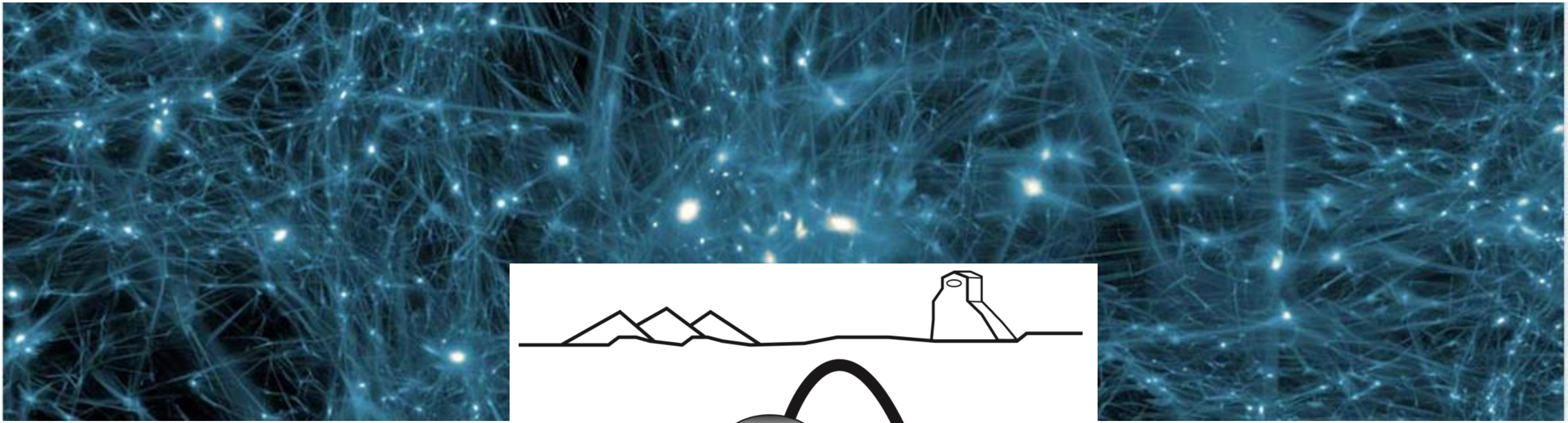
UCLA Dark Matter 2014 Symposium



Origins and Distributions of the Backgrounds

15 min

S. Fiorucci – Brown University

What is a signal for LUX?

Signal

- Nuclear recoil
- Single scatter
- Low energy, typically < 25 keV_{nr}
- Typically follows an exponential energy distribution
- Localized inside a fiducial volume, away from detector edges

Not a Signal

- Electron recoils, at the 99.6% (avg) level
- Multiple scatters which can be recognized as such
- Energy > 25 keV_{NR} ~ 5.3 keV_{ee}
- Event populations which do not fit an expected DM energy distribution
- Events too close to the edges of the detector

- Canonical unit : DRU (DRU_{nr} or DRU_{ee})
  1 DRU = 1 event / kg / day / $keV_{(nr\ or\ ee)}$

  We are talking in $nDRU_{nr}$ and $mDRU_{ee}$

What is a background for LUX?

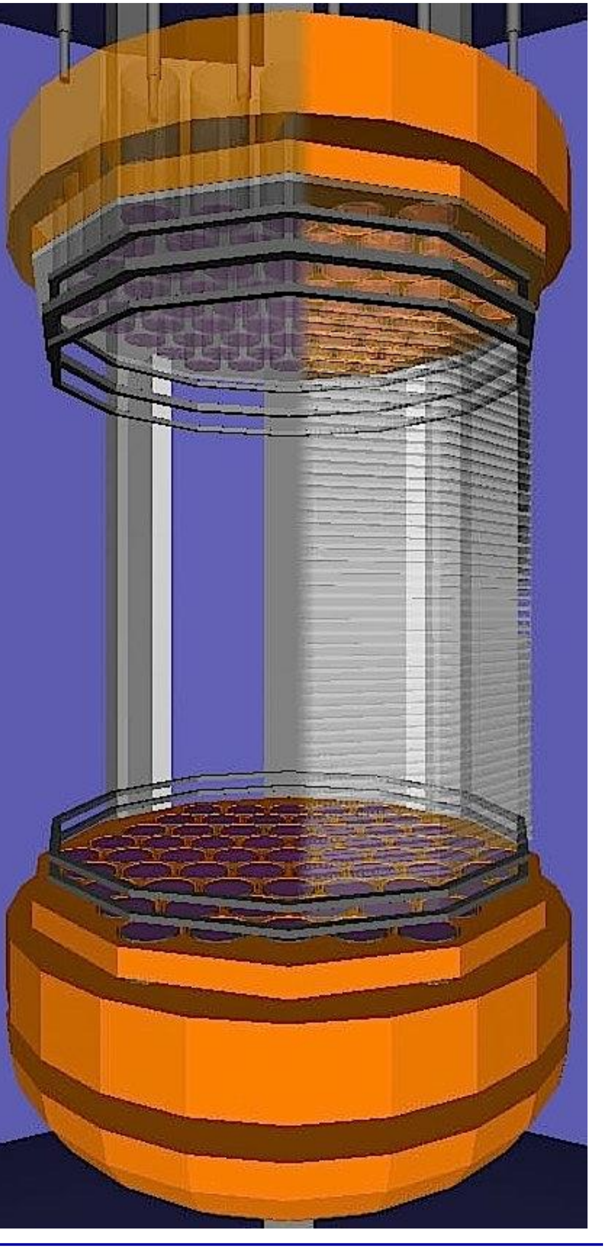
- 1. **Strictly**: anything that can directly mimic a DM interaction
  - Neutron, single scatter
- 2. **Less strictly**: anything that will conspire, through systematic error or statistical fluctuation, to look like a DM interaction
  - Neutron multiple scatters, missed or misreconstructed
  - Edge events, misreconstructed in a fiducial volume
  - ER events, statistically leaking (0.4%) into NR area of parameter space

  Analysis technique: outside the scope of this presentation
- 3. **Loosely**: anything that will contribute significantly to the overall event rate, or introduce a source of noise in the signal
  - High event rates, leading to accidental coincidences and loss of livetime
  - Electronic noise
  - Unrecorded / uncorrected detector instabilities

