Materials Screening for the LUX-ZEPLIN Experiment

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on behalf of the LZ Collaboration

UCLA Dark Matter 2016

LZ Backgrounds

Irreducible/Physics Backgrounds

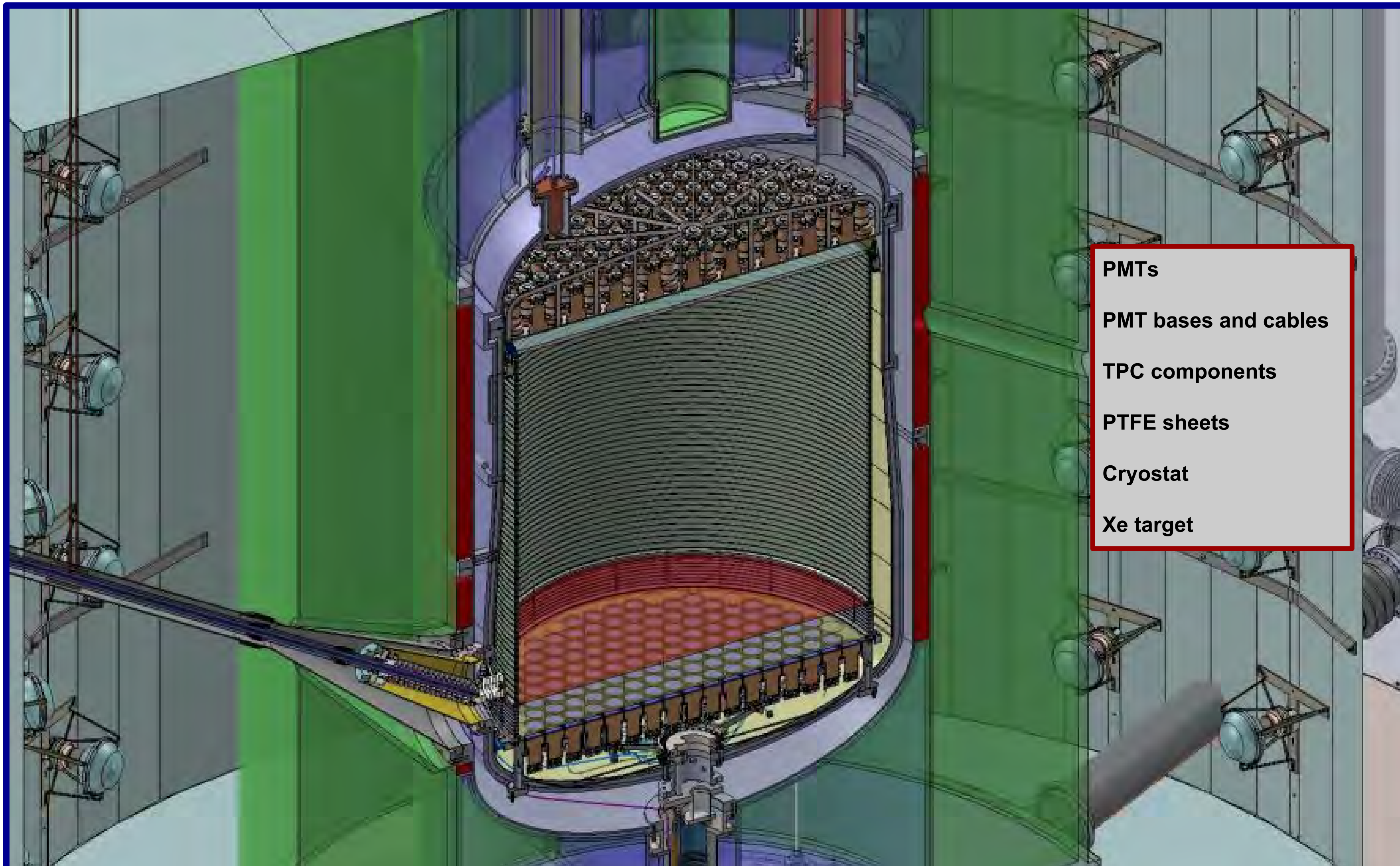
- ^{136}Xe double beta decay ER
- solar neutrinos ER
- solar neutrinos NR

