Materials Screening for the LUX-ZEPLIN Experiment

Kelsey Oliver-Mallory (for Paul Scovell)
on behalf of the LZ Collaboration

UCLA Dark Matter 2016
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
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
This talk will focus on gamma spectroscopy

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

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

<table>
<thead>
<tr>
<th>Assay</th>
<th>U-early mBq/kg</th>
<th>U-Late mBq/kg</th>
<th>Th-early mBq/kg</th>
<th>Th-late mBq/kg</th>
<th>$^{60}$Co mBq/kg</th>
<th>$^{40}$K mBq/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>&lt;1.6</td>
<td>&lt;0.09</td>
<td>0.28(3)</td>
<td>0.23(2)</td>
<td>&lt;0.02</td>
<td>&lt;0.54</td>
</tr>
<tr>
<td>Middle</td>
<td>2.9(15)</td>
<td>&lt;0.10</td>
<td>&lt;0.2</td>
<td>0.25(2)</td>
<td>&lt;0.03</td>
<td>&lt;0.68</td>
</tr>
</tbody>
</table>

Maeve
Titanium

Red: Sum 10% pp Solar Neutrino Signal + 0.2 NR
Yellow: 5% Solar + 0.05 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 $^{210}\text{Pb}$. Components have been identified with adequately low levels of U, Th, K contamination.

<table>
<thead>
<tr>
<th>PMT Bases</th>
<th>$^{238}\text{U}$-early mBq/kg</th>
<th>$^{238}\text{U}$-late mBq/kg</th>
<th>$^{210}\text{Pb}$ mBq/kg</th>
<th>$^{232}\text{Th}$ mBq/kg</th>
<th>$^{40}\text{K}$ mBq/kg</th>
<th>$^{60}\text{Co}$ mBq/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>R8520</td>
<td>338.4</td>
<td>85.78</td>
<td>6863.8</td>
<td>28.23</td>
<td>159.43</td>
<td>4.12</td>
</tr>
<tr>
<td>R11410</td>
<td>230.23</td>
<td>77.10</td>
<td>5320.2</td>
<td>28.51</td>
<td>96.89</td>
<td>2.69</td>
</tr>
</tbody>
</table>

Chaloner
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.

<table>
<thead>
<tr>
<th>Name</th>
<th>U-early mBq/kg</th>
<th>U-late mBq/kg</th>
<th>Th-early mBq/kg</th>
<th>Th-late mBq/kg</th>
<th>$^{60}$Co mBq/kg</th>
<th>$^{40}$K mBq/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Weighted Average</td>
<td>57.15</td>
<td>2.94</td>
<td>2.94</td>
<td>2.53</td>
<td>2.52</td>
<td>16.56</td>
</tr>
</tbody>
</table>

SOLO

Chaloner

Graph: Log-log plot of NR cts/1000d/5.6t vs. ER cts/1000d/5.6t with data points.
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

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

-New Site of Boulby’s Low Background Assay
-1100 m (2805 mwe)
-Relocating in Feb 2016

Future Laboratories

- **Experiment Hall**
  Proposed third generation dark matter and/or 1T neutrinoless double-beta decay

- **DUNE at LBNF**
  Proposed Deep Underground Neutrino Experiment at the Long Baseline Neutrino Facility
  at 4820 Level—four 10T liquid argon detectors

4850 Level (4300 mwe)
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)*
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.

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

Intrinsic Contamination

- 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 $^{210}\text{Pb}$ 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)

<table>
<thead>
<tr>
<th>Name</th>
<th>U-early mBq/kg</th>
<th>U-late mBq/kg</th>
<th>Th-early mBq/kg</th>
<th>Th-late mBq/kg</th>
<th>$^{60}$Co mBq/kg</th>
<th>$^{40}$K mBq/kg</th>
<th>Ref</th>
<th>Detector$^1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faceplate</td>
<td>11</td>
<td>0.63</td>
<td>0.98</td>
<td>0.80</td>
<td>0.15</td>
<td>0.41</td>
<td>LZ</td>
<td>Maeve</td>
</tr>
<tr>
<td>Al seal</td>
<td>75.0</td>
<td>1.00</td>
<td>2.55</td>
<td>2.55</td>
<td>1.0</td>
<td>7.9</td>
<td>LZ</td>
<td>SOLO</td>
</tr>
<tr>
<td>Body</td>
<td>17.9</td>
<td>0.90</td>
<td>1.7</td>
<td>1.3</td>
<td>0.9</td>
<td>6.4</td>
<td>LZ</td>
<td>Maeve</td>
</tr>
<tr>
<td>Electrode</td>
<td>161.2</td>
<td>3.8</td>
<td>8.</td>
<td>8.</td>
<td>4.8</td>
<td>10.1</td>
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<td>Dynode</td>
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<td>3.0</td>
<td>5.</td>
<td>5.75</td>
<td>2.5</td>
<td>6.75</td>
<td>LZ</td>
<td>SOLO</td>
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<tr>
<td>Shield</td>
<td>106.9</td>
<td>1.9</td>
<td>4.2</td>
<td>2.8</td>
<td>1.8</td>
<td>7.6</td>
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<td>SOLO</td>
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<tr>
<td>L-insulator</td>
<td>21</td>
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<td>1.6</td>
<td>1.2</td>
<td>0.16</td>
<td>6.3</td>
<td>LZ</td>
<td>Maeve</td>
</tr>
<tr>
<td>FB flange</td>
<td>108</td>
<td>3.1</td>
<td>4.4</td>
<td>3.9</td>
<td>8.3</td>
<td>13.9</td>
<td>LZ</td>
<td>SOLO</td>
</tr>
<tr>
<td>Stem</td>
<td>105.7</td>
<td>19.98</td>
<td>7.77</td>
<td>7.53</td>
<td>1.</td>
<td>123.</td>
<td>LZ</td>
<td>Chaloner</td>
</tr>
<tr>
<td>Stem Flange</td>
<td>110.0</td>
<td>1.80</td>
<td>3.2</td>
<td>2.1</td>
<td>9.3</td>
<td>5.7</td>
<td>LZ</td>
<td>SOLO</td>
</tr>
<tr>
<td>Getter</td>
<td>3020</td>
<td>61.4</td>
<td>161</td>
<td>161</td>
<td>50</td>
<td>1379286</td>
<td>LZ</td>
<td>SOLO</td>
</tr>
<tr>
<td>Cr$_2$O$_3$</td>
<td>26.57</td>
<td>98.62</td>
<td>8.4</td>
<td>9.29</td>
<td>3.12</td>
<td>74.19</td>
<td>LZ</td>
<td>Chaloner</td>
</tr>
<tr>
<td>Mass Weighted Average$^3$</td>
<td>57.15</td>
<td>2.94</td>
<td>2.94</td>
<td>2.53</td>
<td>2.52</td>
<td>16.56</td>
<td>LZ</td>
<td>X-1T</td>
</tr>
</tbody>
</table>

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 to 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

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