  Outside the scope of this presentation

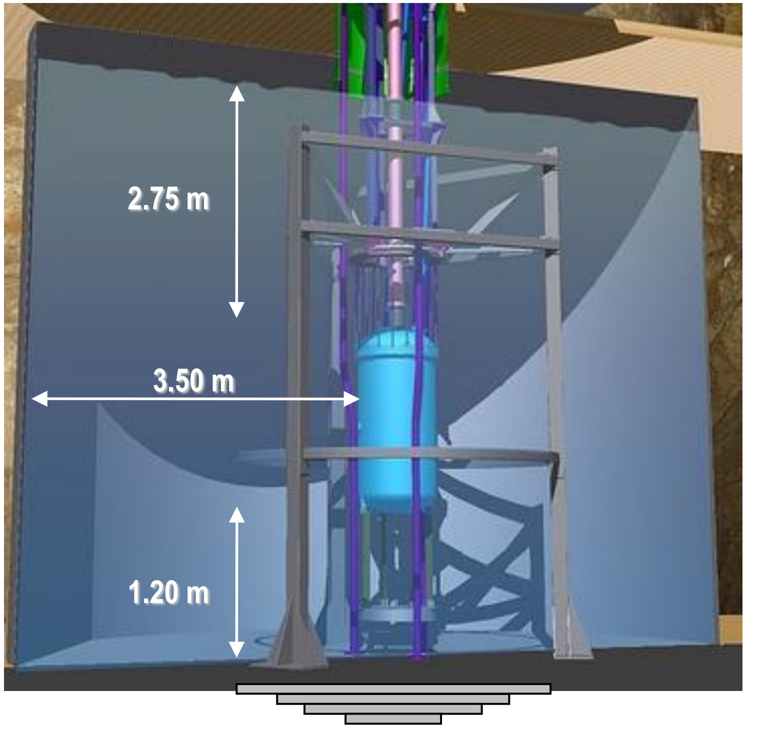
The Tools

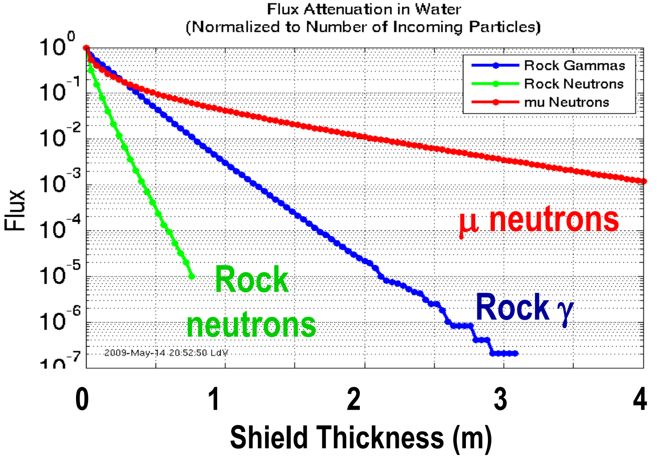
- LUXSim
  - Hi-Fi model of detector based on CAD drawings
  - Includes water tank
  - Outputs deposited energies and locations
- NEST
  - Outputs NR and ER S1 + S2 signals
  - Used to predict low-energy S1 spectrum
- ACTIVIA
  - Predicts activation isotopes based on exposure and input neutron spectrum
- Material Screening Program
  - Use of SOLO and LBL-Oroville facilities
  - 75 samples, ~95% of detector mass screened



Contribution from External Sources

- 300 tonne water shield design against gammas and neutrons
  - Provides linear attenuation + geometric effect
  - Steel pyramid provides further x1/40 for gamma attenuation
- Neutron sources
  - (α,n) and fission in the rock: ~10^{-16} n/year incident on LUX > 1 keV
  - Muon-induced in rock and water
    - Higher energy (> 10 MeV - GeV), less easily attenuated
    - 180 nDRU_{nr} in WIMP ROI (R:1 W:2) → 0.1 WIMP-like / 100 kg / year
    - Cherenkov veto ability: not yet exercised
- Gamma sources (^{238}U, ^{232}Th, ^{40}K) from Homestake rock + concrete: negligible
  - Overall Flux reduction: 2 x 10^{-10}
  - Resulting fiducial ER rate < 5.3 keV_{ee} = 27 nDRU_{ee}





Contribution from Detector Components

- **Gammas:**

Component	Counting Unit	Counting Results [mBq/unit] ^{238}U	^{226}Ra	^{232}Th	^{40}K	^{60}Co	Other
PMTs	PMT	<22	9.5±0.6	2.7±0.3	66±6	2.6±0.2	
PMT bases	base	1.0±0.4	1.4±0.2	0.13±0.01	1.2±0.4	<0.03	
Field ring supports (inner panels)	kg		<0.5	<0.35			
Field ring supports (outer panels)	kg		<6.3	<3.1			
Reflector panels (main)	kg		<3	<1			
Reflector panels (grid supports)	kg		<5	<1.3			
Cryostats	kg	4.9±1.2	<0.37	<0.8	<1.6		
Cryostats	kg						4.4±0.3 (^{46}Sc)
Electric field grids	kg		1.4 ± 0.1	0.23 ± 0.07	<0.4	1.4 ± 0.1	
Field shaping rings	kg		<0.5	<0.8		<0.3	
PMT mounts	kg		<2.2	<2.9		<1.7	
Weir	kg		<0.4	<0.2		<0.17	
Superinsulation	kg	<270	73±4	14±3	640±60		
Thermal insulation	kg		130±20	55±10	<100		

In 118 kg:

~1.2 $mDRU_{ee}$

~0.5 $mDRU_{ee}$

- **Neutrons:**
  - **Dominated by PMTs contribution (α,n) and fission: 1.2 n / PMT / year (x 122 PMTs)**
    - Resulting single scatter rate in WIMP ROI = 0.06 / 118 kg / 85 days (Run 3) (aka 250 $nDRU_{nr}$)
  - **(α,n) from Rn daughters on PTFE: 8.8 n / year ~ 6% of PMT emission rate**
    - From observed 14 mHz of 5.3 MeV alphas from ^{210}Po on wall surfaces (see later slide)
  - **Checked with multiple scatter in Run 3 data (85 days):**
    - Sim ratio = 1/13 (SS in 118 kg, MS in 180 kg)
    - Multiple scatters found in 180 kg = 0
    - → SS 90% C.L. upper limit for Run 3 = 0.37 events (50% acceptance), consistent with zero observed