Contamination in Detector Components

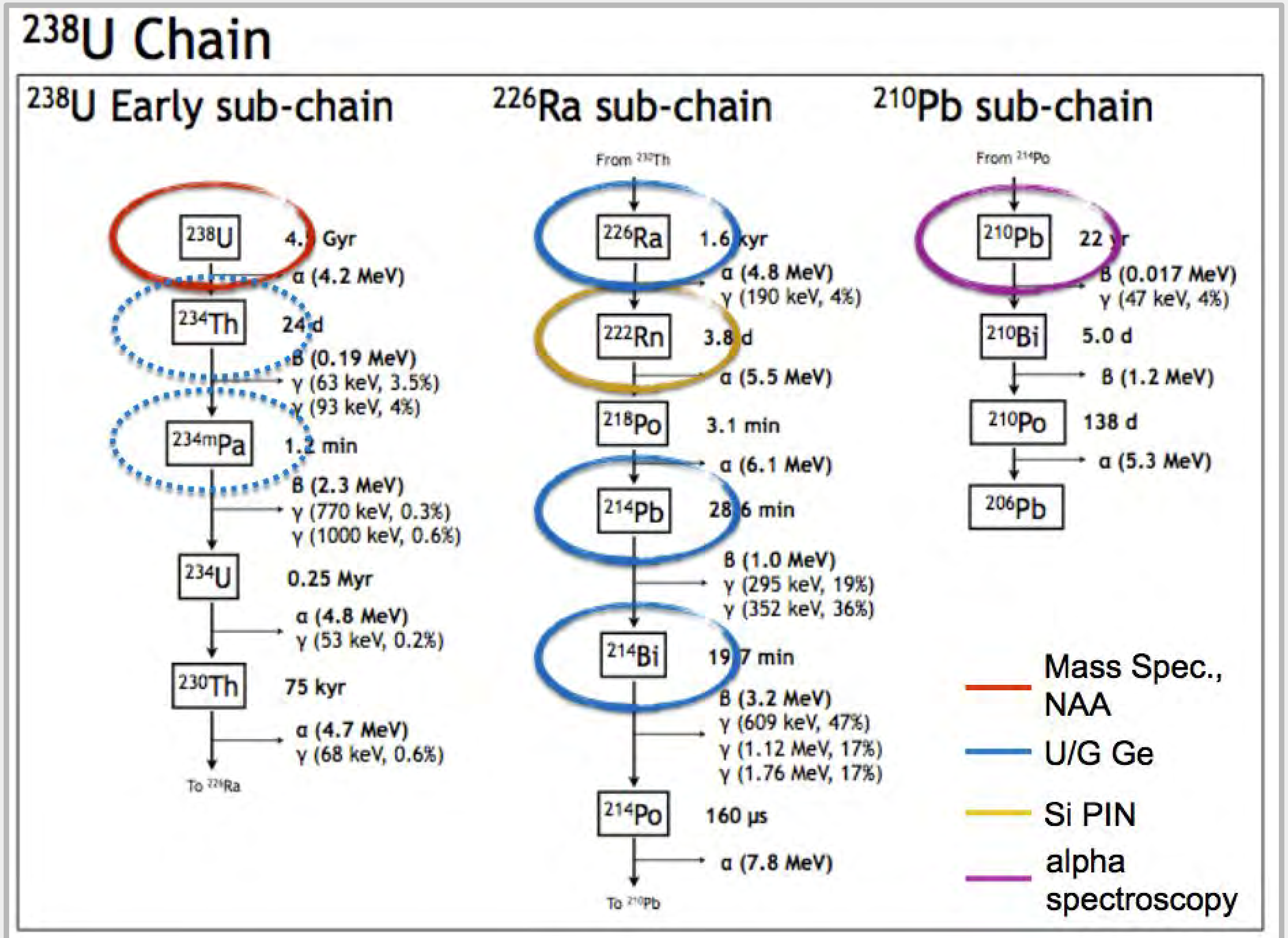
- <10% physics backgrounds in 5.6 tonne FV

Radon and Dust measurement and control are a major focus of the collaboration, but are not discussed here

LUX-ZEPLIN


PMTs
PMT bases and cables
TPC components
PTFE sheets
Cryostat
Xe target

Techniques



How an assay is done?

