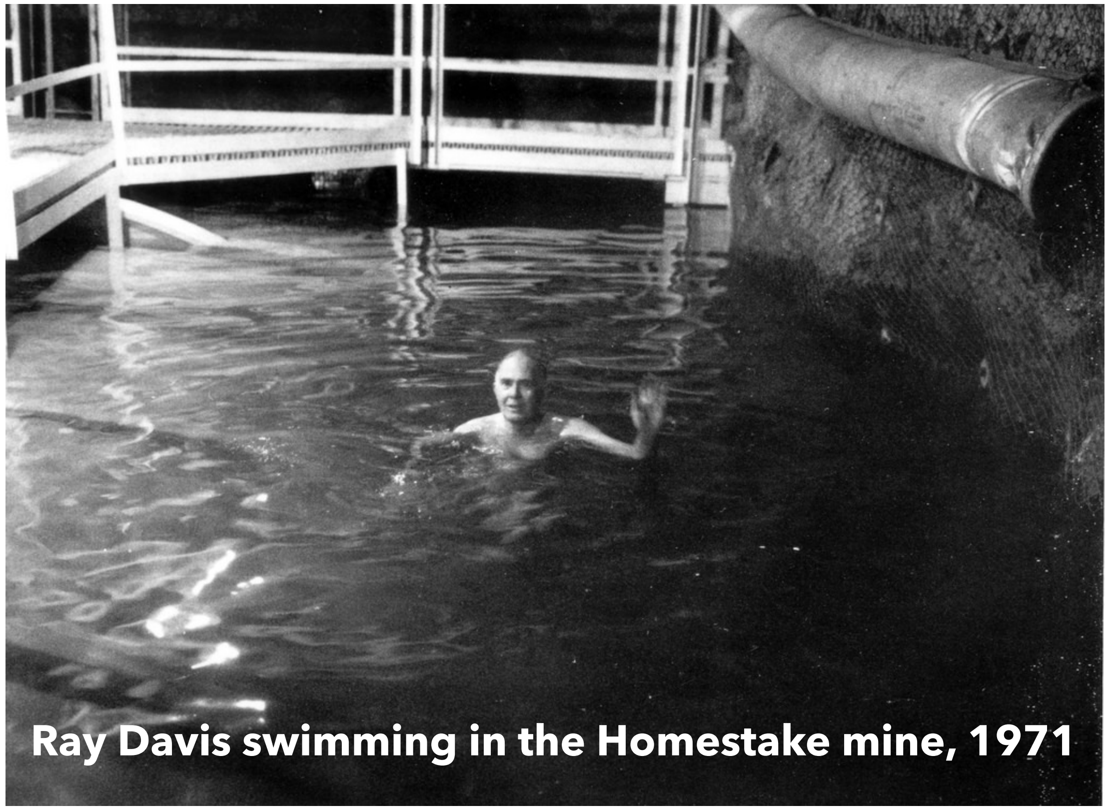


Ray Davis swimming in the Homestake mine, 1971

Measurement of the Davis Cavern γ-ray Background at the Sanford Underground Research Facility

Dr. Sally Shaw
sally@physics.ucsb.edu

COSSURF
Low Background Workshop
14/05/2019

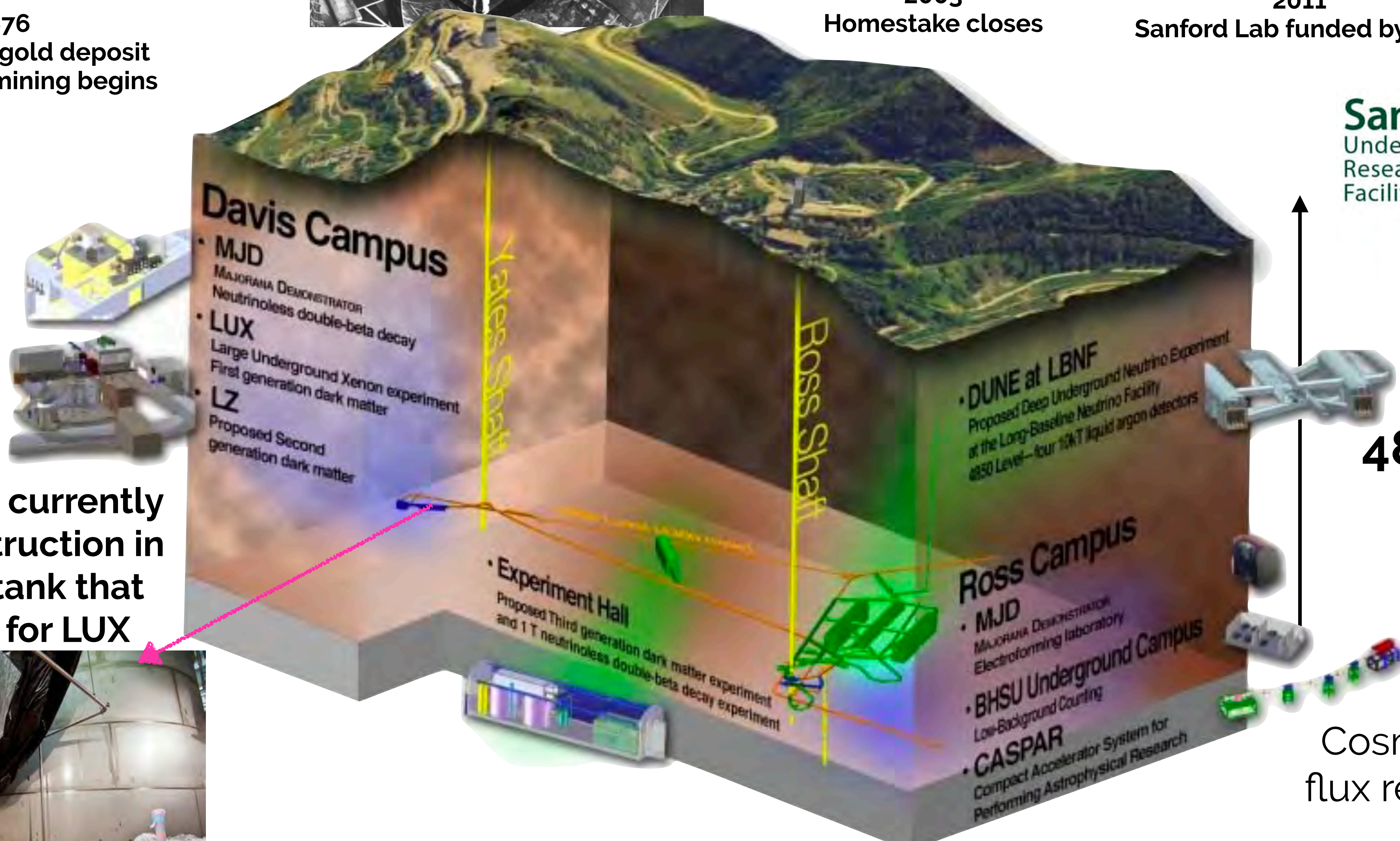
Sanford Underground Research Facility

1876
Homestake gold deposit discovered, mining begins

2003
Homestake closes

2011
Sanford Lab funded by DOE

Sanford Underground Research Facility

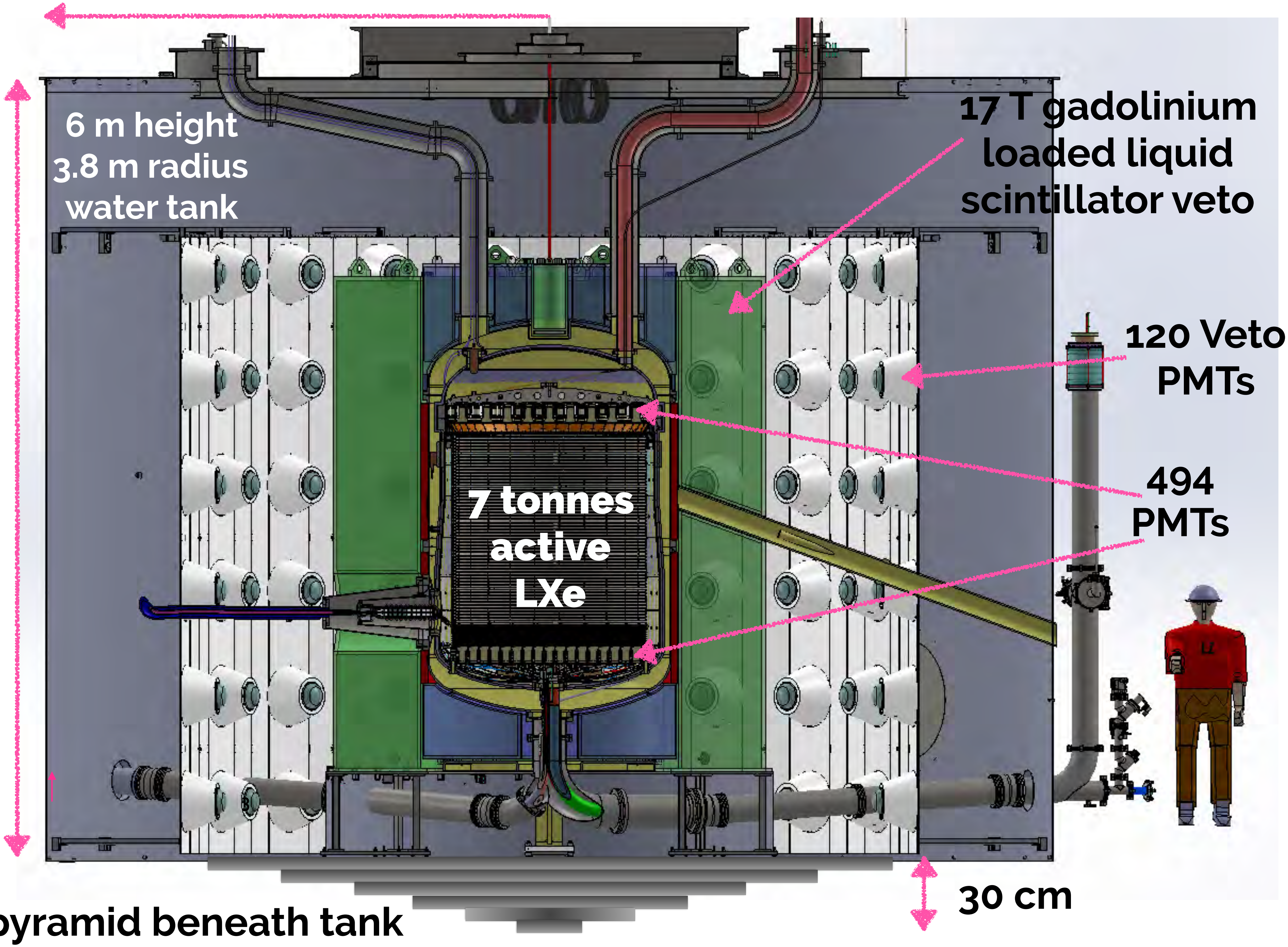


4850 ft

Cosmic muon flux reduced by 10^6

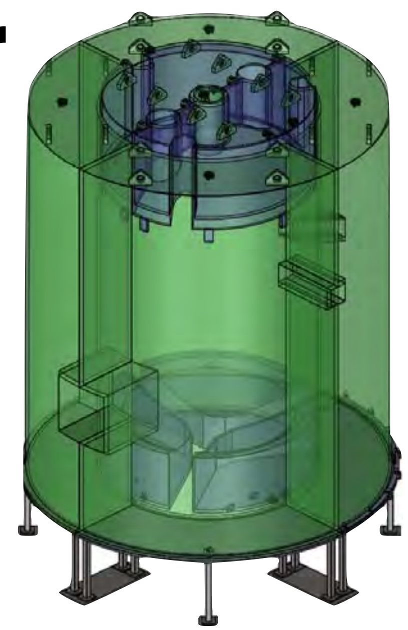
LZ detector currently under construction in the water tank that was used for LUX

The LZ Detector



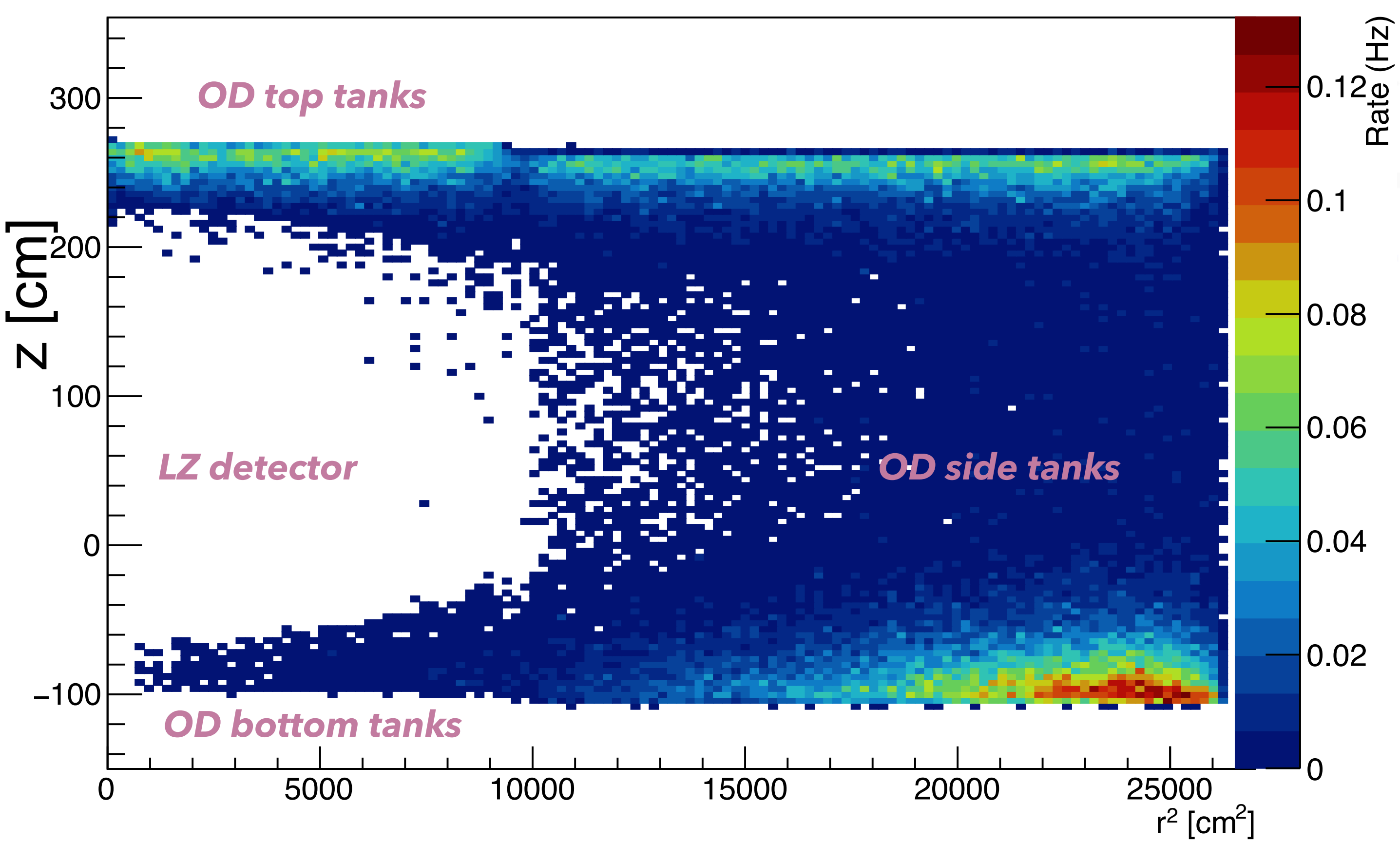
Cavern Backgrounds in LZ

Outer Detector



Need to keep deadtime low for vetoing efficiency

Cavern rate was thought to be ~100Hz - dominant background in OD!