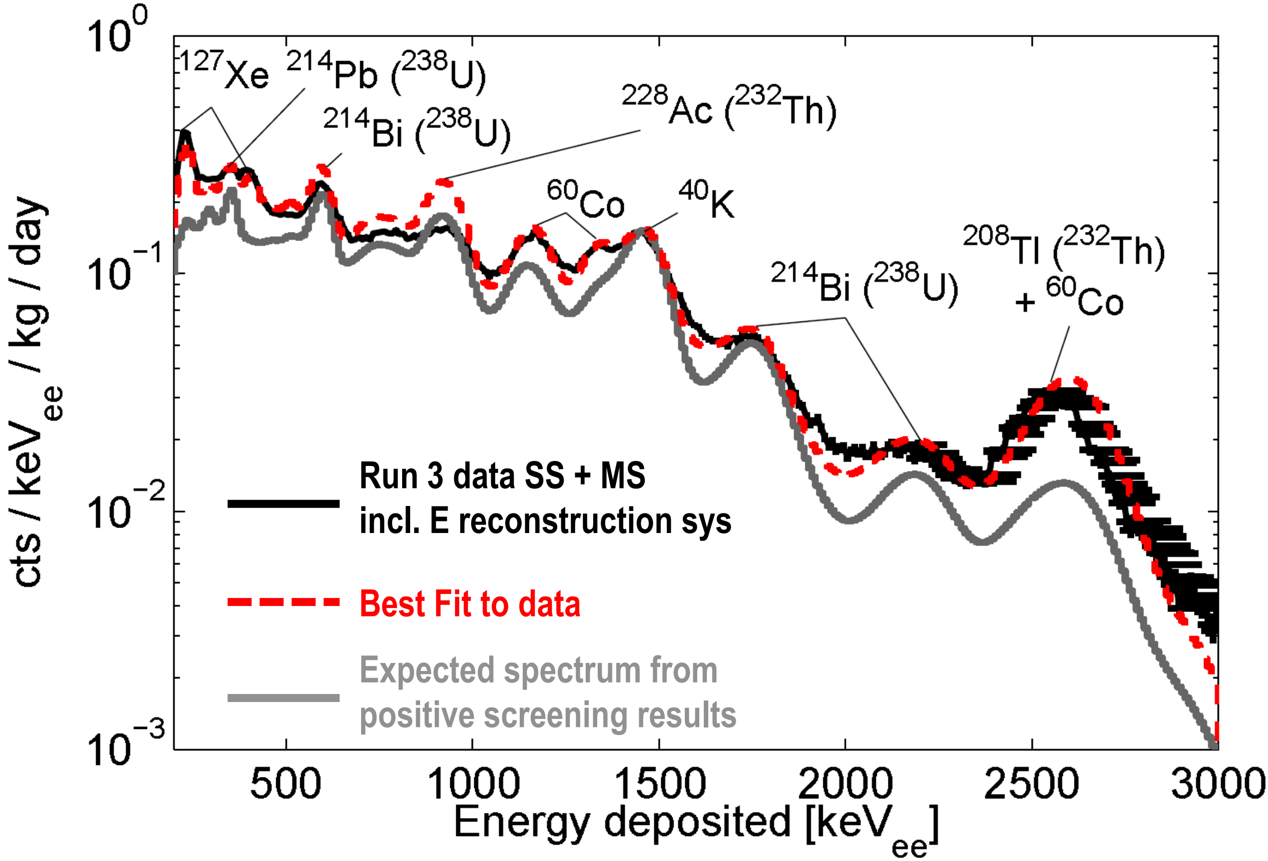
Contribution from Detector Components

- **Cosmogenic activation of Titanium**
  - Isotope of interest = ^{46}Sc ($t_{1/2}$ = 84 days, 2 gammas at ~1 MeV)
  - LUX sample measured after 2 years underground, and then 6 months at SURF surface
  - Results consistent with activation simulation. Expected activity over Run 3 = 85 mBq
  - Puts contribution in Xe active volume below detection threshold because of shielding; indeed, not observed in Run 3 data.

- **Cosmogenic activation of Copper**
  - Isotope of interest = ^{60}Co ($t_{1/2}$ = 5.3 years, 2 gammas at ~1 MeV)
  - 620 kg very close to active Xe volume (PMT holders, field rings, radiation/thermal shields)
  - Expected activity at July 2012 (LUX underground) = 1.0 ± 0.5 mBq/kg
  - Best fit to overall gamma spectrum → ^{60}Co in copper = 1.7 ± 1.0 mBq/kg
  - Corresponds to O(0.1 $mDRU_{ee}$) in 118 kg

Overall Gamma Spectrum

Region	Isotope	Screening Estimate [Bq]	Best Fit [Bq]
Bottom	^{238}U	0.58 ± 0.04	0.62 ± 0.16
	^{232}Th	0.16 ± 0.02	0.23 ± 0.06
	^{40}K	4.0 ± 0.4	2.7 ± 0.7
	^{60}Co	0.16 ± 0.01	0.22 ± 0.06
Top	^{238}U	0.58 ± 0.04	0.87 ± 0.22
	^{232}Th	0.16 ± 0.02	0.25 ± 0.06
	^{40}K	4.0 ± 0.4	3.8 ± 1.0
	^{60}Co	0.16 ± 0.01	0.30 ± 0.08
Side	^{238}U	0.94 ± 0.14	0.22 ± 0.06
	^{232}Th	0.36 ± 0.07	1.5 ± 0.38
	^{40}K	1.4 ± 0.1	2.4 ± 0.6
	^{60}Co	–	0.36 ± 0.09



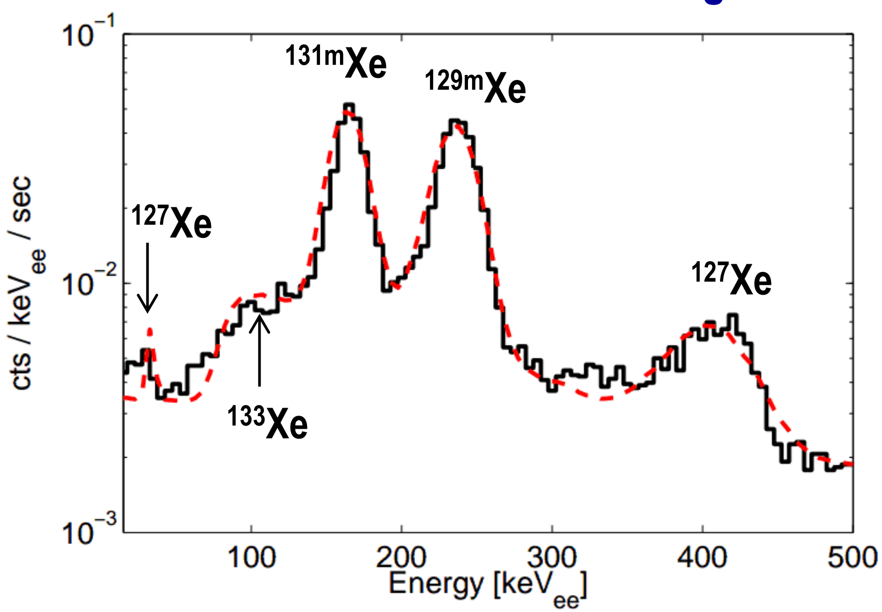
- Fit top, side, bottom contributions separately
- Fit above 500 keV_{ee} to avoid Xe activation lines
- Uses a multiple-scatter reconstruction technique to go up to 2.6 MeV, 225 kg volume
- Outstanding agreement. Notable x2 discrepancy for ^{228}Ac, perhaps indicative of ^{228}Ra removal from construction materials. It has no impact on WIMP ROI spectrum.