Early ^{232}Th refers to measures of ^{228}Ra and ^{228}Ac

Late refers to ^{228}Th and below

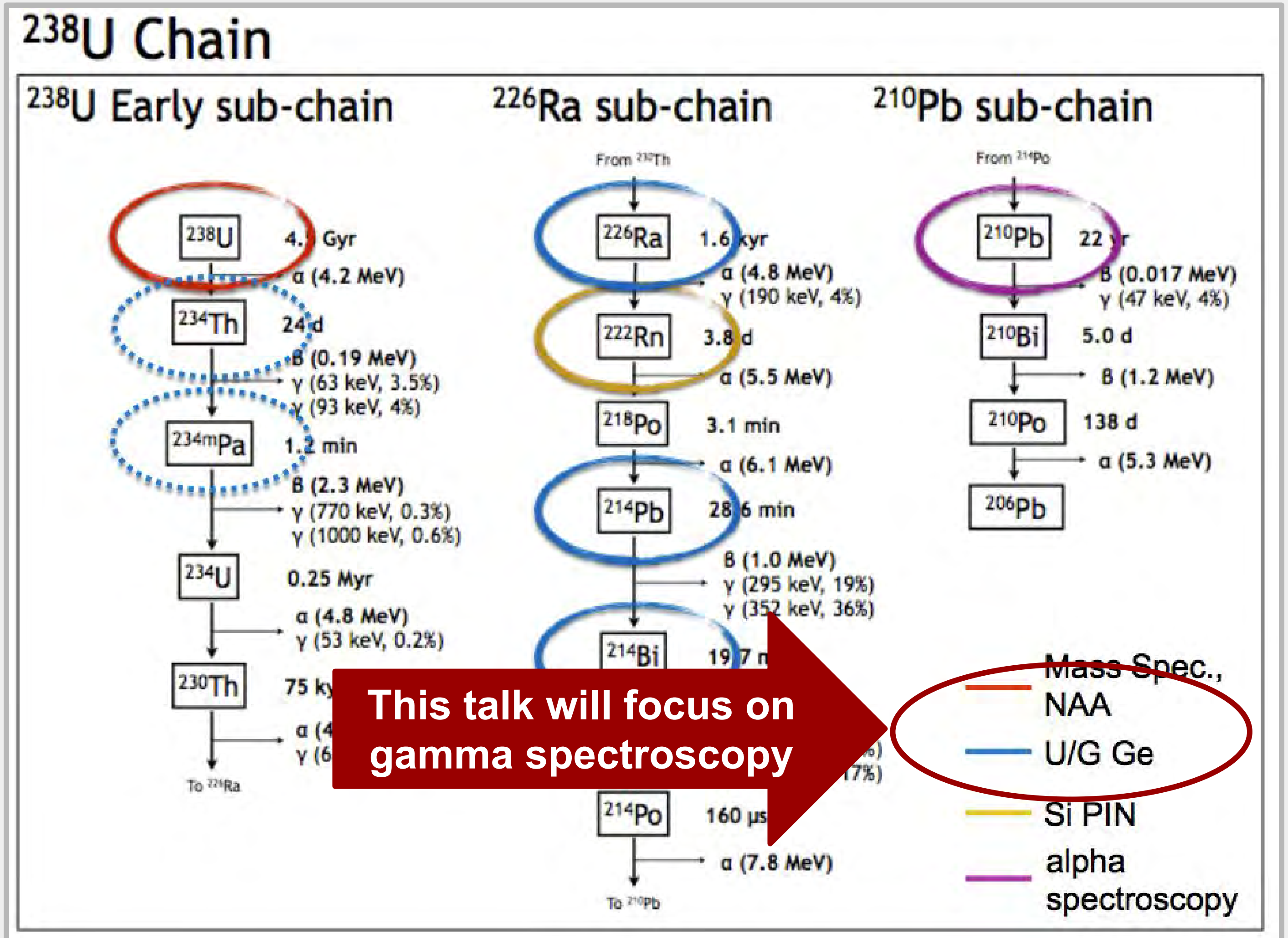
Techniques

No single assay technique is sufficient

Techniques:

- Gamma ray spectroscopy with ultralow-background high purity germanium detectors (HPGe)
- Neutron activation analysis (NAA)
- Inductively coupled mass spectroscopy (ICP-MS)
- Alpha spectroscopy, optical inspection (surface contamination)
- Rn emanation

Techniques



Gamma ray spectroscopy we're most sensitive to gamma lines between ~50-3000 keV

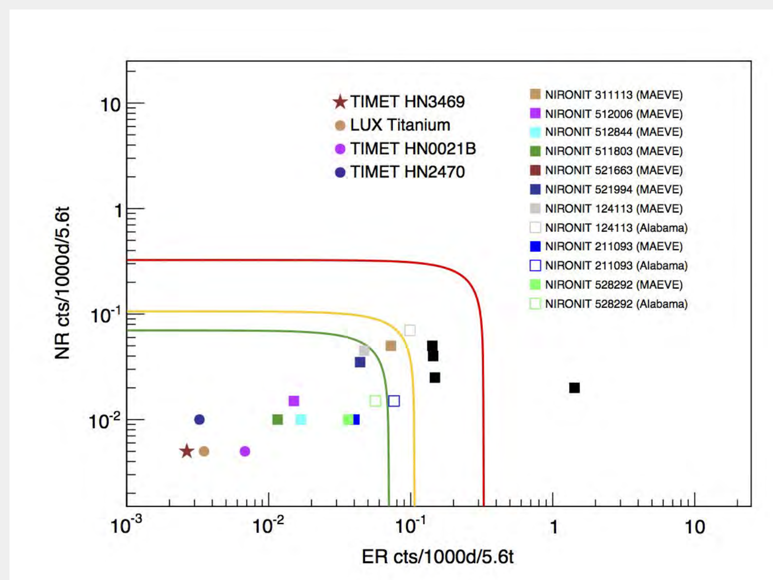
Gamma Spectroscopy

Detector	Site	Depth mwe	Crystal	[U] mBq/kg	[Th] mBq/kg	Status
Chaloner	Boulby	2805	BEGe	0.6	0.2	Online
Mordred	SURF	4300	N-type	0.7	0.7	Install March 2016
Ge-II	UA	0	P-type	4	1.2	Online
Ge-III	UA	0	P-type	4	1.2	Online
Lumpsey	Boulby	2805	Well	0.4	0.3	Online
Lunehead	Boulby	2805	P-type	0.7	0.2	Online
Merlin	LBNL	0	N-type	6.0	8.0	Online
Maeve	SURF/BHUC	4300	P-type	0.1	0.1	Online
SOLO	Soudan /SURF	2200	P-type	0.5	0.2	Moved to BHUC Jan 2016
Morgan	SURF	4300	P-type	0.2	0.2	Online Nov 2015
Wilton	Boulby	2805	BEGe	7.0	4.0	Online