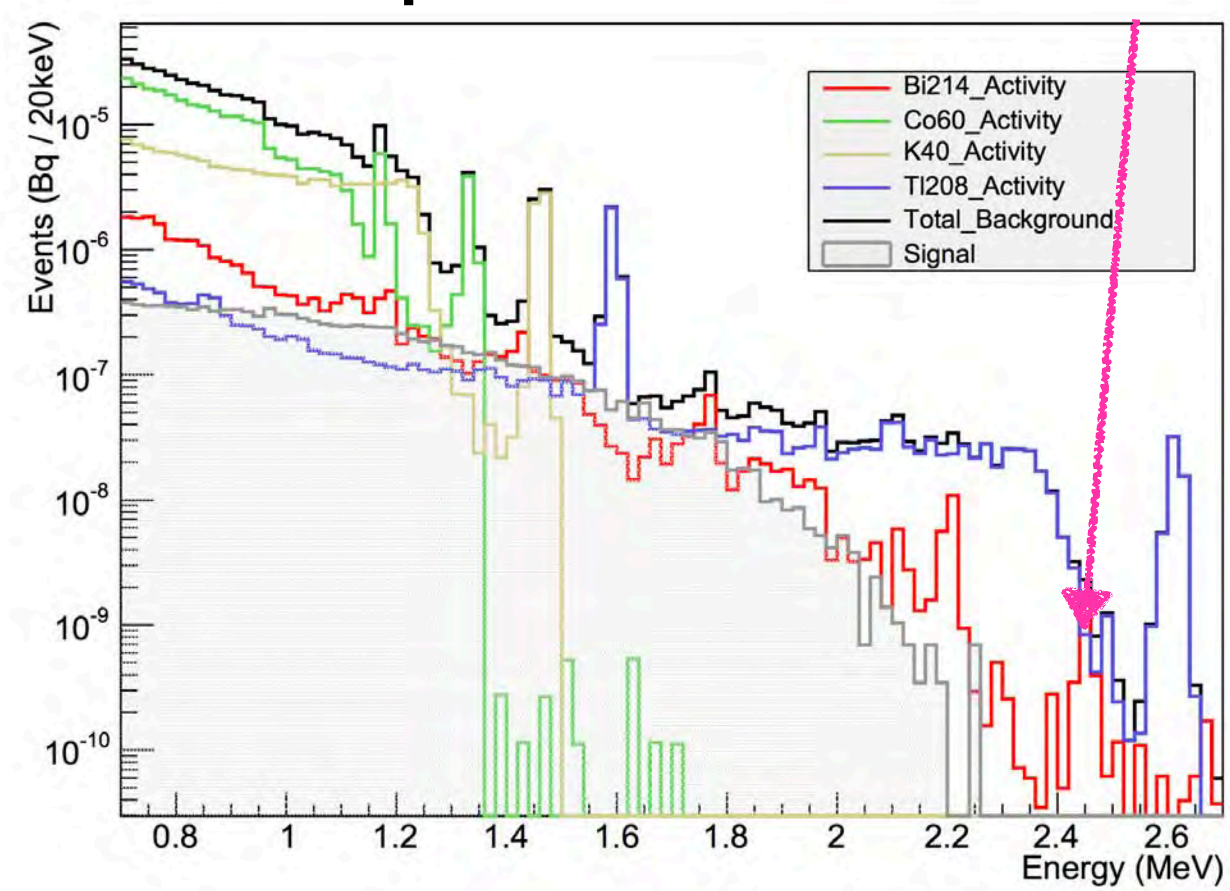
LXe Detector

Main impact is on ^{136}Xe 0νββ search

High energy γ from ^{214}Bi (^{238}U chain) and ^{208}Tl (^{232}Th chain) chains can fall into signal region for 0νββ decay

^{136}Xe Q value 2458 keV

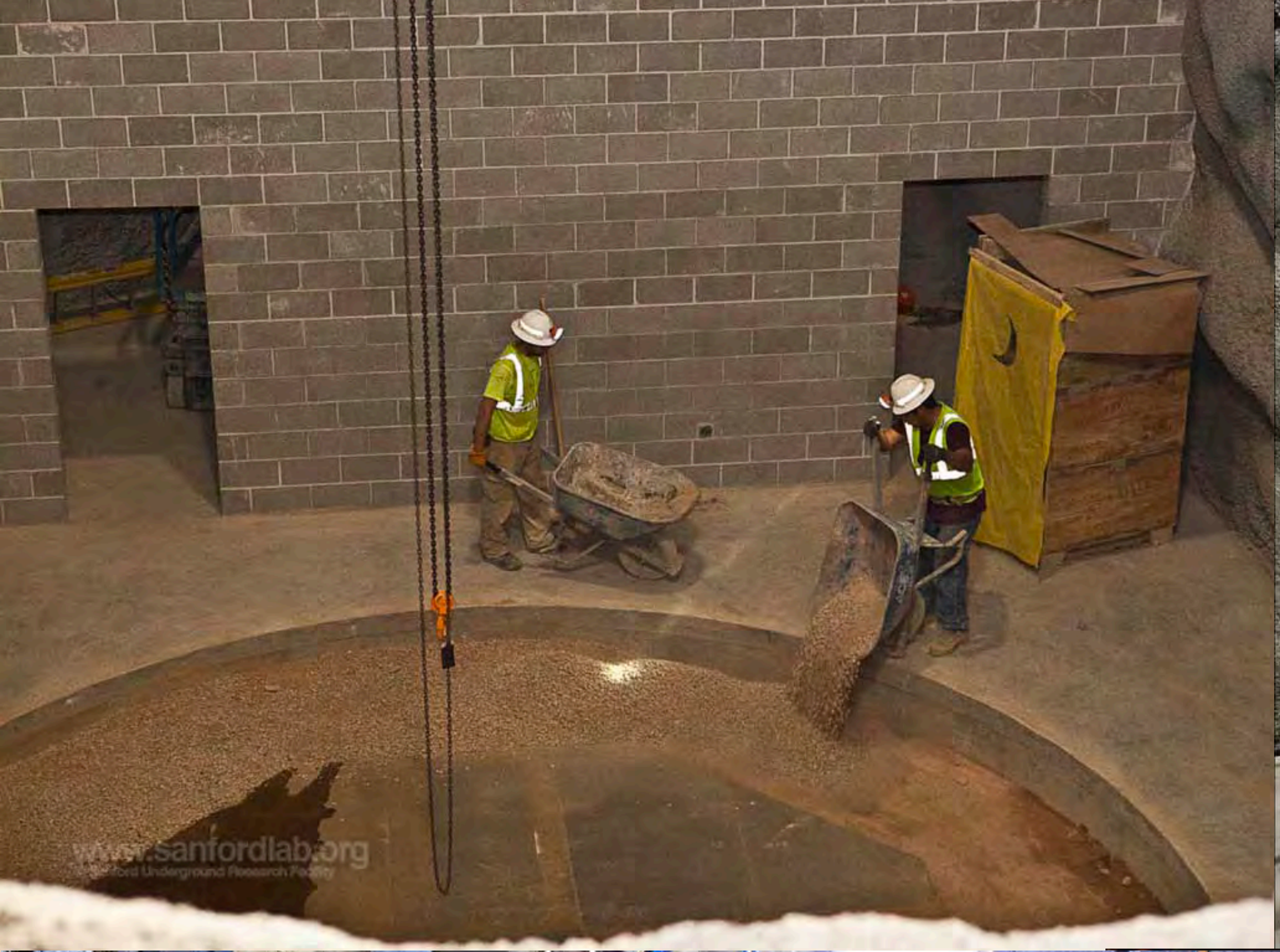
NEXT experiment



Nebot-Guinot et al, "Backgrounds and sensitivity of the NEXT double beta decay experiment"

About Us


www.sanfordlab.org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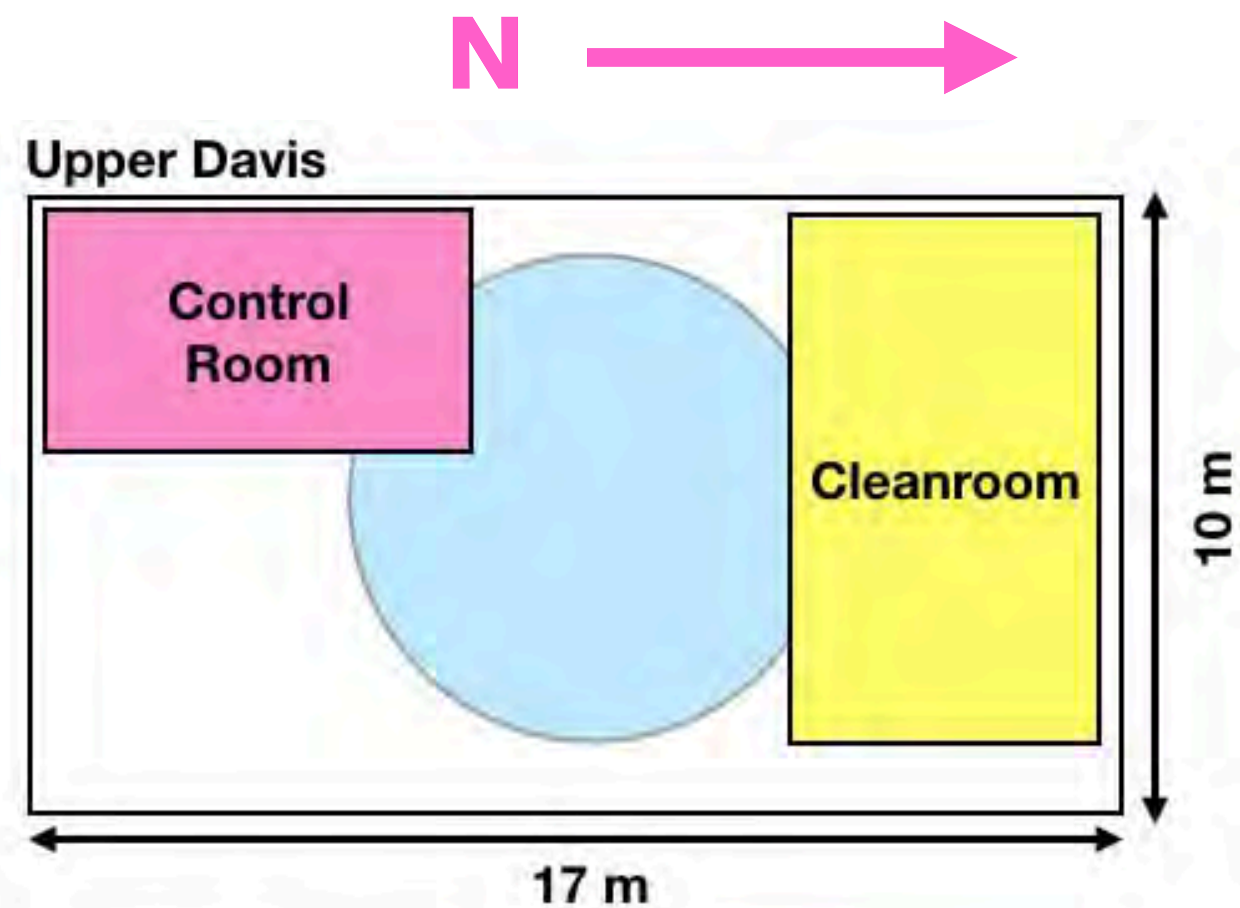
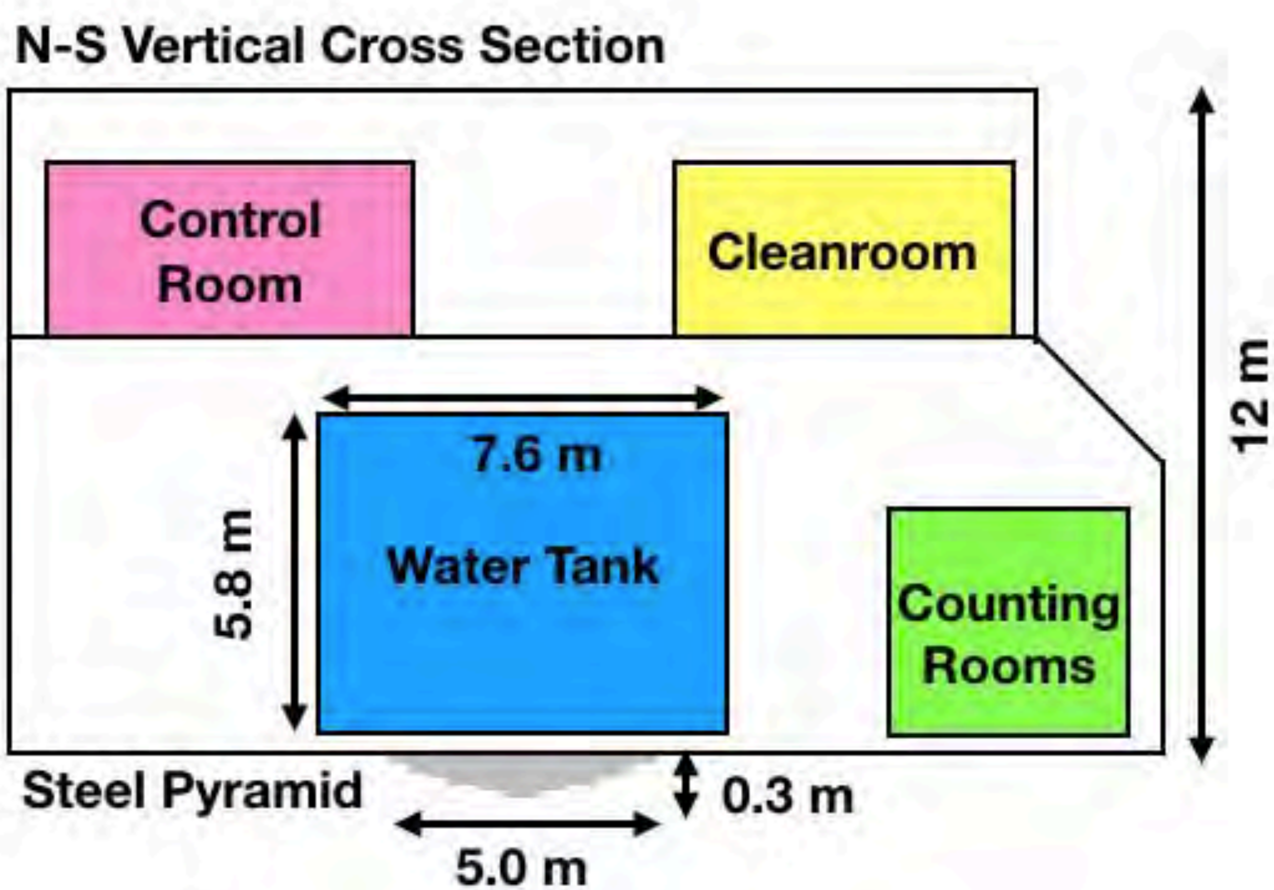
ordlab.org