Contribution from Intrinsic Xe Sources

- **Cosmogenic activation of xenon**
  - **4 isotopes of interest: 127, 129m, 131m, 133**
  - **Others are too short-lived to matter**
  - **Non-noble elements quickly filtered out**
  - **Prediction based on ACTIVIA software and exposure history of LUX xenon**
  - **Observed rates based on S1-only data 12 days after xenon arrived underground. Decay constants were verified throughout the run.**
  - **Ratios agree fairly well. Overall prediction too small by a factor x8; attributed to the uncertainty on thermal neutron flux at one or more storage locations.**

Isotope	Half-life [Days]	Decay Rate [μBq kg^{-1}] Predicted	Observed
^{127}Xe	36	420	490 ± 95
^{129m}Xe	8.9	4.1	3.2 ± 0.6
^{131m}Xe	12	25	22 ± 5
^{133}Xe	5.3	0.014	0.025 ± 0.005

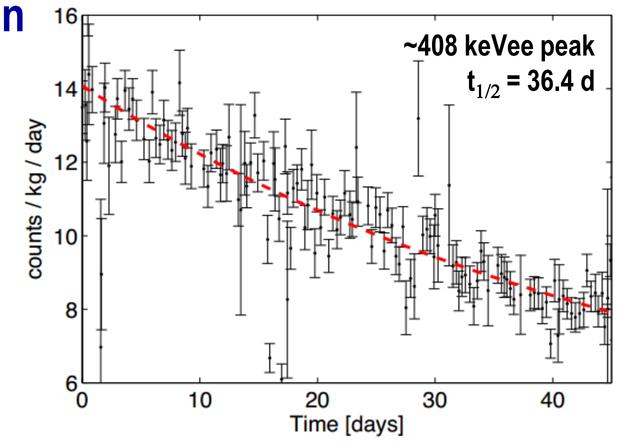
Predicted rates all multiplied by x8



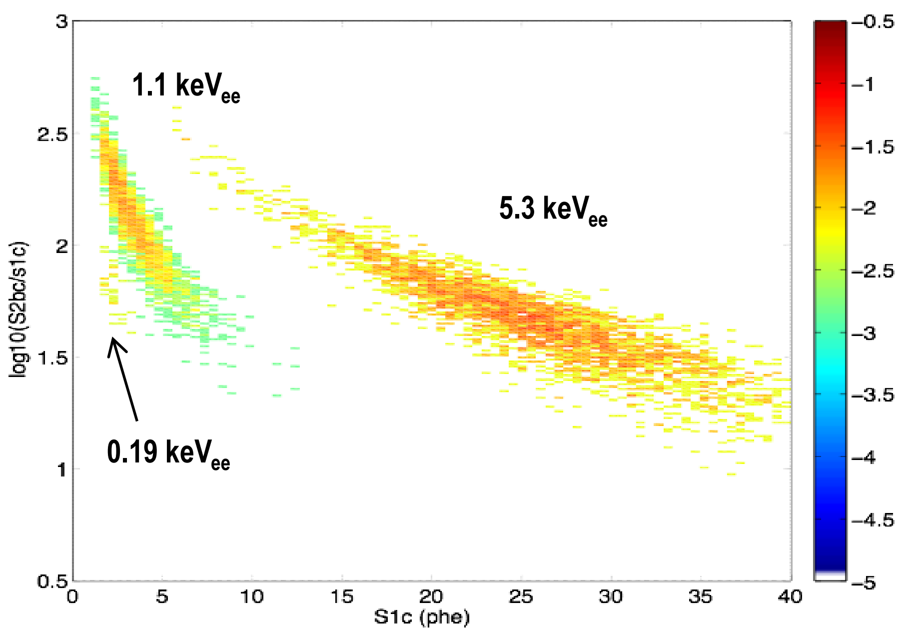
S1-only spectrum taken 12 days after xenon arrived underground

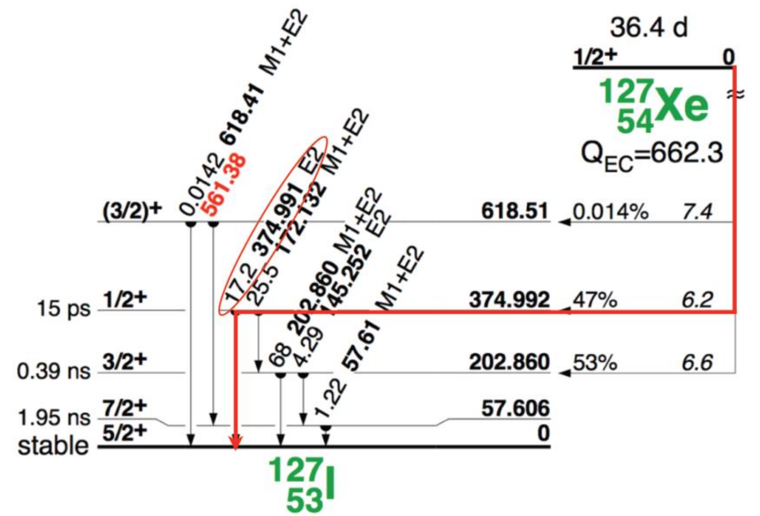
Contribution from Intrinsic Sources: ^{127}Xe

- **Isotope of interest for WIMP search = ^{127}Xe**
  - **EC decay with gammas 203 or 375 keV, possibility to escape the active volume.**
  - **X-ray / Auger emission corresponding to ^{127}I levels: 33.2 keV_{ee} (K), 5.3 (L), 1.1 (M), 0.19 (N)**
  - **Depth-dependent background profile; data follows prediction**
  - **Contribution modeled as a nuisance in the PLR analysis**
  - **Accounts for 0.5 $mDRU_{ee}$ (avg) in WIMP ROI over Run 3**
  - **It will have disappeared for Run 4**