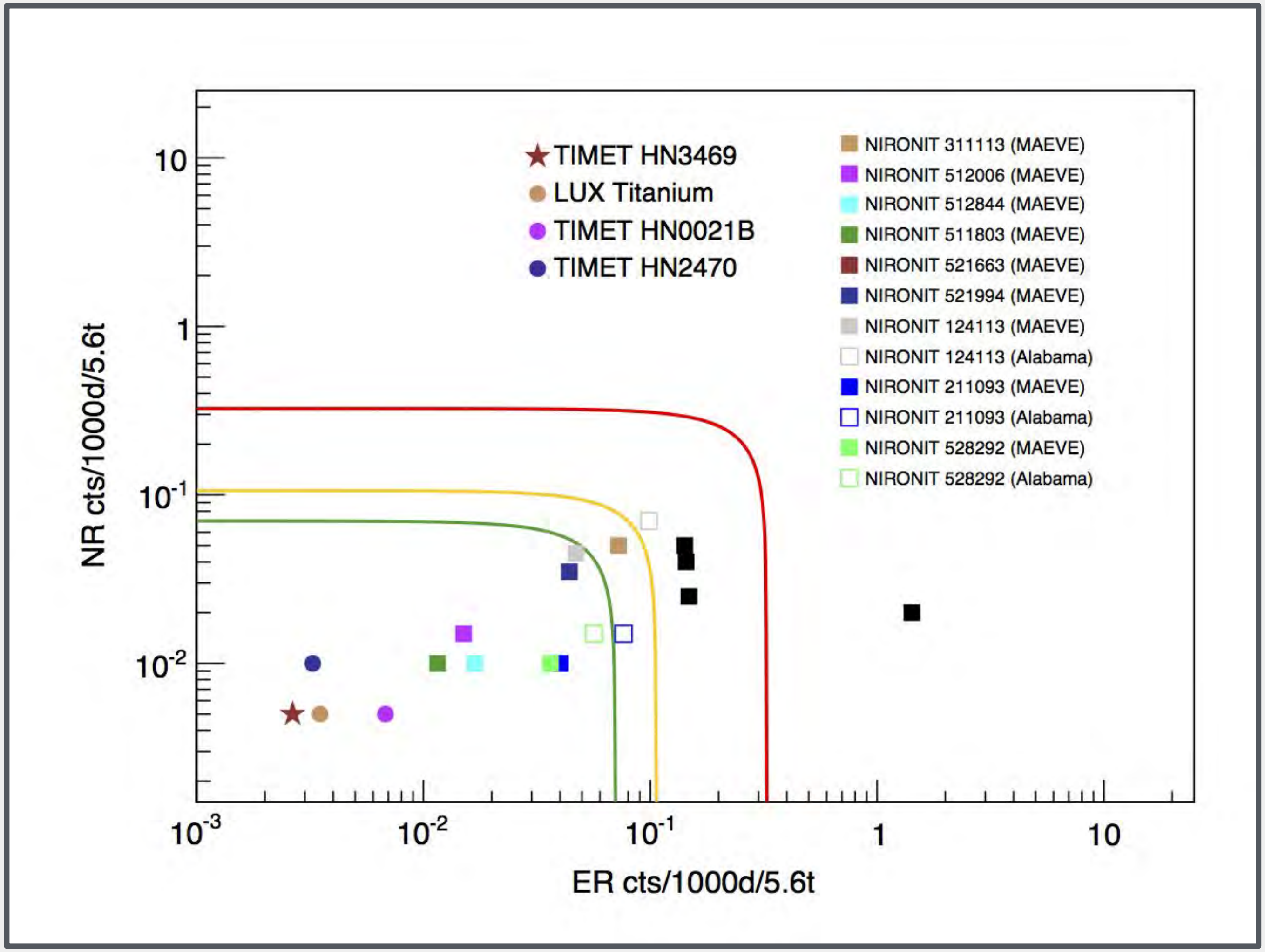
Titanium

Cryostat & field Rings, many Ti and steel samples were assayed. Each sample started as long slab. Pieces were cut at top and middle. Chose Ti sample (TIMET HN3469 Top and Middle)

Assay	U-early mBq/kg	U-Late mBq/kg	Th-early mBq/kg	Th-late mBq/kg	^{60}Co mBq/kg	^{40}K mBq/kg	
Top	<1.6	<0.09	0.28(3)	0.23(2)	<0.02	<0.54	Maeve
Middle	2.9(15)	<0.10	<0.2	0.25(2)	<0.03	<0.68	Maeve



Titanium



Red: Sum 10% pp Solar Neutrino Signal + 0.2 NR
Yellow: 5% Solar + .05 NR
Green: 3.3% + 0.03 NR

applying ER and NR analysis rejection factors of 200 and 2 (99.5% and 50 rejected)

PMT Bases

For the PMT bases all components have been assayed separately for radioactivity, including ^{210}Pb. Components have been identified with adequately low levels of U, Th, K contamination.

PMT Bases	^{238}U-early mBq/kg	^{238}U-late mBq/kg	^{210}Pb mBq/kg	^{232}Th mBq/kg	^{40}K mBq/kg	^{60}Co mBq/kg	
R8520	338.4	85.78	6863.8	28.23	159.43	4.12	Chaloner
R11410	230.23	77.10	5320.2	28.51	96.89	2.69	Chaloner

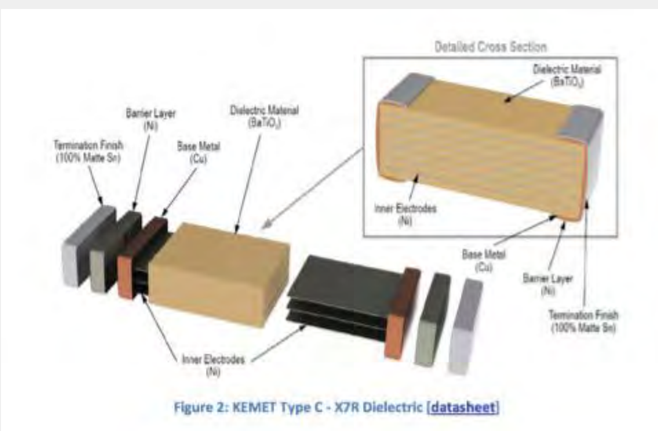
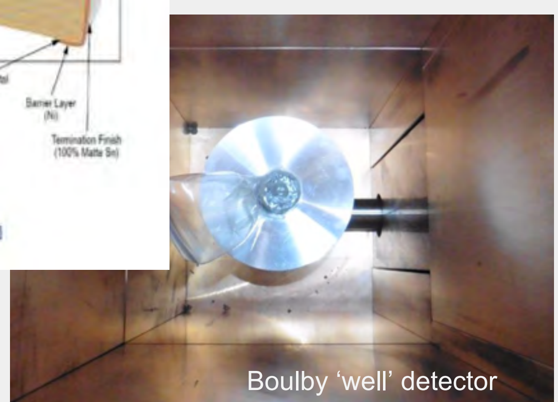
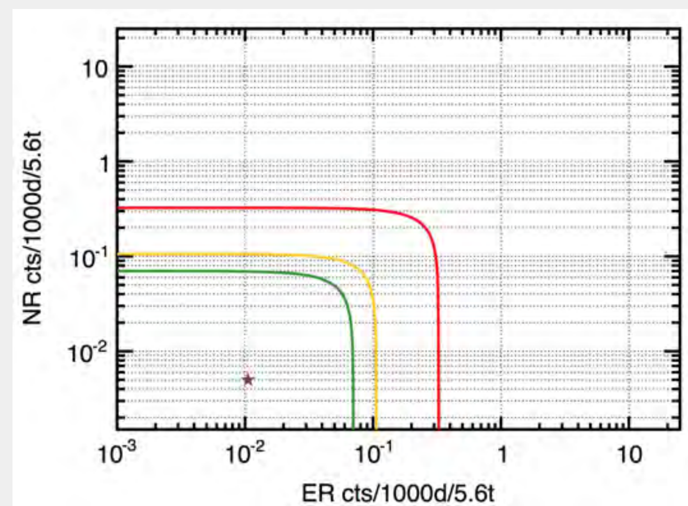