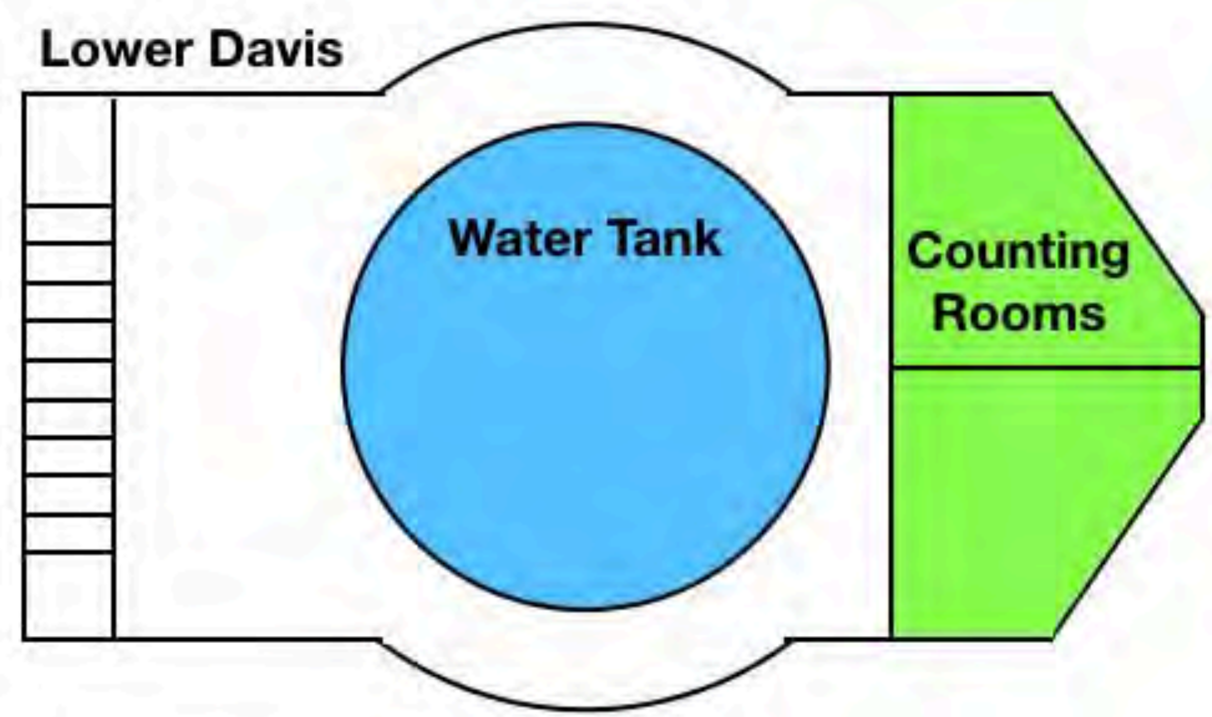
The Davis Cavern

NB - old layout, from the time of the measurements. Cleanroom has gone for LZ and the counting rooms are now joined as the compressor room

Dimensions are rough - shotcrete on the walls makes them uneven



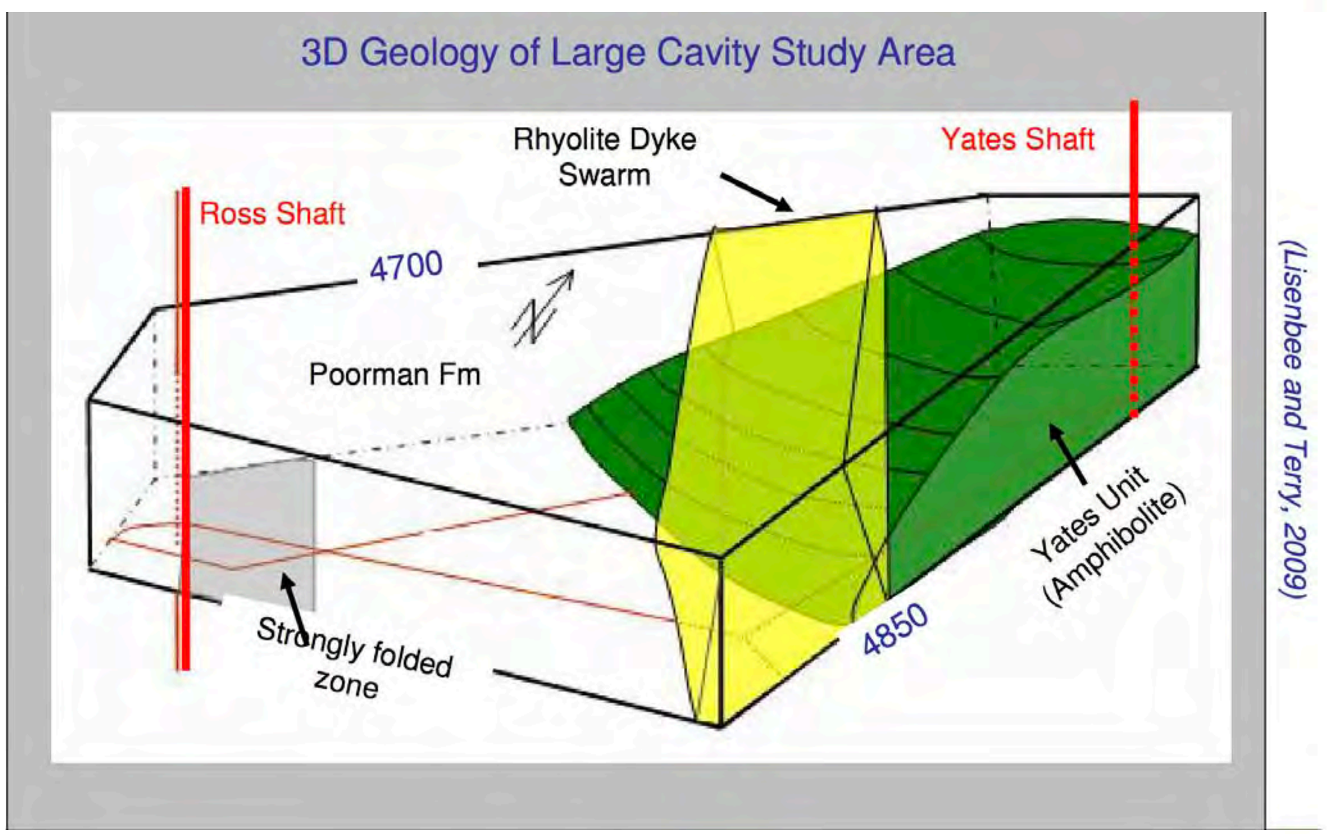




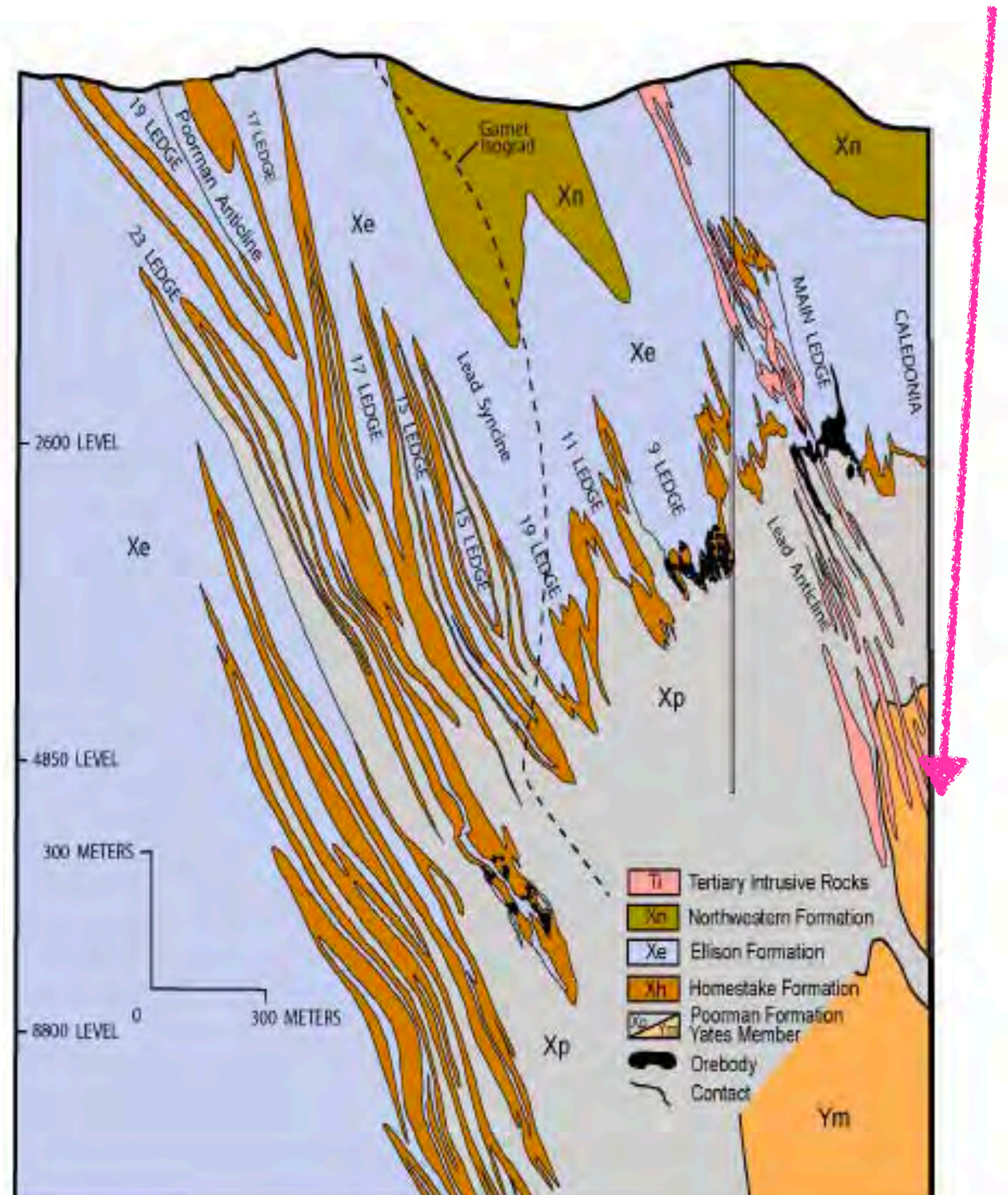
Homestake Geology

Most rock in the Davis cavern is "Yates member **amphibolite**"
- a metamorphic rock

- **Amphibolite is relatively low radioactivity in U, Th, K**
- There is a **rhyolite** dyke / intrusion that passes through the Davis cavern
  - **Much higher levels of radioactivity** - can be up to 50x higher than the amphibolite
  - Floor, north and west walls of the Davis cavern >50% rhyolite, rest of the walls < 2%
  - Could this result in a flux asymmetry?