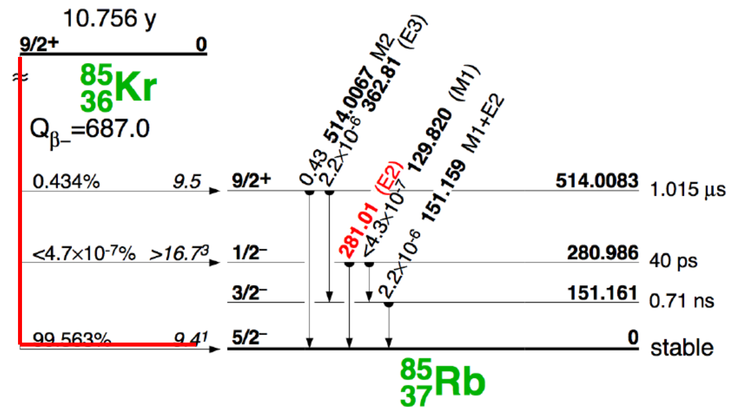
Probability Density Function

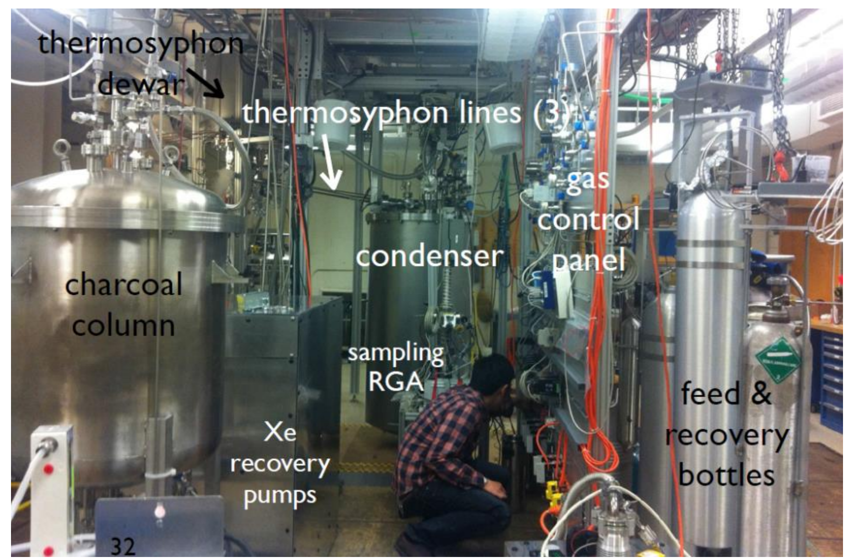




Contribution from Intrinsic Sources: ^{85}Kr

- Commercial xenon ~ 0.1 ppm ^{nat}Kr / Xe
  - ^{nat}Kr contains ^{85}Kr at ~2 x 10^{-11}
  - → Would lead to 5 DRU_{ee} in WIMP ROI
- LUX Krypton removal used dedicated charcoal column for gas phase chromatography, achieved (measured) 4 ppt ^{nat}Kr / Xe (arXiv:1103.2714)
- In-line sampling throughout Run 3: 3.5 ± 1.0 ppt g/g
  - Corresponds to a WIMP ROI rate of 0.17 ± 0.1 $mDRU_{ee}$
- Potential signature: 514 keV gamma + beta
  - BR = 0.4%
  - Expected rate in Run 3 = 3.6 decays / 85 days
  - Will be explored further in Run 4



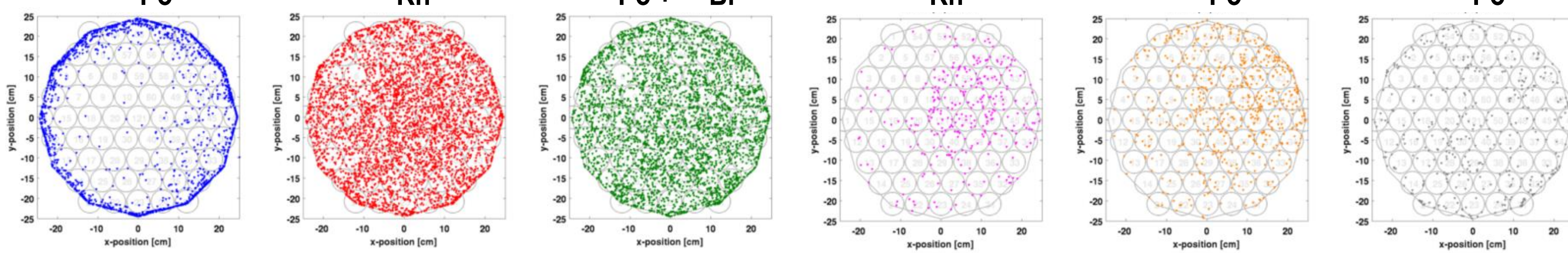


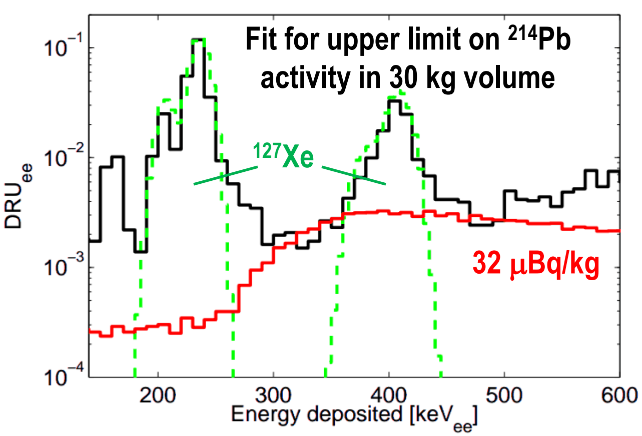
Contribution from Intrinsic Sources: Radon

- Present in bulk xenon, and plated-out on inner surfaces. Both ^{238}U and ^{232}Th chains.
  - Tracking via alpha signatures in LUX data (very large S1 signals)
  - Clear localization of different isotopes, consistent with plumbing outgassing / deposition model
  - Actual backgrounds = naked and semi-naked β decays in the bulk:
    - ^{212}Pb: bounded by ^{216}Po measurement < 2.8 mBq; potentially further removed due to $t_{1/2}$ = 11 hours
    - ^{214}Bi: but daughter ^{214}Po $t_{1/2}$ = 160 μs so vetoing with alpha coincidence is automatic
    - ^{214}Pb: bounded by ^{218}Po and ^{214}Po measurement to [3.5 – 14 mBq]
    - Additional constraint from ER spectrum in 30 kg inner volume: A < 32 μBq/kg → 0.2 $mDRU_{ee}$ in WIMP ROI