Figure 2: KEMET Type C - X7R Dielectric [datasheet]

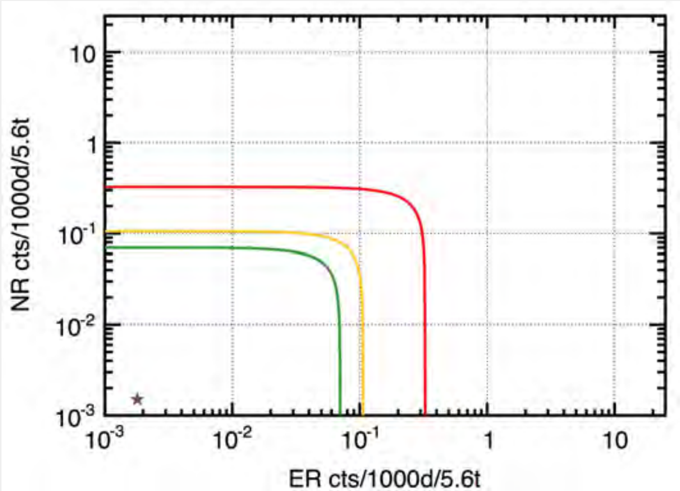




PMT Materials

- The raw PMT materials, that will be used by Hamamatsu, have been assayed and they have sufficiently low contamination
- After the PMTs have been finished they will be assayed again to confirm as-built levels of contamination

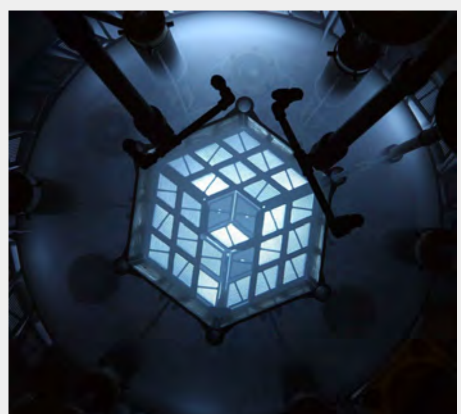
Name	U-early mBq/kg	U-late mBq/kg	Th-early mBq/kg	Th-late mBq/kg	^{60}Co mBq/kg	^{40}K mBq/kg
Mass Weighted Average	57.15	2.94	2.94	2.53	2.52	16.56

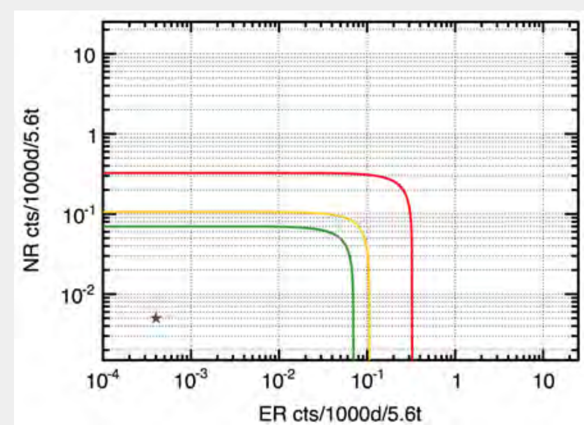


PTFE NAA

- PTFE requires NAA to achieve the required sensitivity
- UA group completed NAA and found the PTFE was high quality
- Additional R&D being performed to confirm ^{210}Pb levels in the PTFE raw materials

Sample	UA302 PTFE8764	UA303 DuPont 807NX	UA304 DuPont NXT85	UA305 Flontech FLON008
Th [pg/g]	3.13 ± 0.62	7.18 ± 0.48	6.94 ± 0.53	12.60 ± 0.79
U [pg/g]	0.90 ± 1.55 <3.44(90% CL)	3.11 ± 0.73	-0.07 ± 1.08 < 1.70(90% CL)	-0.89 ± 1.88 < 2.19(90% CL)





