Alpha tomography, calibrations and backgrounds in the LUX dark matter experiment

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The LUX Detector
The LUX Detector

- 350 kg LXe detector
- 122 PMTs (2” round)
- Low-background Ti cryostat
- PTFE reflector cage
- Thermosyphon used for cooling (>1 kW)

See K. Gibson’s plenary talk tomorrow
Xe Circulation

Weir

Active Region

Filler-Chiller Shield

Internal

Two Phase Heat Exchanger

Evaporator

Condenser

External

Outgoing

Incoming

Vacuum Heat Exchanger

Mass Flow Controller

Circulation Pump

Getter

C.Carmona
• Early in the run, using diagnostic pressure and LXe level sensor data, we discovered that a specific point in the condenser circulation path was opened to the bath.

• This location was predicted to be a loose fitting, which compromised the Xe circulation path.

• In order to learn more about the actual Xe flow path, we injected $^{222}$Rn as an alpha “tracer” source, for a real-time tomography.
Rn Injection
Rn Injection

• 150 Bq of $^{222}$Rn were injected in the system to trace Xe circulation path by looking at the evolution of the large alpha signals over time.

• This rate guaranteed that alpha signals would still be available for calibrations at the end of the surface run, while still keeping $^{210}$Pb backgrounds subdominant.
Pay close attention:

- Detector tomography time-lapse shows alpha tracer entering the active region from above heat exchanger at $t = +0.6$ min.

- At $t = +10$ min, a new hit pattern forms on the bottom PMT array, directly below original entry point.
Alpha Peaks

\[ S_{1_{\text{weighted}}} = S_{1_{\text{top}}} \times \cos(0.33) + S_{1_{\text{bot}}} \times \sin(0.33) \]

LUX Preliminary
At the end of the surface run, the detector was opened, and a visual inspection confirmed both runtime diagnostics from instrumentation data and alpha tomography.
Position Resolution
Beta-Alpha Physics from BiPo

- $^{222}$Rn
- $^{218}$Po
- $^{214}$Bi
- $^{210}$Pb
- $^{210}$Po

Radioactive Decays:
- $^{222}$Rn → $^{218}$Po (3.8 days)
- $^{218}$Po → $^{214}$Bi (3.1 m)
- $^{214}$Bi → $^{210}$Pb (27 m)
- $^{210}$Pb → $^{210}$Po (160 µs)
- $^{210}$Po → $^{210}$Bi (5 days)
- $^{210}$Bi → $^{210}$Pb (22 years)
- $^{210}$Pb → $^{210}$Po (138 days)
This coincidence event is highly localized in x,y,z.

Beta range (E\text{mean} = 642 \text{ keV}) in LXe is \sim 1.5 \text{ mm}

Alpha range in LXe is \sim 50 \mu\text{m}

\( ^{214}\text{Bi} \) lone beta (18% BR)

\( ^{214}\text{Po} \) 7.7 MeV alpha

\( Q_\beta = 3.2 \text{ MeV} \)

\( \tau_{1/2} = 164 \text{ \mu s} \)
Sample $\beta$-$\alpha$ Bi-Po event in surface data

Pulses < 100 phe not displayed

Position reconstruction computed with Zeplin III Mercury algorithm (Solovov, arXiv:1112.1481v1)
Bi-214 half-life measurement with S1

Actual $^{214}$Bi decay half-life is 164 $\mu$s
Alpha Populations - High and Low S2 Yield

Gate wire alphas
~5x10^5 phe S2 yield
("High Energy")

Bulk alphas
3x10^2 - 3x10^4 phe S2 yield
("Low Energy")
x,y Statistical Component of Resolution

**Bulk alphas**

- Alpha S2 signal equivalent to ER gamma $S2(z=0) < 20$ keV$_{ee}$
- The statistical resolution in x or y is 0.7 cm

- $\Delta x$ between $^{214}$Bi $\beta$ and $^{214}$Po $\alpha$ [cm]
- $\Delta x$ between $^{214}$Bi $\beta$ and $^{214}$Po $\alpha$ [cm]

- $\Delta y$ between $^{214}$Bi $\beta$ and $^{214}$Po $\alpha$ [cm]
- $\Delta y$ between $^{214}$Bi $\beta$ and $^{214}$Po $\alpha$ [cm]

**Gate wire alphas**

- Alpha S2 signal equivalent to ER gamma $S2(z=0)$ of ~200 keV$_{ee}$
- The statistical resolution in x or y is 0.21 cm

- $\Delta x$ between $^{214}$Bi $\beta$ and $^{214}$Po $\alpha$ [cm]
- $\Delta x$ between $^{214}$Bi $\beta$ and $^{214}$Po $\alpha$ [cm]

- $\Delta y$ between $^{214}$Bi $\beta$ and $^{214}$Po $\alpha$ [cm]
- $\Delta y$ between $^{214}$Bi $\beta$ and $^{214}$Po $\alpha$ [cm]
Position Reconstruction - Event Map
Position Reconstruction - Gate Wires

Charge focusing at the gate grid

$E_2 > E_1$

Grid

$LUX$

Position Reconstruction - Gate Wires

Projection along the wires

$LUX$

Preliminary

$5 \text{ mm}$
Residual contamination
$^{210}\text{Pb}$ Residual BG

- $^{222}\text{Rn}$
  - $3.8$ d
  - $\alpha$ to $^{218}\text{Po}$
  - $3.1$ m
  - $\alpha$ to $^{214}\text{Pb}$
  - $27$ m
  - $\beta$ to $^{214}\text{Bi}$
  - $20$ m
  - $\beta$ to $^{214}\text{Po}$
  - $160 \mu s$
  - $\alpha$ to $^{210}\text{Bi}$
  - $5$ d
  - $\beta$ to $^{210}\text{Pb}$
  - $22$ y
  - $^{210}\text{Po}$
  - $138$ dy
  - $\alpha$ to $^{206}\text{Pb}$
\( \text{\textsuperscript{210}Pb Residual Contamination} \)

- We consider the worst-case scenario where every \( \text{\textsuperscript{222}Rn} \) daughter is attached to a fluorinated surface (PTFE) that leaves a residual \( \text{\textsuperscript{210}Pb} \) atom in it.

\[
R_{\text{\textsuperscript{210}Pb}} = R_{\text{\textsuperscript{222}Rn}} \times \frac{T_{\text{\textsuperscript{222}Rn}}}{T_{\text{\textsuperscript{210}Pb}}}
\]

\[
R_{\text{\textsuperscript{210}Pb}} \approx \frac{R_{\text{\textsuperscript{222}Rn}}}{2130}
\]

- Our 150 Hz initial \( \text{\textsuperscript{222}Rn} \) activity would then correspond to 70 mHz of \( \text{\textsuperscript{210}Pb} \) residual activity. This will yield \( \sim 11.2 \) n/yr from (alpha,n) reactions in F, which represents 7.5\% of the expected total PMT neutron rate (150 n/yr).
Thank You