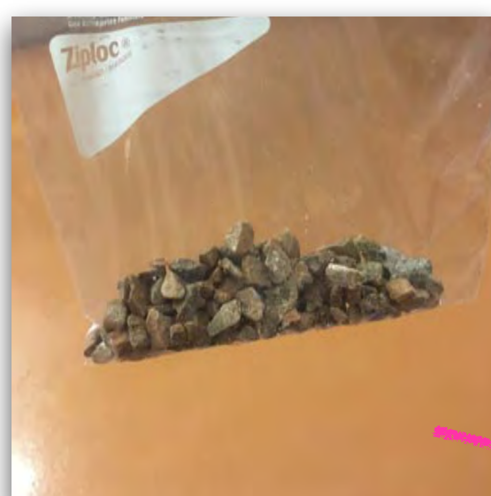
Davis cavern



Cavern Materials

- Most of cavern thought to be **amphibolite**
- extra-hot **rhyolite** intrusion passes through cavern, mostly on the floor and the west wall
- 12.7 cm (avg.) coating of **shotcrete** on walls & ceiling
- 0.5 ft of **concrete** on floor (1 ft in counting room)
- **gravel** beneath water tank

Water tank gravel sample and shotcrete sample taken in 2017 & sent for HPGe measurements

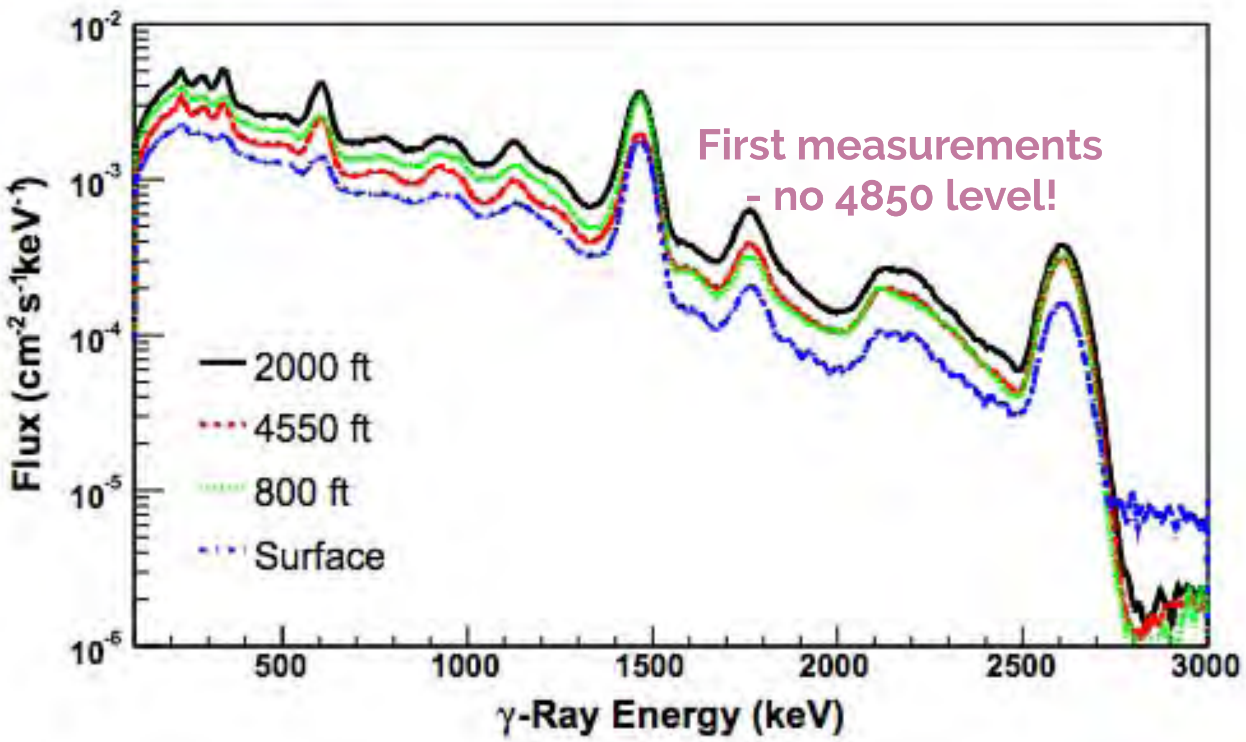


Older measurements from time of construction

Sample		^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
Homestake	avg.	297	2.7	1.3
	range	31–601	0.7–9.5	1.0–6.5
Rhyolite	avg	1291	108	44
	range	523–2127	99–135	7.7–61
Concrete	avg.	381	27	13
	range	393–368	22–27	13–14
Shotcrete	avg.	272	23	12
	range	127–393	22-28	8.1–14
Shotcrete	-	220 ± 30	21 ± 1	11.4 ± 0.4
Gravel	-	35.0 ± 0.6	26.3 ± 0.1	1.7 ± 0.8

Early Results on Radioactive Background Characterization for Sanford Laboratory and DUSEL Experiments

D.-M. Mei[a], C. Zhang[a,b], K. Thomas[a], F. Gray[c]



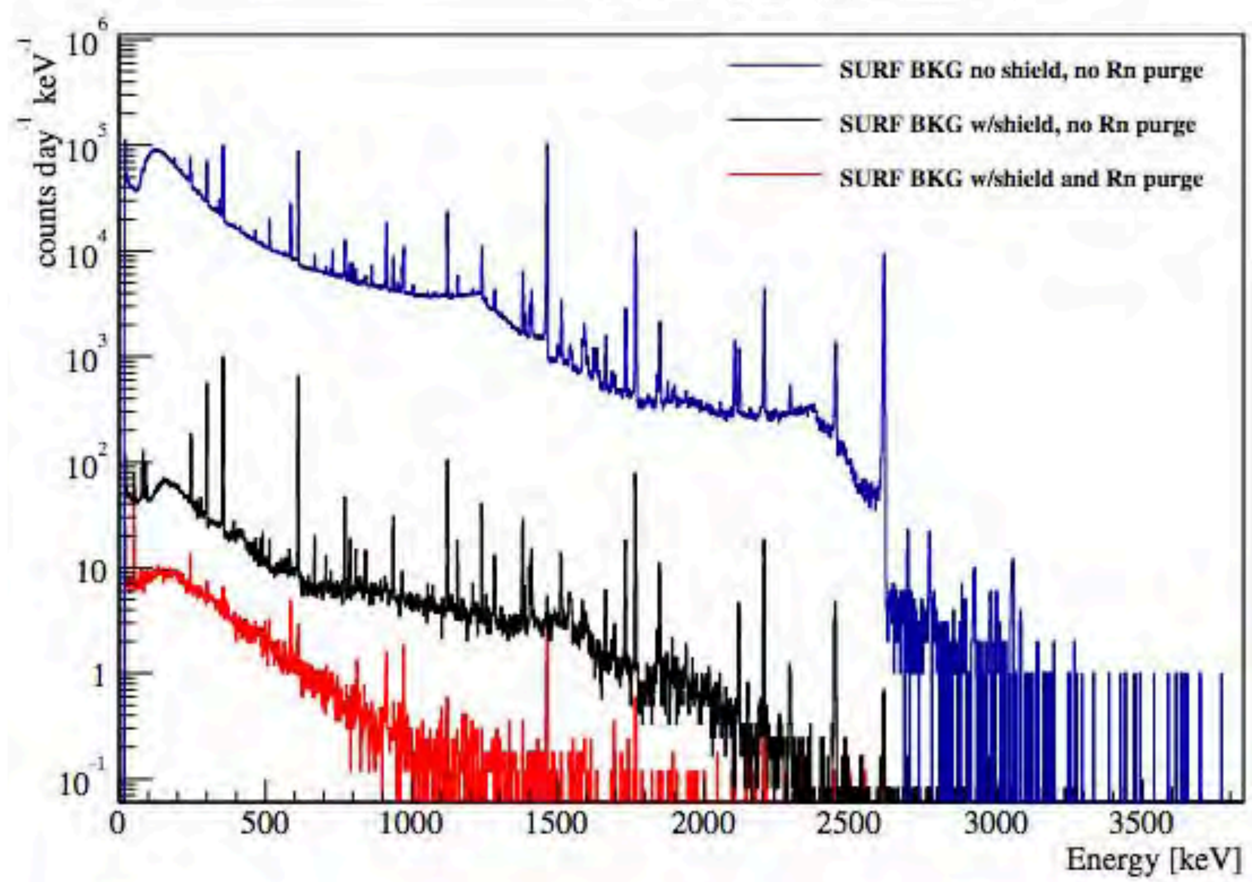
First measurements - no 4850 level!

An Estimate of the Gamma Flux in the East Counting Room of the Davis Cavern

November 21, 2014

K.J. Thomas[a,b]

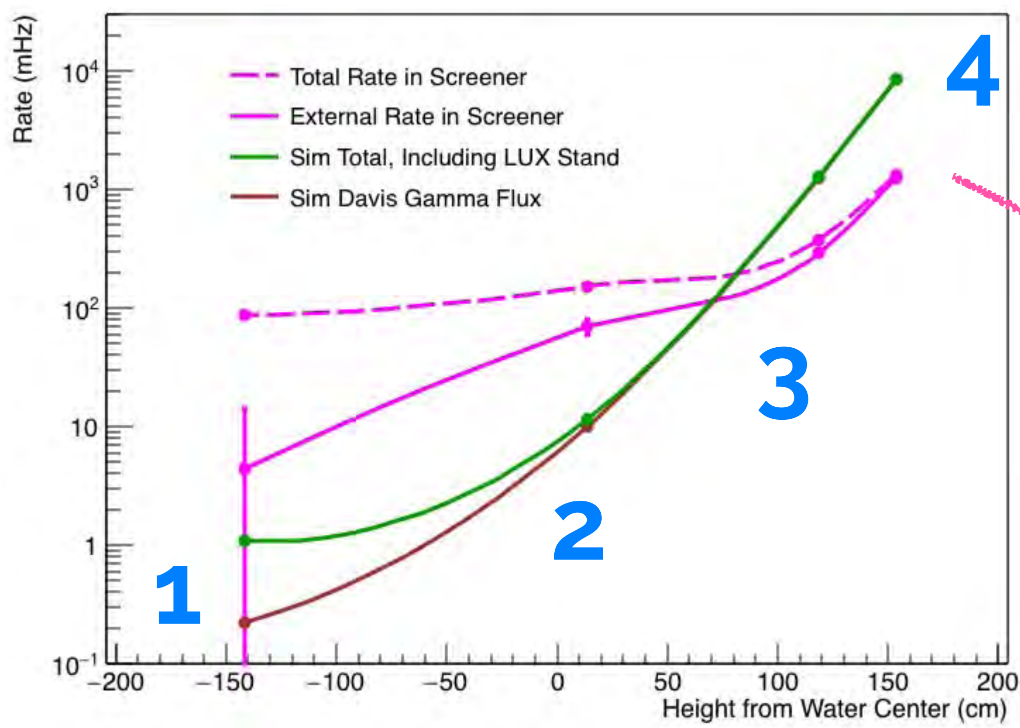
HPGe measurements done in 2014, provided an upper limit due to calibration uncertainties



"The variation of the γ-ray flux at different locations on the same level depends on the variation of the rock formations and the radioactivity levels in the rock. This variation can be as large as 30% as seen in the measurements. This is to say that the γ- ray flux must be measured in the experimental area where a low-background experiment is to be located."

LS Screener Measurement of the γ-flux

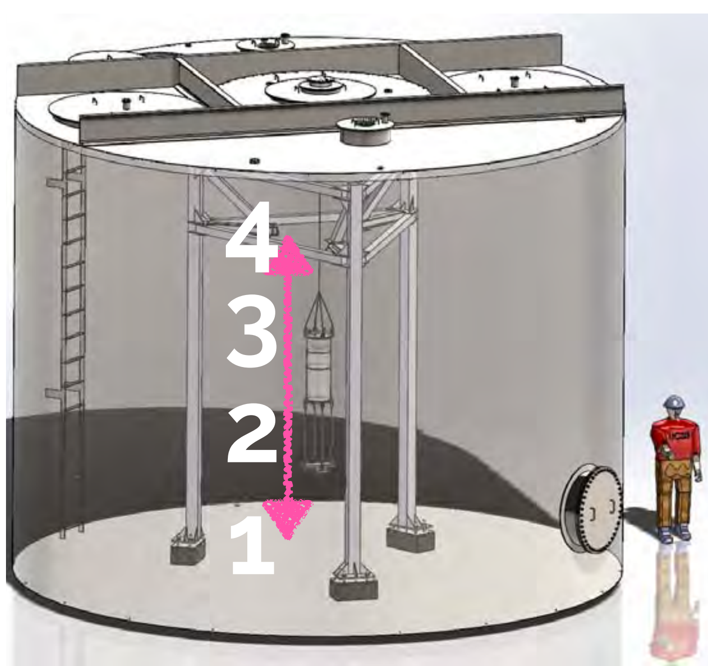
(S. Haselschwardt's talk from COSSURF 2017)