Intrinsic Contamination

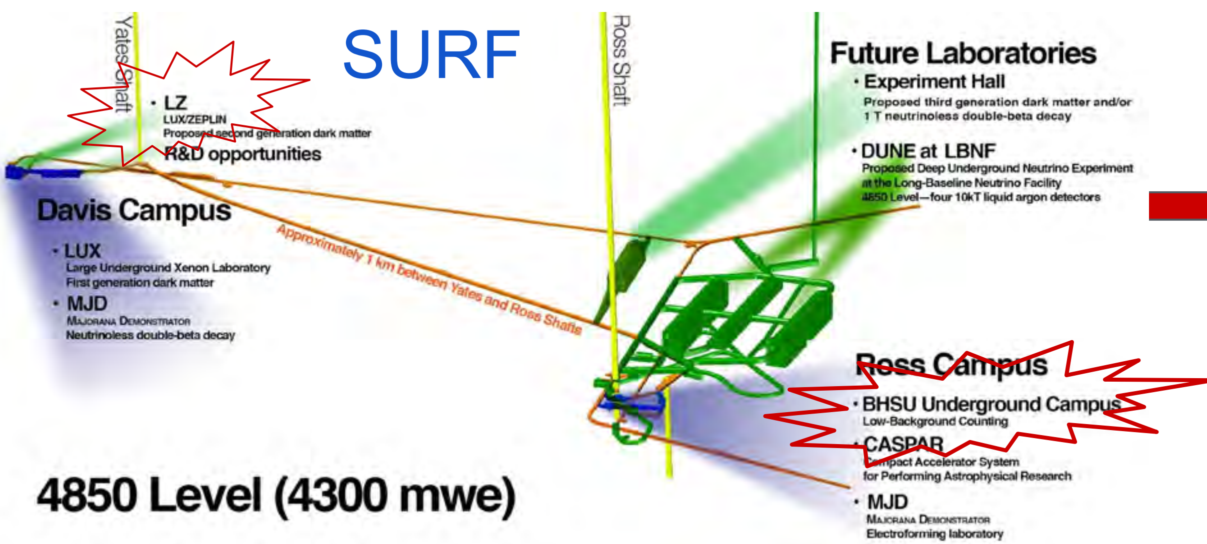
Status, identified all principle materials for building LZ:

- Ti - material identified well below goal
- PMT Bases - all components assayed, [U,Th, K, Co] at or below goals
- PMT - all raw materials assayed, [U,Th, K, Co] at or below goals
- PTFE – initial NAA performed, following EXOs success, [U,Th, K, Co] at or below goals

Continuing to screen for quality control

Will screen completed components as they are finished

SURF & BOULBY: Low Background Assay Labs



Black Hills Underground Campus

- MAEVE/MORGAN relocated from Davis in November. (**ready for samples**)
- SOLO moved from Soudan (Jan 2016)
- MORDRED upgrading to low background detector (likely March 2016)

Initial Assembly of Maeve and Morgan

Black Hills Underground Campus

Liquid nitrogen system and computer control
D. Taylor (SURF),
K. Oliver-Mallory (UCB/LBL),
Danny Johnson (SURF intern)

- Runs independently
- Collaborative site

Black Hills Underground Campus

Open to accepting and screening samples for other people

Contact Keenan Thomas (kjthomas@lbl.gov) for information on obtaining assay services