Illustrated decay chains available in backup slides

^{210}Po | ^{222}Rn | ^{218}Po + ^{212}Bi | ^{220}Rn | ^{216}Po | ^{214}Po



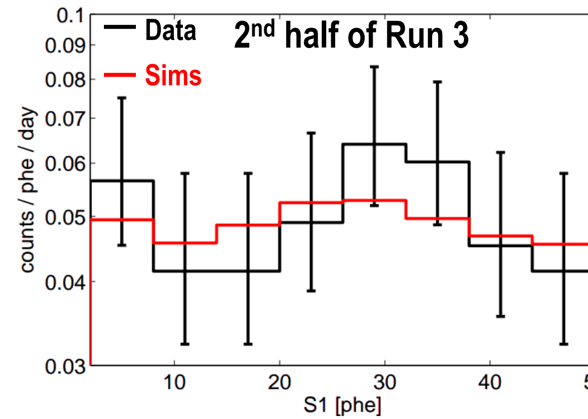


Decay Chain	Isotope	Energy [MeV]	Measured Energy [MeV]	Half-life	Event Rate [mHz]
^{238}U	^{222}Rn	5.59	5.59 ± 0.08	3.8 d	17.9 ± 0.2
	^{218}Po	6.16	6.12 ± 0.10	3.1 min	14.4 ± 0.2
	^{214}Po	7.84	7.80 ± 0.2	160 μs	3.5 ± 0.1
	^{210}Po	5.30	5.22 ± 0.09	140 d	14.3 ± 0.2 (on walls) 7.2 ± 0.2 (on cathode)
^{232}Th	^{220}Rn	6.41	6.47 ± 0.09	56 s	2.6 ± 0.1
	^{216}Po	6.91	6.95 ± 0.1	0.15 s	2.8 ± 0.1
	^{212}Bi	6.21	6.12 ± 0.10	61 min	14.4 ± 0.2
	^{212}Po	8.83	–	0.30 μs	–

Low Energy (WIMP ROI) Background Rate in Run 3

- **Main contributions summary:**

Source	Background Rate [$mDRU_{ee}$]
γ rays	$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$ (PMTs: 1.2)
^{127}Xe	$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$
^{214}Pb	$0.11 - 0.22$ (0.20 expected)
^{85}Kr	$0.17 \pm 0.10_{sys}$
Total predicted	$2.6 \pm 0.2_{stat} \pm 0.4_{sys}$
Total observed	$3.6 \pm 0.3_{stat}$



Discrepancy decreases in the second half of the run:

1st half: 4.4 ± 0.4 $mDRU_{ee}$

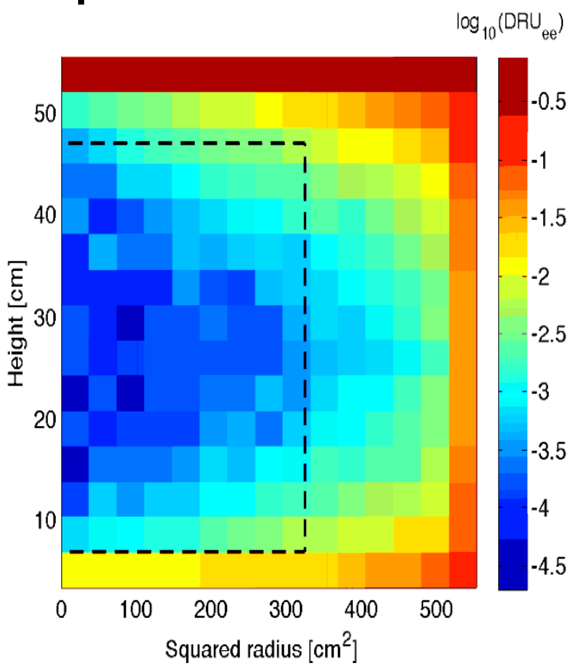
2nd half: 2.8 ± 0.4 $mDRU_{ee}$

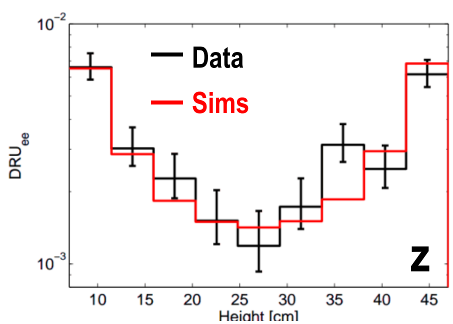
Decrease cannot be explained by ^{127}Xe decay alone (x2.7 too fast)

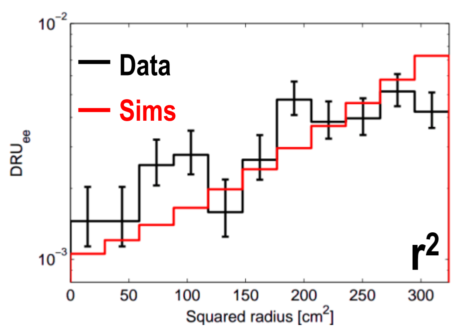
→ What are we missing in the early data model?

→ Whatever it is, it will have gone away for Run 4

- **Spatial distributions and fiducial volume:**







Run 4 (300 livedays) Projection

- 100 kg fiducial → Reduce gamma background rate by 50% compared to 118 kg
- ^{127}Xe contribution disappears
- ^{214}Pb, ^{85}Kr, neutrons: assumed to be the same as Run 3

Source	Background Rate
γ rays	$(1.0 \pm 0.1_{\text{stat}} \pm 0.1_{\text{sys}})$ mDRU$_{ee}$
^{214}Pb	0.2 mDRU$_{ee}$
^{85}Kr	$(0.17 \pm 0.10_{\text{sys}})$ mDRU$_{ee}$
Int. neutrons	170 nDRU$_{nr}$
Ext. neutrons	180 nDRU$_{nr}$
Total predicted	1.4 ± 0.2 mDRU$_{ee}$ + 350 nDRU$_{nr}$
Total observed	1.7 ± 0.3 mDRU$_{ee}$ $(0.14 \pm 0.03\ ^{127}\text{Xe})$

- 100 kg
- 300 days
- [0 – 30 phe]
- 50% NR accept.

