNOLAB, but each needed to be refurbished.

  The Canberra Well detector is now in full operation

  The Canberra Coax detector is underground and will undergo further background testing. Engineering drawings of the shielding design are in progress.

- Specialized counting can be done using the Electrostatic Counters and Alpha-Beta Counters and materials can be emanated for Radon.

- New low background counting lab will be constructed at SNOLAB, final engineering drawings are now underway.