Maeve and Morgan completed,
Mordred shield partially assembled

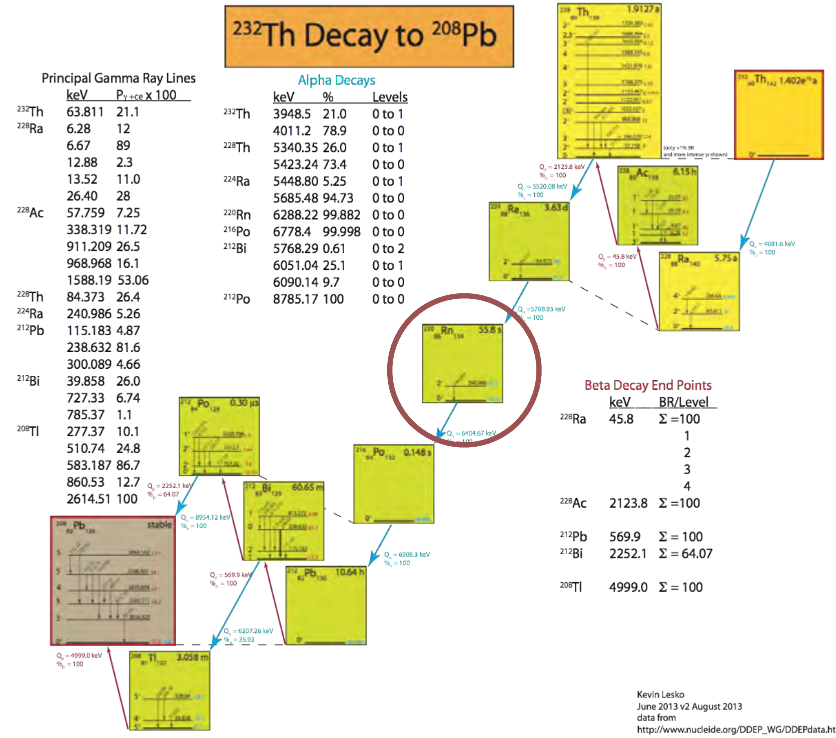
Summary

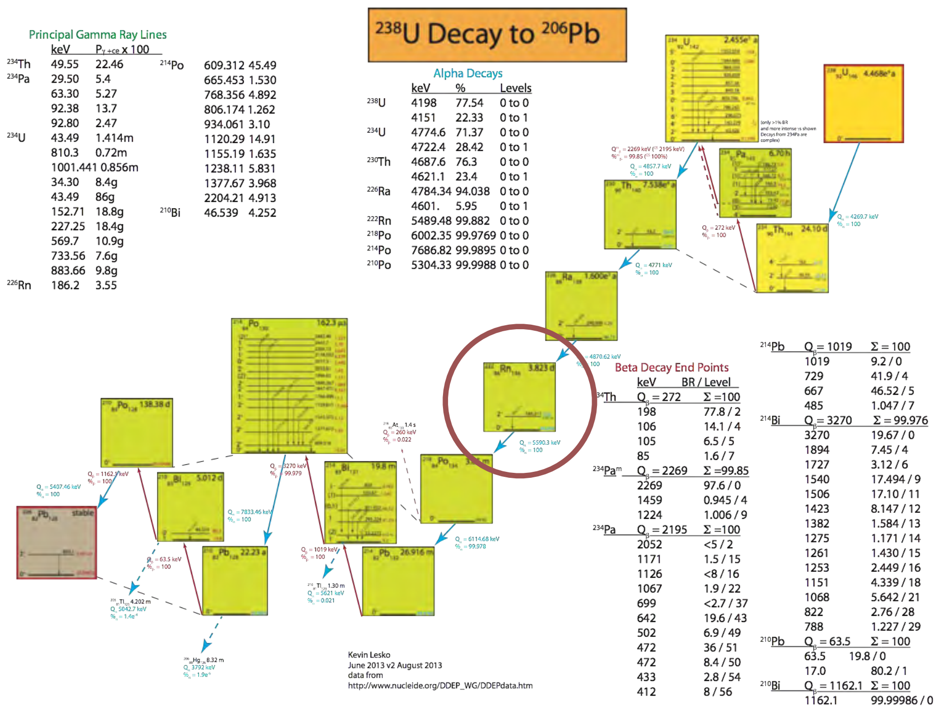
- Good progress on high priority items: Ti, PMTs, PMT bases.
  - Overall the estimates are very encouraging
  - Many Requirements already met
  - On schedule with major milestones
- NAA work initiated, leveraging EXO expertise, yielding adequate levels of U, Th.
- ICP-MS assays at UCL anticipated early in 2016 to confirm many of the direct counting results for top-of-chain U and Th.
- On-schedule for completing all direct counting of LZ components to meet construction schedule.

backups

Long-lived decay species & chains with α, β, γ, & n emissions: U, Th, K, Co, …

All materials contain trace contamination. Some are in secular equilibrium, others are not. Chains pass through a noble gas, Rn.





γ-assay can determine ‘top and bottom’ of chains. Other techniques only the top forcing assumptions about equilibrium

Background Summary
Intrinsic Contamination

Intrinsic Contamination Backgrounds	Mass (kg)	Composite	U early (mBq/kg)	U late (mBq/kg)	Th early (mBq/kg)	Th late (mBq/kg)	Co60 (mBq/kg)	K40 (mBq/kg)	n/yr (inc. S.F. rej.)	ER (cts)	NR (cts) (w/ SF rej.)	NR (cts)	WBS	Name	Assay verified	Signoff Bkgds	Signoff WBS1.10
Upper PMT Structure	40.2	Y	3.86	0.23	0.49	0.38	0.13	1.45	2.25	0.03	0.001	0.004	1.5	Saba	N	N	N
Lower PMT Structure	64.1	Y	2.40	0.13	0.29	0.23	0.07	0.90	4.45	0.02	0.002	0.005	1.5	Saba	N	N	N
R11410 3" PMTs	93.7	Y	67.08	2.68	2.01	2.01	3.86	62.05	71.96	1.24	0.033	0.085	1.5	Gaitskell	N	N	N
R11410 PMT Bases *	2.6	Y	230.23	77.10	28.51	24.53	2.69	96.89	41.02	0.14	0.019	0.030	1.5	Araujo	N	N	N
R8520 Skin 1" PMTs	4.2	Y	60.50	5.19	4.75	4.75	24.20	332.76	8.90	0.09	0.001	0.002	1.5	Gaitskell	N	N	N
R8520 Skin PMT Bases *	0.6	Y	311.10	80.26	33.42	25.94	3.88	147.54	12.29	0.05	0.002	0.003	1.5	Araujo	N	N	N
PMT Cabling	85.5	Y	29.83	1.47	3.31	3.15	0.65	33.14	2.13	0.82	0.000	0.007	1.5	Gaitskell	N	N	N
TPC PTFE	275.0	N	0.02	0.02	0.01	0.01	0.00	0.10	19.14	0.17	0.007	0.007	1.5	Webb	N	N	N
Grid Wires	0.75	N	1.20	0.27	0.33	0.49	1.60	0.40	0.02	0.01	0.000	0.000	1.5	Webb	N	N	N
Grid Holders	62.2	Y	1.20	0.27	0.33	0.49	1.60	0.40	6.33	0.07	0.003	0.004	1.5	Webb	N	N	N
Field Shaping Rings	91.6	Y	4.79	0.86	0.80	0.75	0.00	1.21	38.83	1.85	0.013	0.018	1.5	Webb	N	N	N
TPC Sensors	0.90	Y	10.64	9.06	9.99	3.07	0.46	15.24	0.57	0.15	0.000	0.000	1.5	Kraus	N	N	N
TPC Thermometers	0.70	Y	331.93	328.68	135.86	135.86	4.90	657.88	77.32	4.58	0.026	0.029	1.5	Kraus	N	N	N
Xe Recirculation Tubing	15.1	Y	0.79	0.18	0.22	0.323	1.05	0.30	0.36	0.01	0.000	0.000	1.5	Shutt	N	N	N
HV Conduits and Cables	137.7	Y	1.8	2.0	0.5	0.6	1.4	1.2	7.2	0.64	0.001	0.001	1.5	McKinsey	N	N	N
HX and PMT Conduits	199.6	Y	1.25	0.40	2.59	0.66	1.24	1.47	5.27	0.46	0.000	0.001	1.3	Taylor	N	N	N
Cryostat Vessel	2406.1	N	1.59	0.11	0.29	0.25	0.07	0.56	123.70	0.92	0.010	0.020	1.2	Majewski	N	N	N
Cryostat Seals	4.4	Y	103.60	103.60	34.34	34.34	6.88	22.65	24.62	0.70	0.002	0.003	1.2	Majewski	N	N	N
Cryostat Insulation	23.8	Y	18.91	18.91	3.45	3.45	1.97	51.65	69.82	0.82	0.006	0.007	1.2	Majewski	N	N	N
Cryostat Teflon Liner	70.7	N	0.02	0.02	0.01	0.01	0.00	0.10	4.92	0.00	0.000	0.000	1.5	Saba	N	N	N
Outer Detector Tanks	4007.0	Y	0.15	0.37	0.02	0.06	0.04	4.28	93.19	0.14	0.000	0.001	1.6	Kyre	N	N	N
Liquid Scintillator	20789.3	Y	0.01	0.01	0.01	0.01	0.00	0.00	16.83	0.00	0.000	0.000	1.6	Nelson	N	N	N
Outer Detector PMTs	122.4	Y	1,507	1,507	1,065	1,065	0	3,900	14,539	0.08	0.058	0.079	1.6	Nelson	N	N	N
Outer Detector PMT Supports	770.0	N	1.20	0.27	0.33	0.49	1.60	0.40	14.30	0.31	0.000	0.000	1.6	Kyre	N	N	N
222Rn (0.67 mBq)										39.14	-		1.4	Hall			
220Rn (0.07 mBq)										6.43	-		1.4	Hall			
natKr (0.015 ppt g/g)										24.51	-		1.4	Hall			
natAr (0.45 ppb g/g)										2.47	-		1.4	Hall			
Subtotal (Non-ν counts)										**85.85**	**0.185**	**0.306**					