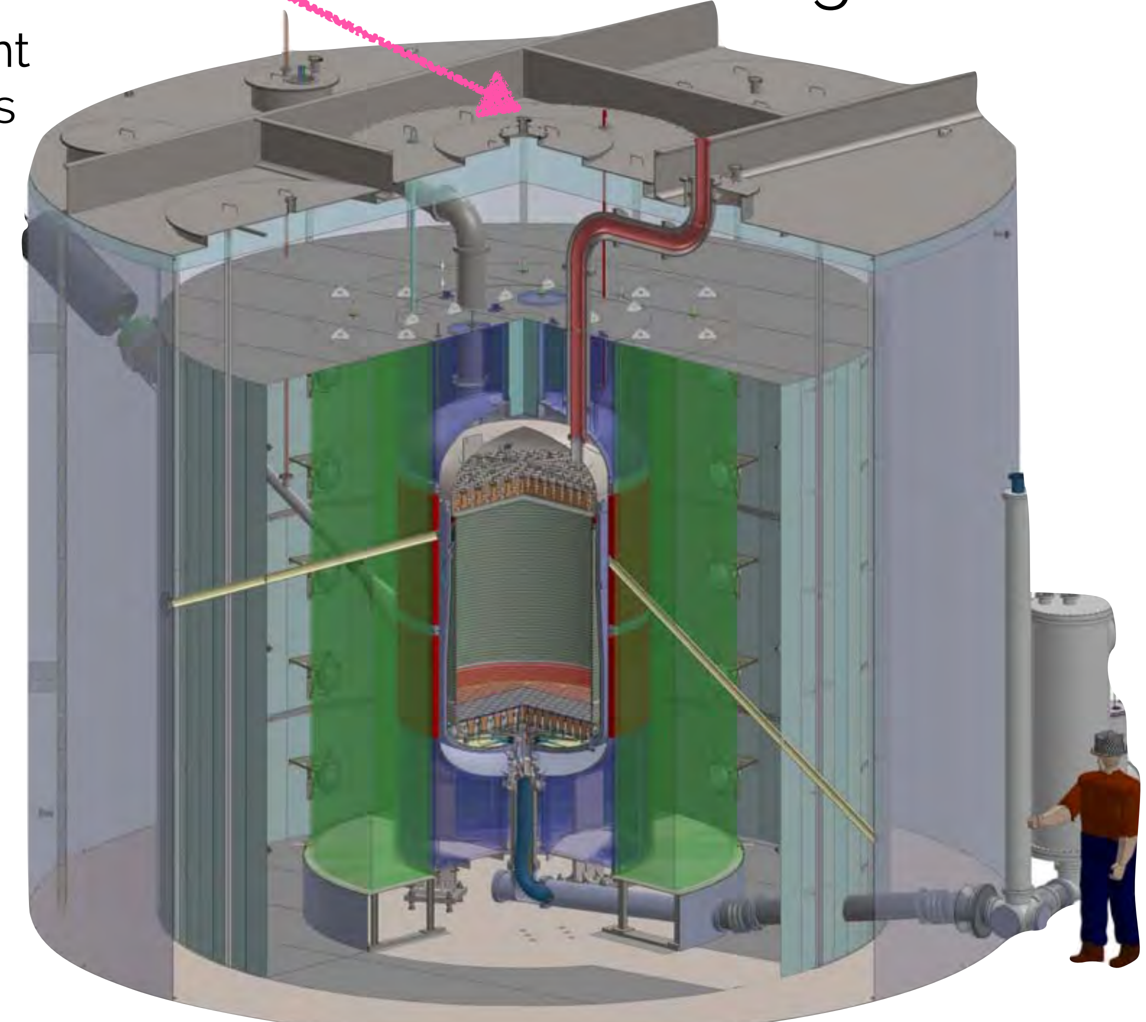
LS Screener detector measured an external **γ**-ray rate ~7x lower than expected at top of water tank

Important because **rate is concentrated at top and bottom of OD tanks** (least water shielding)

Sim normalisations clearly too high - based off older HPGe measurement intended for use as upper limit



LS Screener ran inside LUX/LZ water tank in 2016/2017



NaI(Tl) Detector Measurement

2 week campaign in October 2017 at SURF

Luke Korley (Brandeis)

Scott Haselschwardt (UCSB)

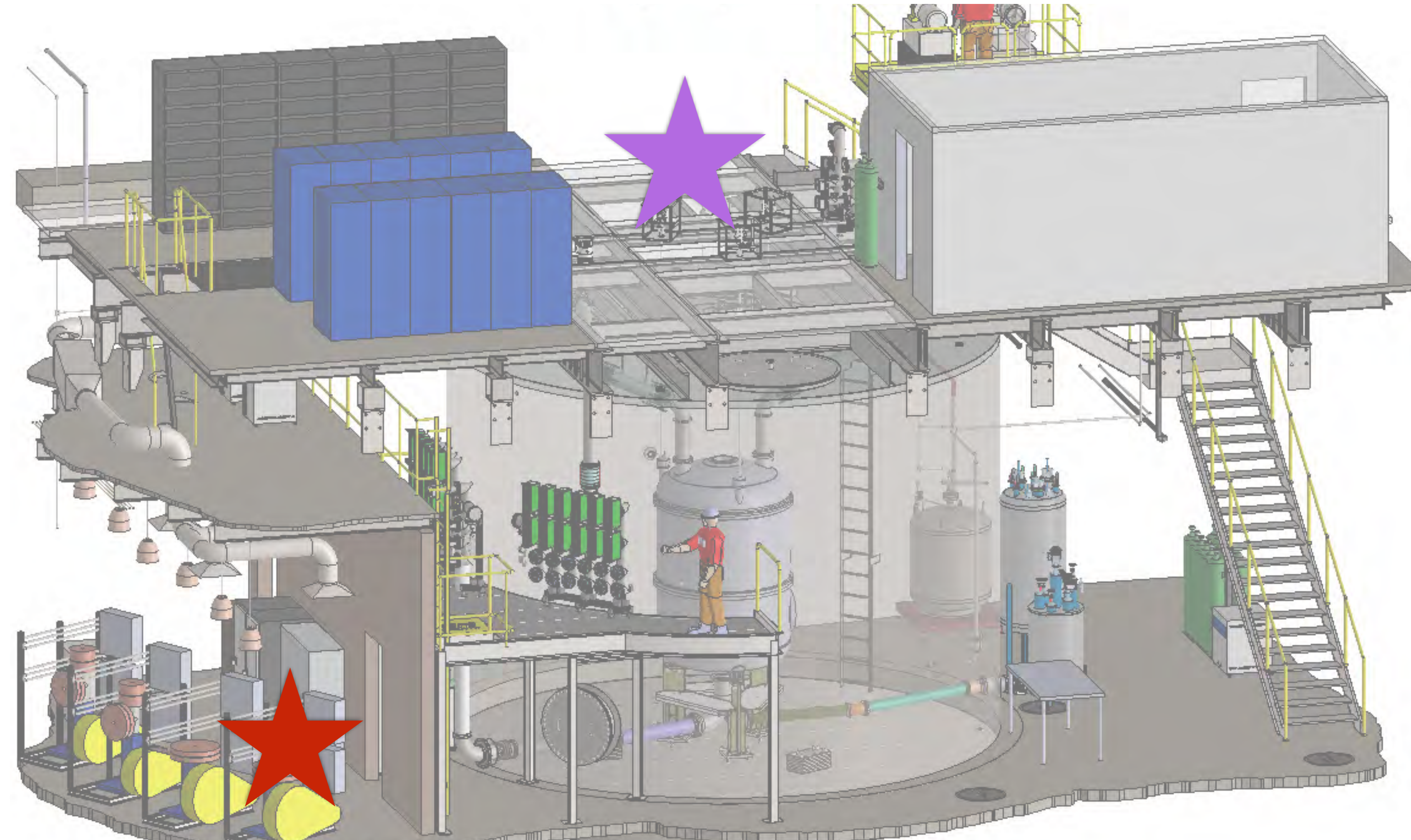
Melih Solmaz (UCSB)

Umit Utku (UCL)

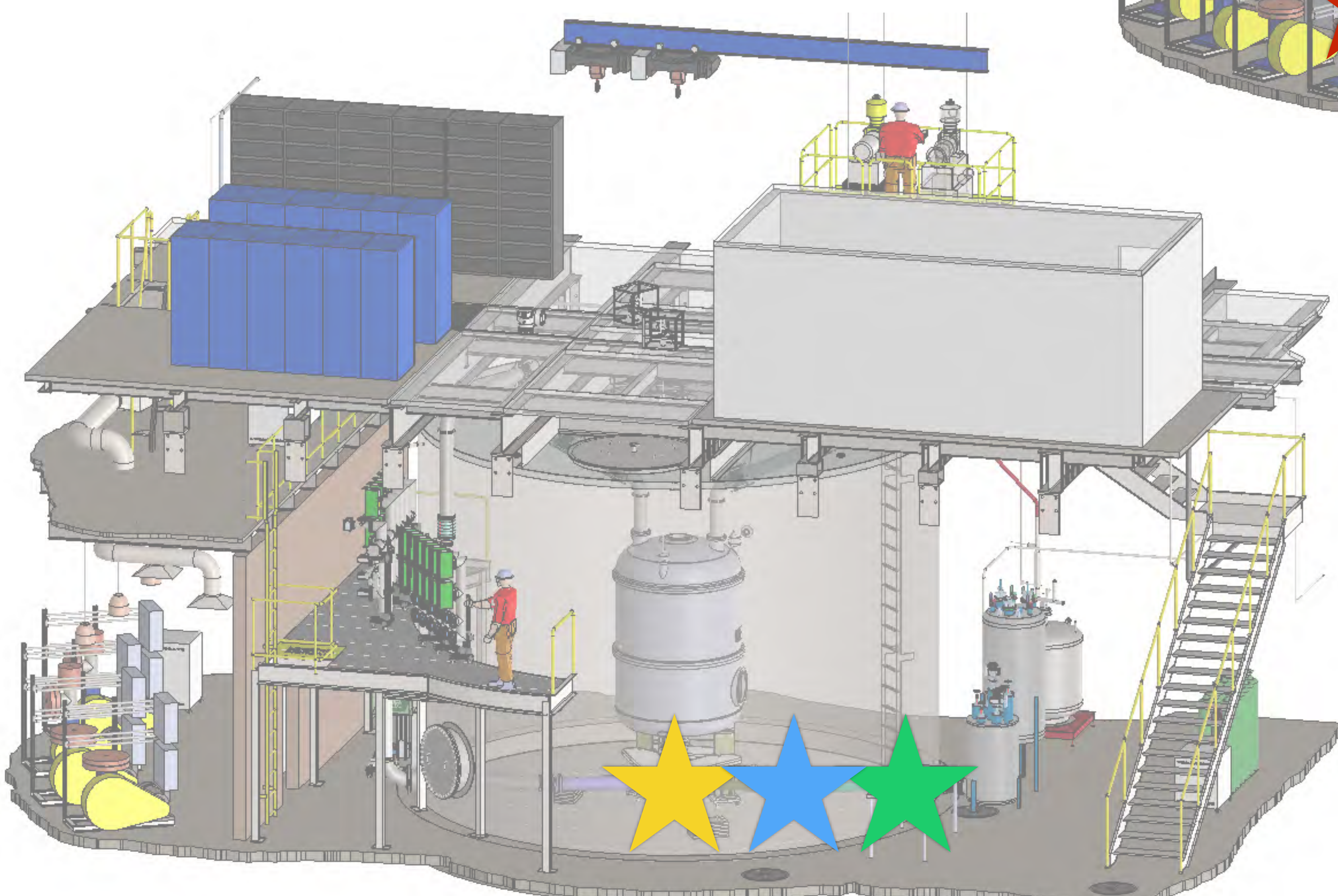
Goal: collect spectra from a variety of places in the Davis cavern
Use lead shielding to focus the measurement on different directions