→ 1.1 ± 0.2 event

- Observed during the second half of Run 3
- 350 nDRU$_{nr}$ → ~0.1 event / 100 kg / 300 days in [3 – 25 keV$_{nr}$] with 50% NR acceptance
  - Cherenkov veto may remove some of it

Result paper accepted by PRL
http://arxiv.org/abs/1310.8214

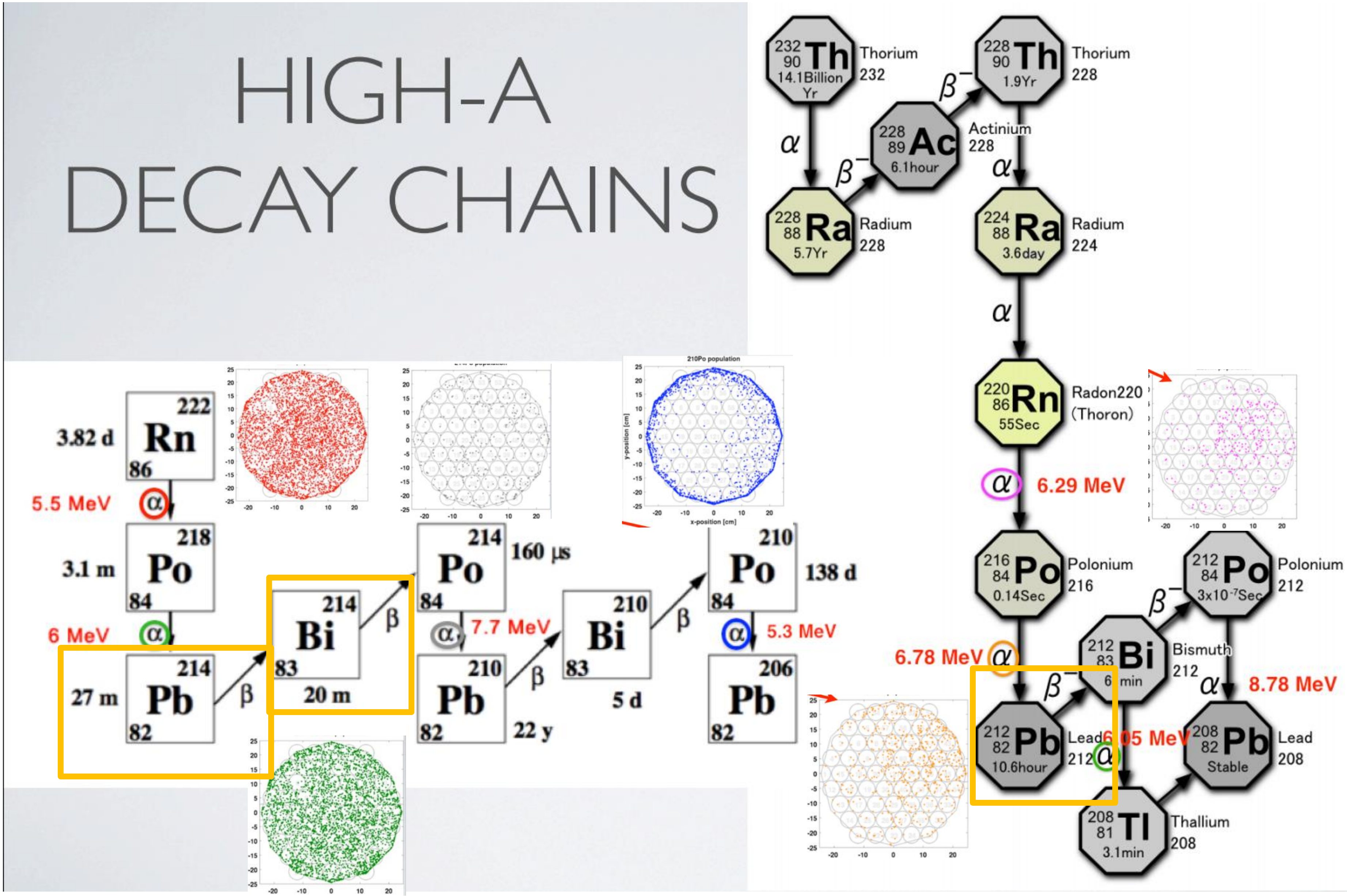
Instrument paper NIM A 704 111-126 (2013)
http://arxiv.org/abs/1211.3788

Dedicated LUX Backgrounds paper coming soon to an arXiv server near you

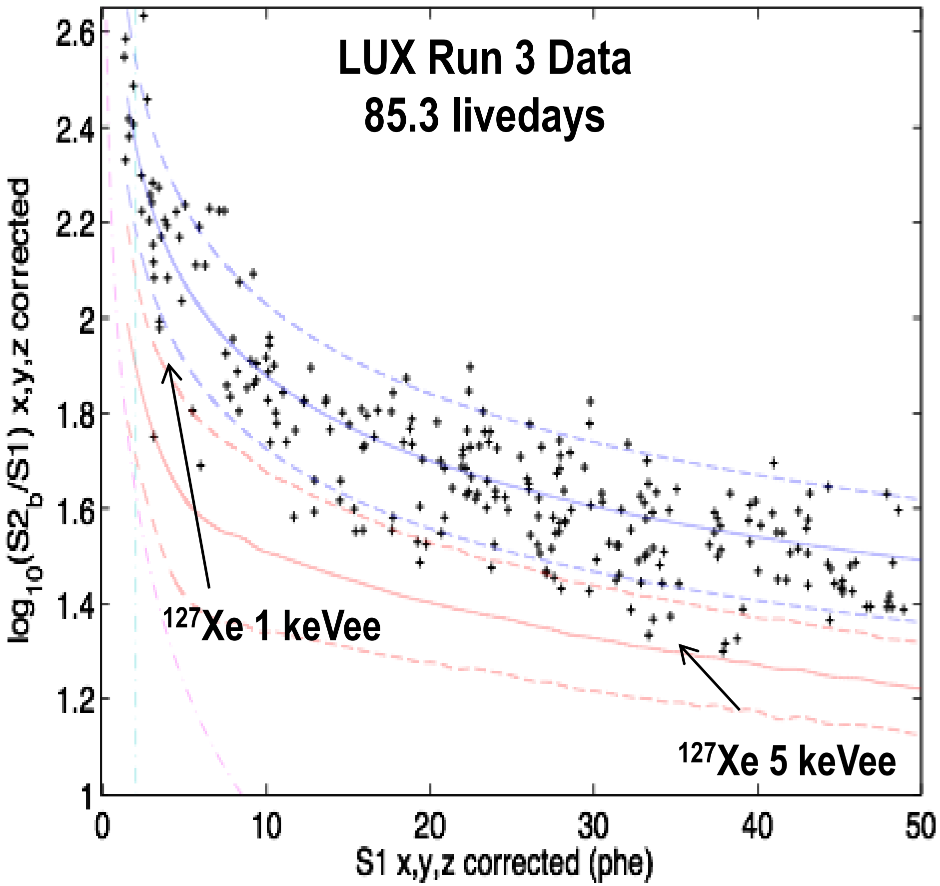
Thank you!