- 1.10 working closely with cognizant engineers and managers to ensure table of materials and design is followed.
- Procurement of TPC elements roughly establishes the critical path for assay
- Including ^{210}Pb assays for critical components, SF veto is now implemented
- More on this and the assay 'score card' later in the review

Boulby Lab Move

- Looking like this will happen late Feb/early March
- We must be in and ready to go by end March
- Lab committed to this and also to postponing switch-off to last possible moment
- Air-con chiller (biggest potential problem) now underground

PMT Materials (detail)

Name	U-early mBq/kg	U-late mBq/kg	Th-early mBq/kg	Th-late mBq/kg	^{60}Co mBq/kg	^{40}K mBq/kg	Ref	Detector[1]
Faceplate	11	0.63	0.98	0.80	0.15	0.41	LZ	Maeve
Al seal	75.0	1.00	2.55	2.55	1.0	7.9	LZ	SOLO
Body	17.9	0.90	1.7	1.3	0.9	6.4	LZ	Maeve
Electrode	161.2	3.8	8.	8.	4.8	10.1	LZ	SOLO
Dynode	80.0	3.	5.	5.75	2.5	6.75	LZ	SOLO
Shield	106.9	1.9	4.2	2.8	1.8	7.6	LZ	SOLO
L-insulator	21	1	1.6	1.2	0.16	6.3	LZ	Maeve
FB flange	108	3.1	4.4	3.9	8.3	13.9	LZ	SOLO
Stem	105.7	19.98	7.77	7.53	1.	123.	LZ	Chaloner
Stem Flange	110.	1.80	3.2	2.1	9.3	5.7	LZ	SOLO
Getter	3020	61.4	161	161	50	1379286	LZ	SOLO
Cr_2O_3 [2]	26.57	98.62	8.4	9.29	3.12	74.19	LZ	Chaloner
Mass Weighted Average [3]	57.15 84.52	2.94 4.23	2.94 3.90	2.53 3.01	2.52 3.47	16.56 13.77	LZ X-1T	

[1] best value, does not show confirming assays
[2] not included in mass weighted average
[3] most values are upper limits

ICP-MS & GDMS

- Access to UA's (and others) in-house and commercial MS
- UCL has in-house system owned by 1.10 and dedicated to LZ assays
- Will be used verify most materials for direct U/Th progenitor content
- Used PNNL to verify LS and Ti so far

UCL ICP-MS lab

- Agilent 7900 ICP-MS + HF capability
- New ISO Class 6 (1000) cleanroom (ISO class 5 (100) laminar flow unit)
- Microwave digestion and ashing systems for sample prep
- ICP-MS system moved to new lab and sample preparation and auxiliary systems commissioned Oct. 15
- System operating at design sensitivity
- Resources:
  - 2.0 FTE PDRA, 0.5 FTE PGrad, 0.1 FTE detector physicist

Milestone EthosUP digestion system


Pyro-260 microwave ashing system (PTFE, acrylics)

Project milestones:

➢ **ICP-MS cleanroom commissioned: 18 Nov 15**

➢ **ICP-MS U/Th assay on digested sample: 21 Dec 15**

Crystal Types

P-type

- ~50-3000 keV
- Coaxial germanium detector
- N-type contact (diffused lithium) on the outer surface, and a p-type contact (ion implanted boron) on the surface of an axial well
- N-type contact is 0.5 mm and p-type contact is 0.3 μm
- The germanium has a net impurity level of ~1010 atoms/cc,with moderate reverse bias, the entire volume between the electrodes is depleted, and an electric field extends across this active region

N-type

- ~3-3000 keV
- Coaxial detector with electrodes opposite conventional coaxial detectors
- P-type on outside, n-type is on the inside
- Outside contact is extremely thin, so can cover low energy down to 3 keV
- Outside contact collects holes, radiation damage resistant

Broad Energy Germanium (BeGe)

- ~3-3000 keV
- Cylindrical crystal that sits on pin
- Short fat shape that greatly enhances efficiency at low energies

Well

- ~20-3000keV
- Provides maximum efficiency for small samples
- Small sample is placed in hole and surrounded by active detector material