NaI(Tl) Detector Measurement

Measurement Locations

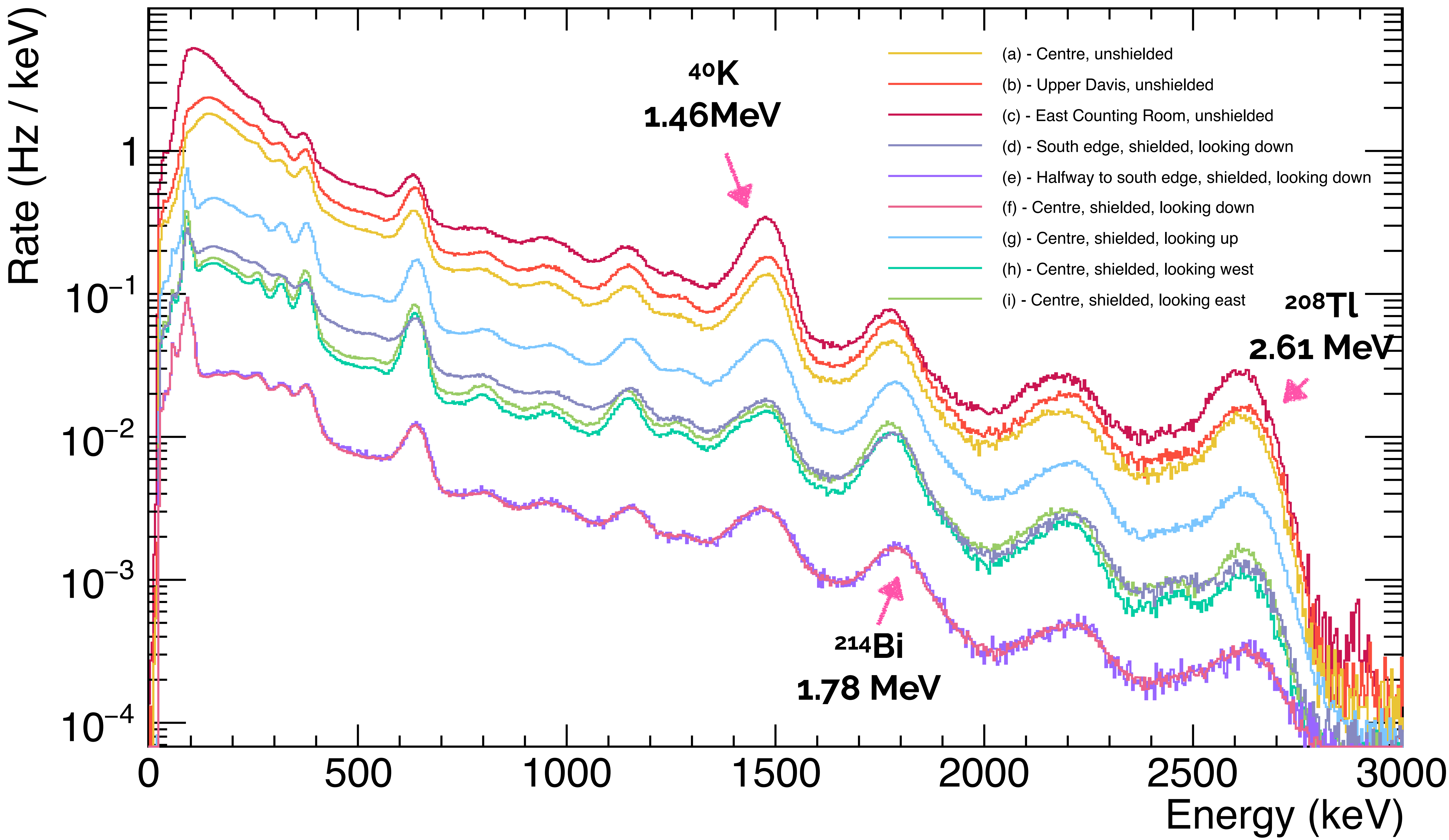


2 measurements outside tank:
Upper Davis
East Counting Room



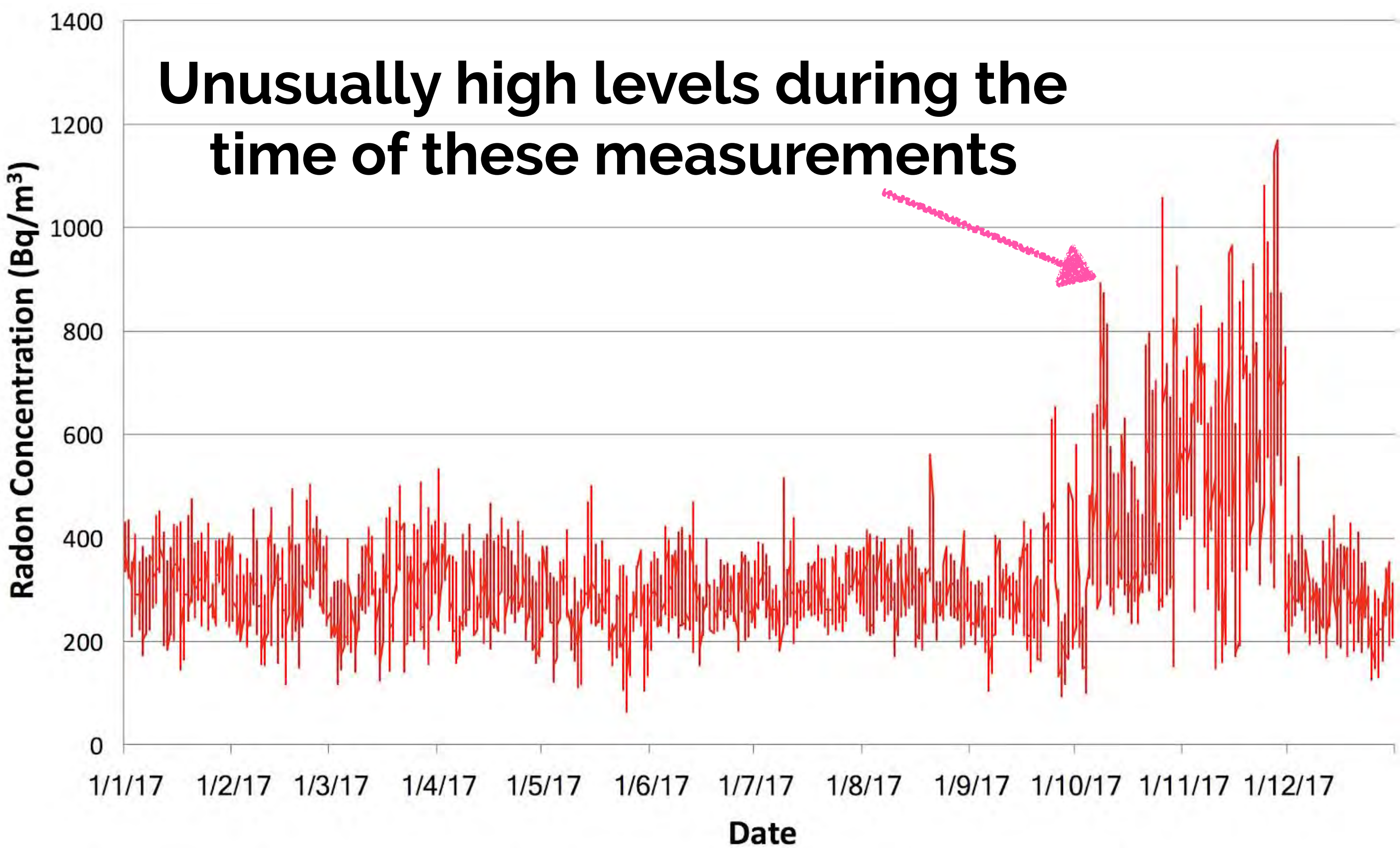
7 measurements in tank:
Centre unshielded
Centre (downwards)
Centre (upwards)
Centre (east facing)
Centre (west facing)
Halfway to edge (downwards)
Edge (downwards)

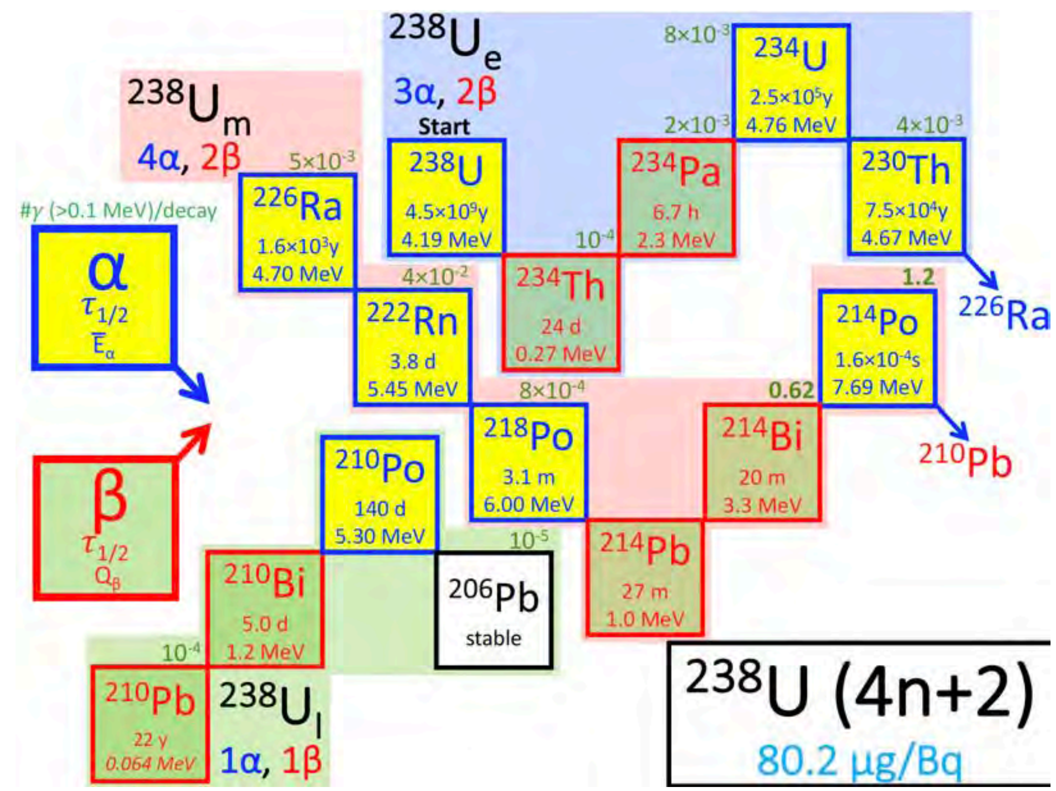
NaI γ-ray Spectra - All Measurements



Radon in the Cavern Air

Average (yearly) radon at SURF: **310 Bq/m³**

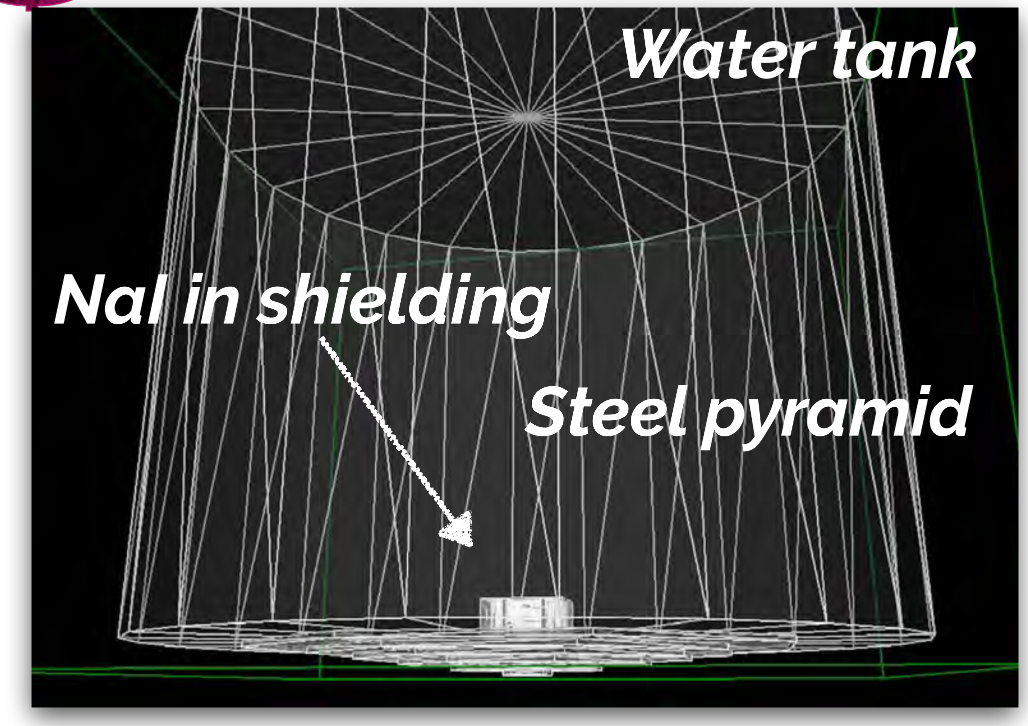




Position of measurement	Start Date	live time (hours)	Avg. Radon (Bq/m³)	Rate (Hz) Total
Centre of water tank, unshielded	24/10/17	4.0	422 ± 34	595.7 ± 0.2
Upper Davis, unshielded	26/10/17	3.6	868 ± 222	794.4 ± 0.2
East Counting Room, unshielded	26/10/17	2.1	929 ± 70	1355.0 ± 0.4
Edge of tank, looking down	16/10/17	18.2	358 ± 80	94.17 ± 0.04
Halfway to edge of tank, looking down	17/10/17	17.9	336 ± 55	17.15 ± 0.02
Centre of tank, looking down	19/10/17	117.0	500 ± 155	16.715 ± 0.006
Centre of tank, looking up	18/10/17	20.2	372 ± 76	203.57 ± 0.05
Centre of tank, looking west	24/10/17	17.3	359 ± 37	95.11 ± 0.04
Centre of tank, looking east	25/10/17	22.3	316 ± 46	106.33 ± 0.4

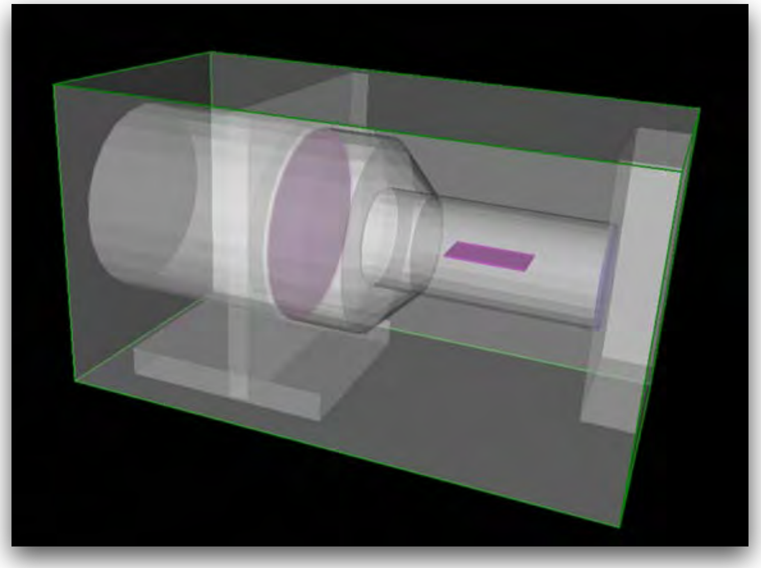
Determined by simulation that radon needs including in the model - **contributes up to 20% of the observed rate** depending on measurement