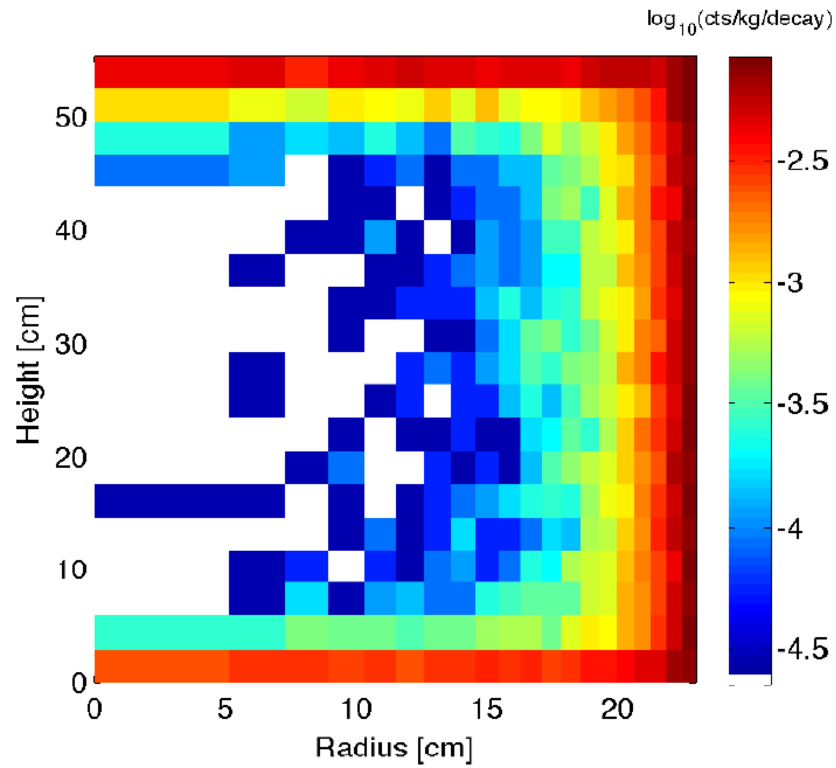
Additional Slides

Uranium and Thorium Chains



^{127}Xe





Simulated spatial distribution of ^{127}Xe events in WIMP ROI

Dead S2 regions ("Gamma-X")

- Predicted Run 3 rate:
  - 0.5 μDRUee
  - → Not a problem for LUX
- Similar phenomenon possible with neutrons
  - End up below the NR band

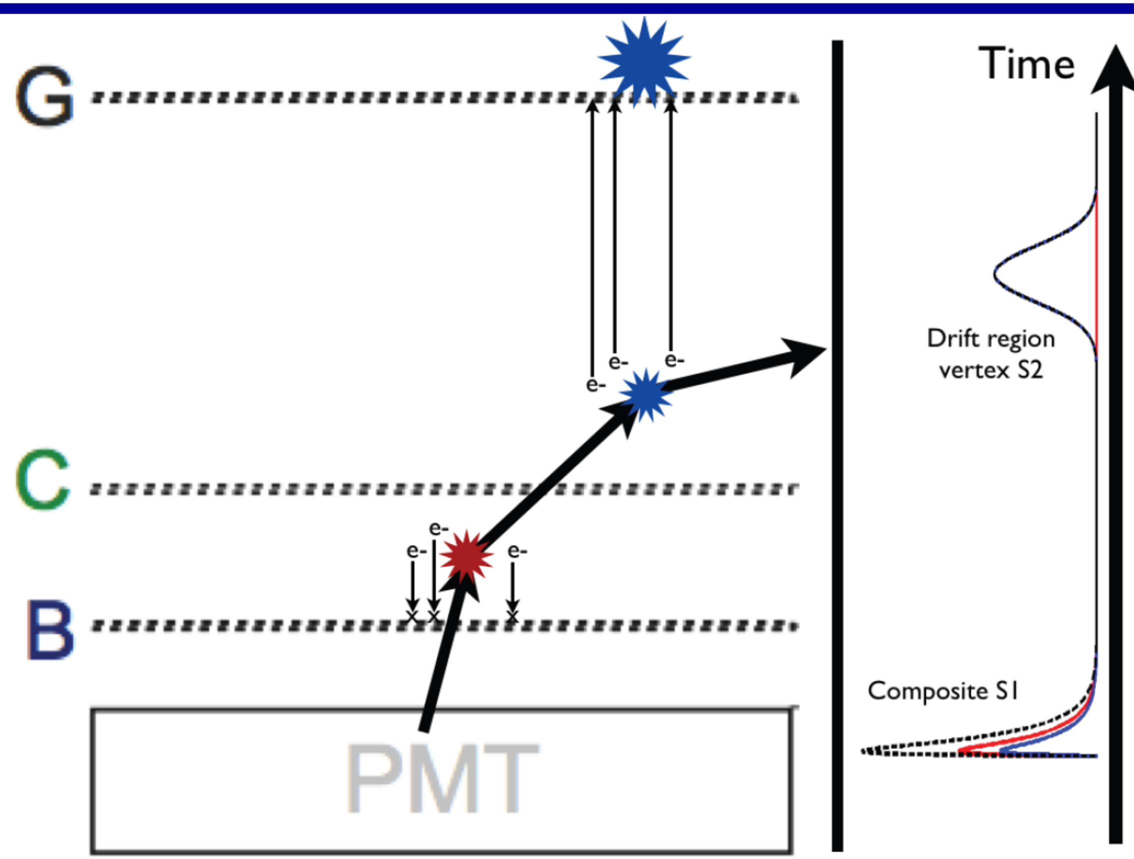


Figure 5.15: Qualitative representation of a gamma-X event. (Left) A γ scatters multiple times in the active region, with a single vertex in the drift region (small blue) and one or more vertices under the cathode (red). The resulting signal is shown at right as a function of time. The measured S1 signal is a composite signal from all vertices. Ionization is not collected from the vertices under the cathode. The resulting event has a single S2 which has a contribution only from the drift region vertex (large blue). (Right) The resulting waveform with detected S1 and S2 signals (black dashed). Shown are the contributions from the drift region vertex (blue) and RFR vertex (red). The reduced S2/S1 ratio for the event greatly lowers discrimination efficiency.