Simulating the Cavern Background



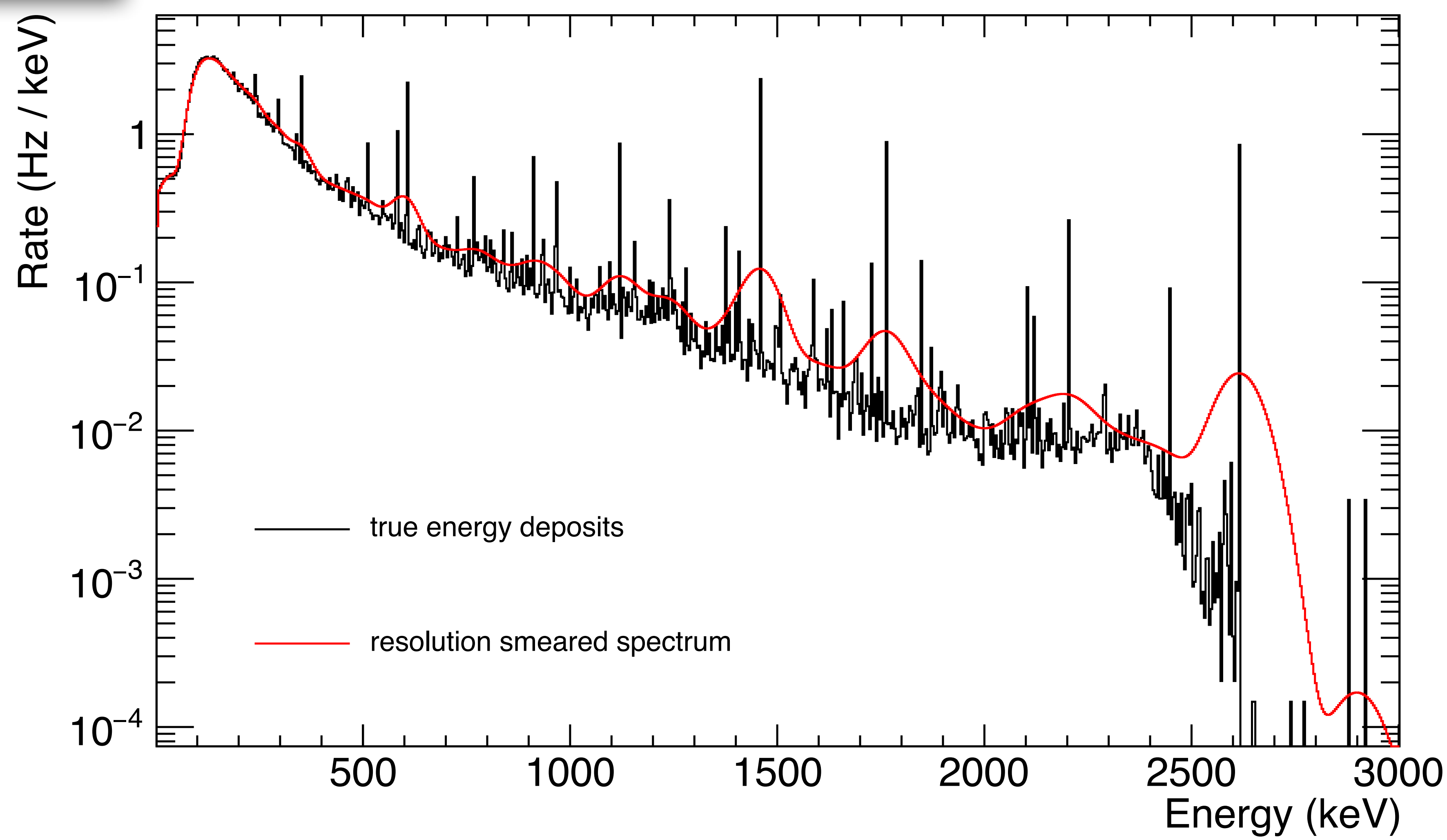
Custom geometry built within the BACCARAT package used for LZ simulations

Special event biasing technique used - save γ-rays on a surface just outside water tank, then propagate with a boost factor (& same momenta) in a second sim



True energy deposit smeared according to calibration data

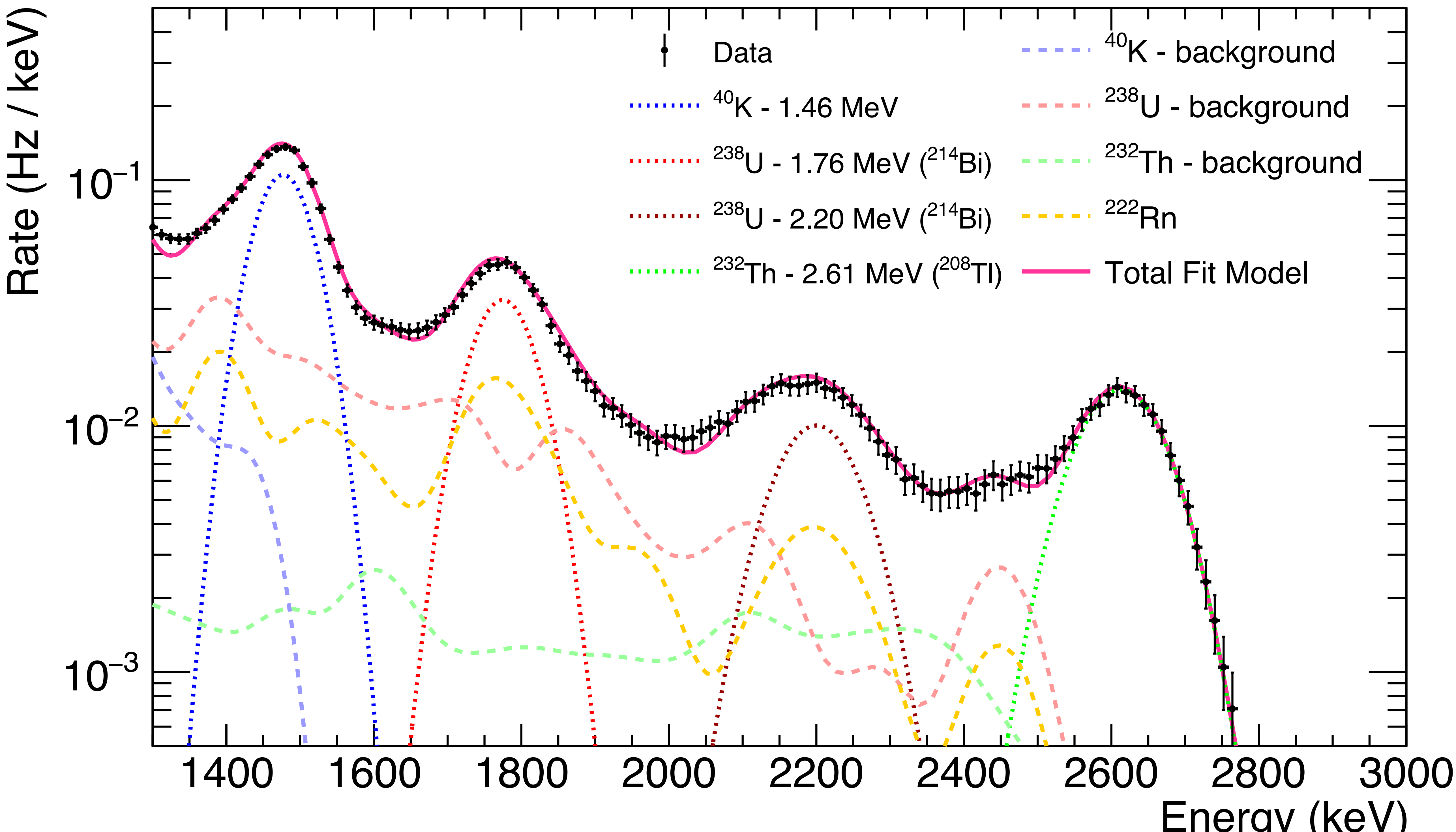
Radioactive decays (^{40}K, ^{238}U & ^{232}Th chains) are simulated in a simple model of the cavern walls, and decays from ^{220}Rn and downwards are simulated in the cavern air.
Energy deposits are saved in the NaI crystal



Fitting the Spectra

Float concentrations of each isotope to to match simulated peaks to data peaks

Centre of water tank, unshielded



Rock Activities & Cavern Flux

Comparing each of the measurement positions, no directional asymmetry in flux observed
Average activities are consistent with shotcrete only

Activities	K (Bq/kg)	U (Bq/kg)	Th (Bq/kg)
These measurements	**220 ± 60**	**29 ± 15**	**13 ± 3**
Amphibolite	297.2	4.1	1.3
Rhyolite	1291.0	108.0	17.0
Shotcrete - low	170.3	18.8	8.8
Shotcrete - standard	380.8	24.7	13.6
Shotcrete - finish coat	244.6	20.0	12.5
Shotcrete	216.7	22.2 (early) 21.36 (late)	11.4
Gravel	35.0	22.2 (early) 26.3 (late)	1.71

Large uncertainty on uranium is due to the uncertainties on radon levels in the cavern
- radon allowed to float with a 20% uncertainty on the average value during the measurement, due to the fact the radon detector is not in the actual Davis cavern

Total γ-flux

$1.9 \pm 0.4\ \gamma\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$

Comparison to other labs

Compare reported K, U, Th activities with other underground labs (all HPGe measurements)

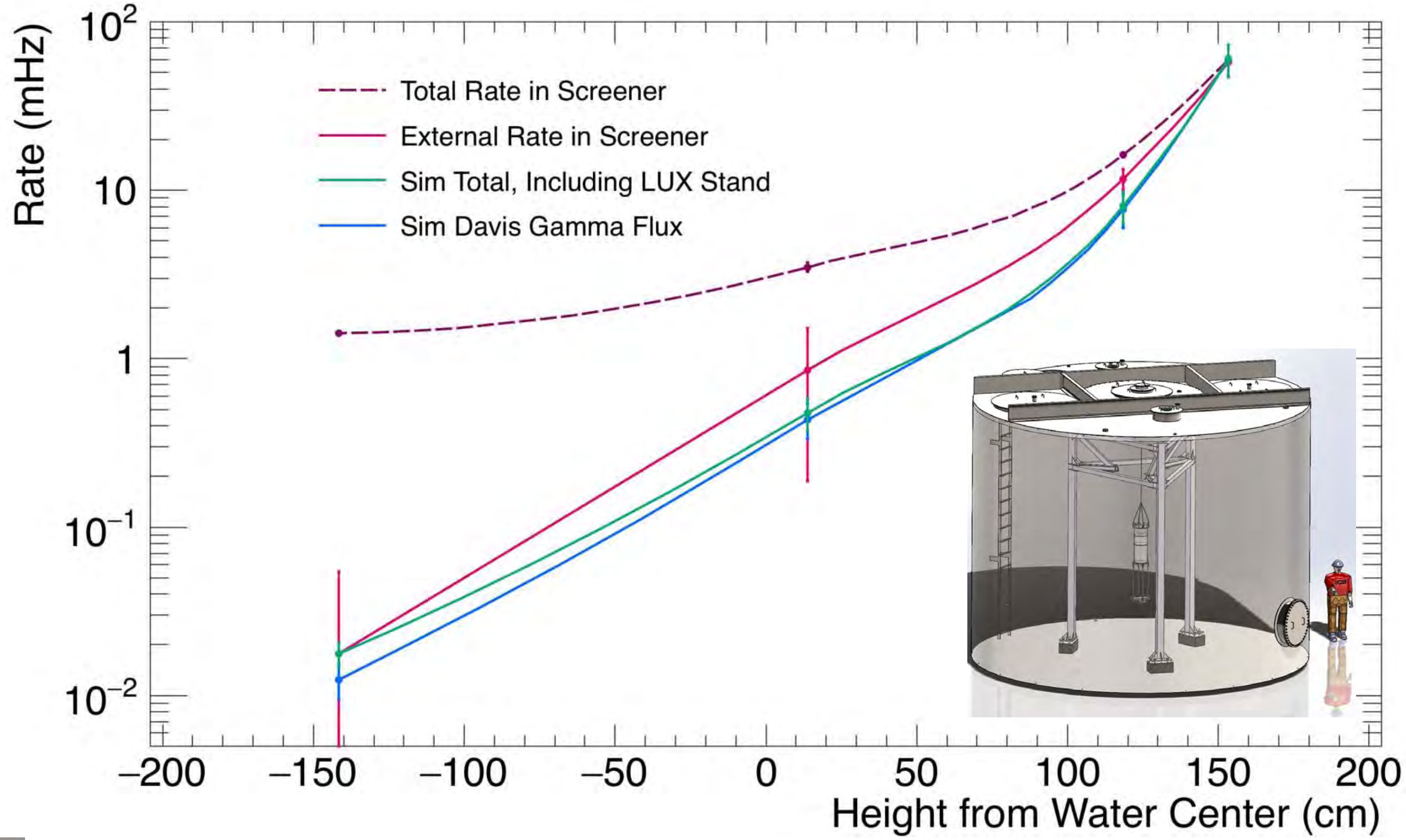
Laboratory	K (Bq/kg)	U (Bq/kg)	Th (Bq/kg)	Flux γ cm^{-2} s^{-1}	Dominant Source
Boulby, UK*	112 ± 2	1.63 ± 0.06	1.88 ± 0.06	0.128	mudstone & halite
Gran Sasso, Italy*	70 ± 2	9.5 ± 0.3	3.7 ± 0.2	0.25	concrete
LSM, Spain*	80 ± 1	19.7 ± 0.7	6.2 ± 2	0.622	concrete
Jinping, China**	36.669	19.880	8.150	?	concrete
SURF, USA	**220 ± 60**	**29 ± 15**	**13 ± 3**	**1.9 ± 0.4**	**shotcrete**

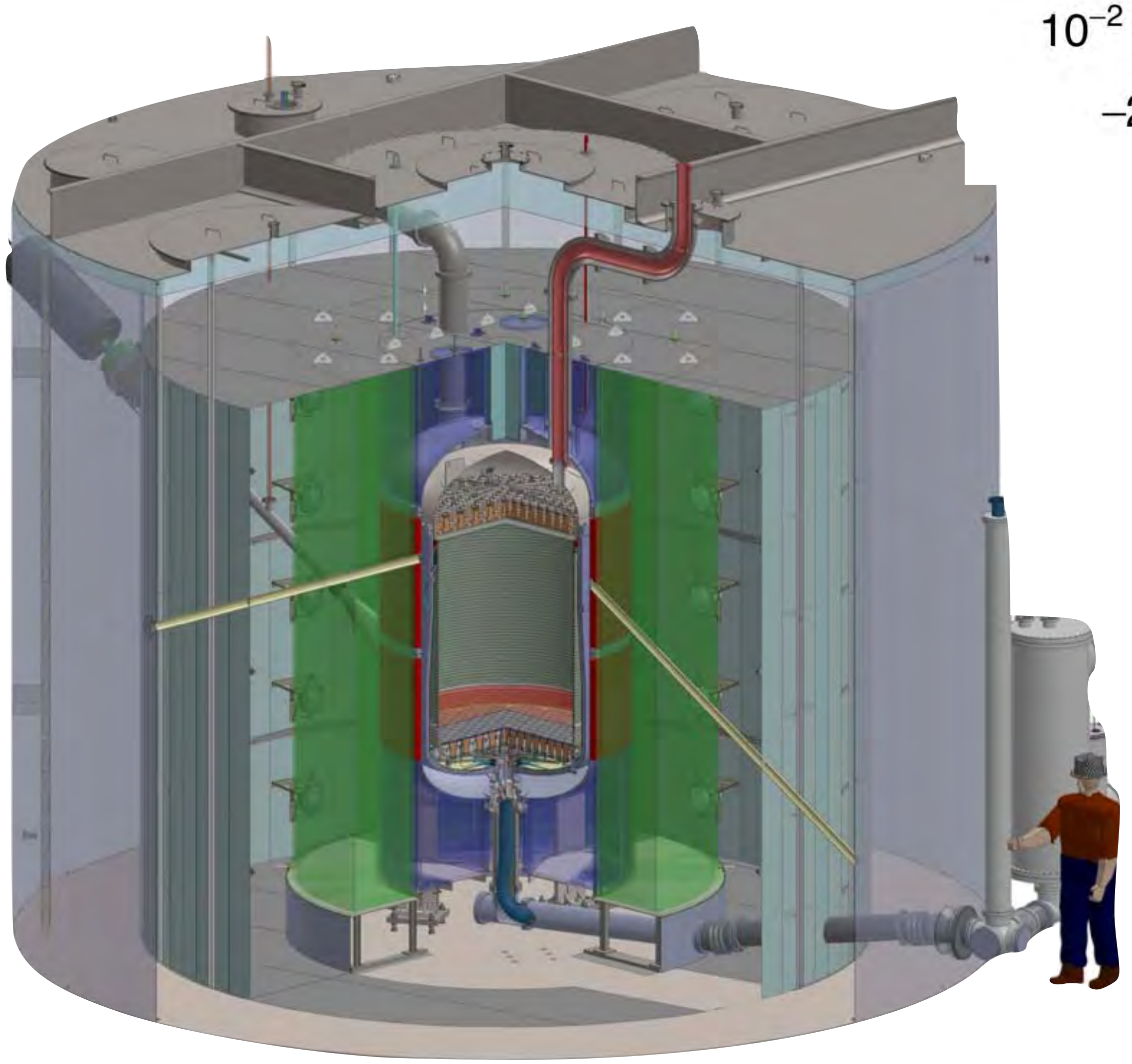
* measurements by Dariusz Malczewski, Jan Kisiel & Jerzy Dorda in J Radioanal Nucl Chem under ILIAS initiative
(DOIs: 10.1007/s10967-013-2540-9
10.1007/s10967-012-1990-9
10.1007/s10967-011-1497-9

**Zheng et al, Environmental gamma background measurements in China Jinping Underground Laboratory, J Radioanal Nucl Chem (2014) 301:443–450

Crosschecks & Implications

Using the new activities, we get agreement with the LS screener data from 2016/2017
60 ± 10 mHz predicted,
60 ± 1 mHz observed
(above 1.4 MeV)





Rate in the LZ Outer Detector now expected to be **27 ± 7 Hz**
- total rate well below the 100 Hz target

0νββ background model now complete with the contribution from the cavern
Paper on LZ 0νββ sensitivity on the way

arXiv:1904.02112

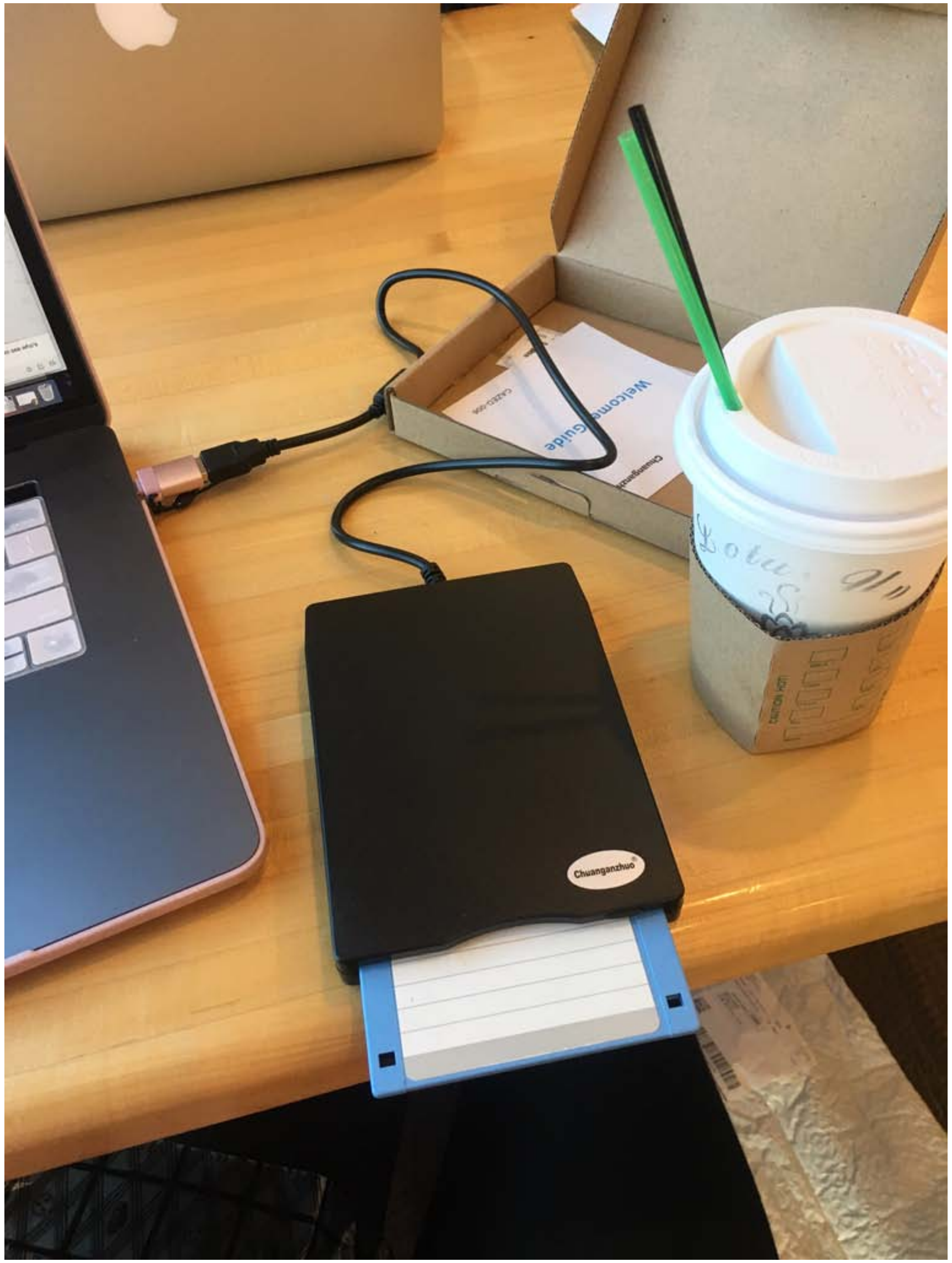
Measurement of the Gamma Ray Background in the Davis Cavern at the Sanford Underground Research Facility

D.S. Akerib,[1,2] C.W. Akerlof,[3] S.K. Alsum,[4] A. Angelides,[5] H.M. Araújo,[6] J.E. Armstrong,[7] M. Arthurs,[3] X. Bai,[8] J. Balajthy,[9] S. Balashov,[10] A. Baxter,[11] E.P. Bernard,[12,13] A. Biekert,[12,13] T.P. Biesiadzinski,[1,2] K.E. Boast,[14] B. Boxer,[11] P. Brás,[15] J.H. Buckley,[16] V.V. Bugaev,[16] S. Burdin,[11] J.K. Busenitz,[17] C. Carels,[14] D.L. Carlsmith,[4] M.C. Carmona-Benitez,[18] M. Cascella,[5] C. Chan,[19] A. Cole,[13] A. Cottle,[20,a] J.E. Cutter,[9] C.E. Dahl,[21,20] L. de Viveiros,[18] J.E.Y. Dobson,[5] E. Druszkiewicz,[22] T.K. Edberg,[7] A. Fan,[1,2] S. Fiorucci,[13] H. Flaecher,[23] T. Fruth,[14] R.J. Gaitskell,[19] J. Genovesi,[8] C. Ghag,[5] M.G.D. Gilchriese,[13] S. Gokhale,[24] M.G.D.van der Grinten,[10] C.R. Hall,[7] S. Hans,[24] J. Harrison,[8] S.J. Haselschwardt,[25] S.A. Hertel,[26] J.Y-K. Hor,[17] M. Horn,[27] D.Q. Huang,[19] C.M. Ignarra,[1,2] O. Jahangir,[5] W. Ji,[1,2] J. Johnson,[9] A.C. Kaboth,[28,10] K. Kamdin,[13,12] D. Khaitan,[22] A. Khazov,[10] W.T. Kim,[29] C.D. Kocher,[19] L. Korley,[30] E.V. Korolkova,[31] J. Kras,[4] H. Kraus,[14] S.W. Kravitz,[13] L. Kreczko,[23] B. Krikler,[23] V.A. Kudryavtsev,[31] E.A. Leason,[32] J. Lee,[29] D.S. Leonard,[29] K.T. Lesko,[13] C. Levy,[33] J. Li,[29] J. Liao,[19] F.-T. Liao,[14] J. Lin,[12,13] A. Lindote,[15] R. Linehan,[1,2] W.H. Lippincott,[20] R. Liu,[19] X. Liu,[32] C. Loniewski,[22] M.I. Lopes,[15] B. López Paredes,[6] W. Lorenzon,[3] S. Luitz,[1] J.M. Lyle,[19] P.A. Majewski,[10] A. Manalaysay,[9] L. Manenti,[5] R.L. Mannino,[4] N. Marangou,[6] M.F. Marzioni,[32] D.N. McKinsey,[12,13] J. McLaughlin,[21] Y. Meng,[17] E.H. Miller,[1,2] M.E. Monzani,[1,2] J.A. Morad,[9] E. Morrison,[8] B.J. Mount,[34] A.St.J. Murphy,[32] D. Naim,[9] A. Naylor,[31] C. Nedlik,[26] C. Nehrkorn,[25] H.N. Nelson,[25] F. Neves,[15] J. Nikoleyczik,[4] A. Nilima,[32] I. Olcina,[6] K.C. Oliver-Mallory,[13,12] S. Pal,[15] K.J. Palladino,[4] E.K. Pease,[13] B.P. Penning,[30] G. Pereira,[15] A. Piepke,[17] K. Pushkin,[3] J. Reichenbacher,[8] C.A. Rhyne,[19] Q. Riffard,[12,13] G.R.C. Rischbieter,[33] J.P. Rodrigues,[15] R. Rosero,[24] P. Rossiter,[31] G. Rutherford,[19] A.B.M.R. Sazzad,[17] R.W. Schnee,[8] M. Schubnell,[3] P.R. Scovell,[14,10] D. Seymour,[19] S. Shaw,[25,b] T.A. Shutt,[1,2] J.J. Silk,[7] C. Silva,[15] M. Solmaz,[25] V.N. Solovov,[15] P. Sorensen,[13] I. Stancu,[17] A. Stevens,[14] T.M. Stiegler,[35,c] K. Stifter,[1,2] M. Szydagis,[33] W.C. Taylor,[19] R. Taylor,[6] D. Temples,[21] P.A. Terman,[35] D.R. Tiedt,[7] M. Timalsina,[8] A. Tomás,[6] M. Tripathi,[9] L. Tvrznikova,[36,12] U. Utku,[5] S. Uvarov,[9] A. Vacheret,[6] J.J. Wang,[30] J.R. Watson,[12,13] R.C. Webb,[35] R.G. White,[1,2] T.J. Whitis,[1,37] F.L.H. Wolfs,[22] D. Woodward,[18] and J. Yin[22]
(The LUX-ZEPLIN (LZ) Collaboration)

Conclusions

- The Davis Cavern γ-ray flux has been measured with a 5-inch NaI detector to be $1.9 \pm 0.4\ \gamma\ cm^{-2}\ s^{-1}$
- Radon in mine air contributed significantly to the cavern flux at the time of these measurements
- Radioactivities in the wall of the cavern were determined to be 220 Bq/kg of ^{40}K, 29 Bq/kg of ^{238}U and 13 Bq/kg of ^{232}Th
- No flux asymmetry due to the rhyolite intrusion that passes through the cavern was observed
- These results are consistent with that expected from the radioactivity measured in HPGe screening of shotcrete samples
- LZ Outer Detector Veto rate from cavern γ -rays is expected to be 27 ±7 Hz
- Contribution to $0\nu\beta\beta$ decay background model finalised, paper on the way
- And finally...

Conclusions



World's first transfer of data from a Windows 97 laptop 4850 ft underground → floppy disk → USB →USBC→MacBook?

Thanks to…

UCSB: Scott Haselschwardt, Harry Nelson, Melih Solmaz

LBNL: Kevin Lesko, Andy Cole

Brandeis: Luke Korley, Bjoern Penning

UCL: Umit Utku, Cham Ghag

School of Mines: Doug Tiedt

SURF: John Keefner, Mark Hanhardt

Penn State: David Woodward

Amazon Prime (for delivering USB Floppy disk reader to Lead, South Dakota in record time)