Calibrating Inner-Shell Electron Recoils in a Xenon Time Projection Chamber

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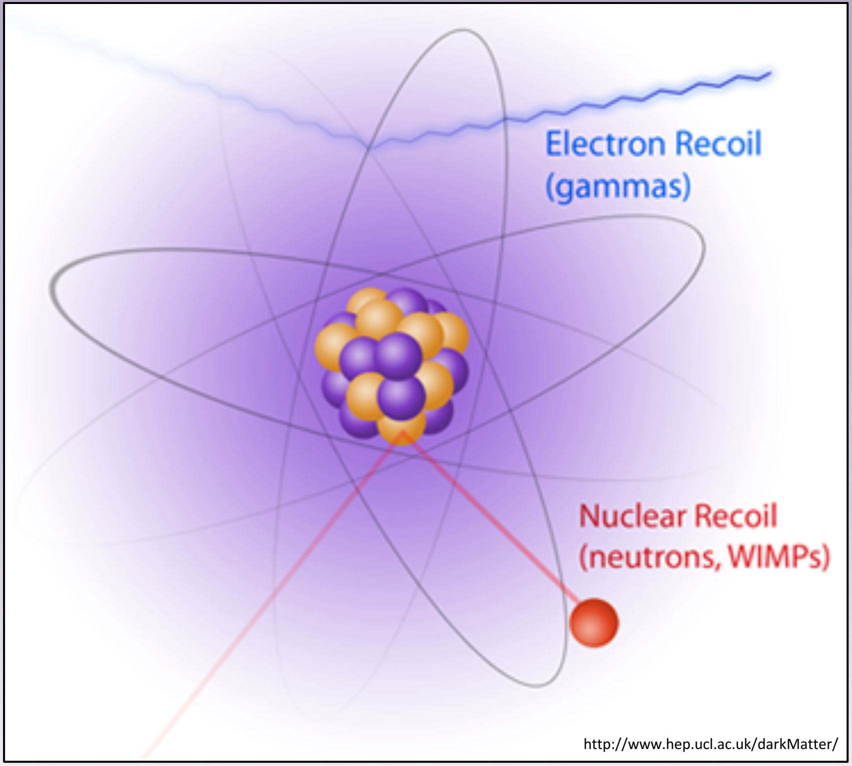
July 25, 2017

XV International Conference on
Topics on Astroparticle and Underground Physics

Direct Detection

- Searching for the small amount of energy deposited by the interaction of a dark matter particle with normal matter
- Nuclear Recoils:
  - WIMPs (dark matter)
  - Neutrons
- Electron Recoils:
  - Neutrino-electron scatters
  - Gamma/X-ray scatters
  - Beta decay
- Other…
  - Alpha decays
  - Muons



Direct Detection

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  - WIMPs (dark matter)
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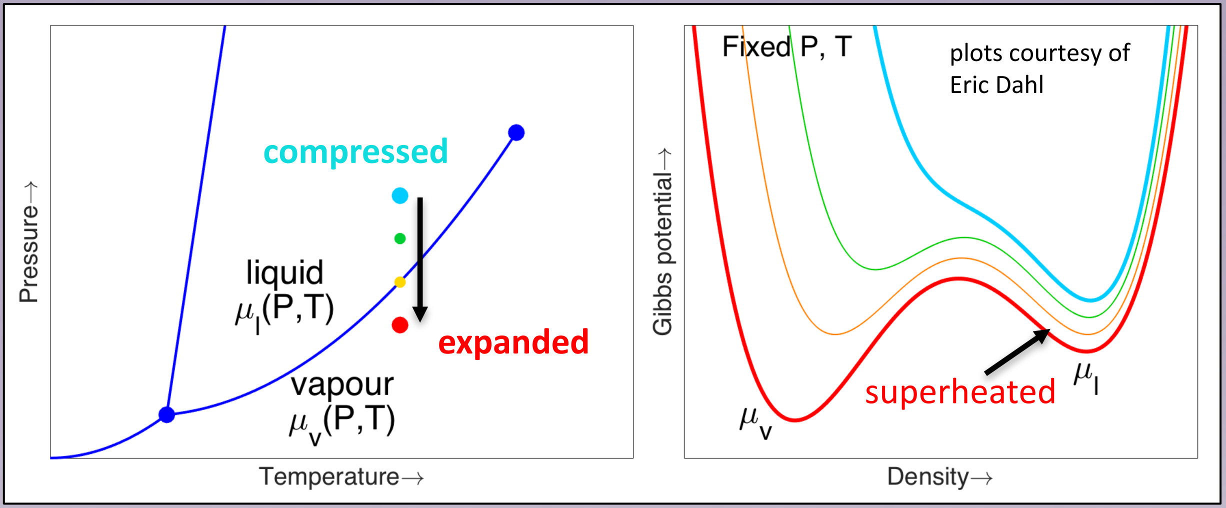
- Can't calibrate detector's efficiency to WIMP scatters directly
- Use neutron single-scatters to simulate nuclear recoils from dark matter

- Calibrate ER backgrounds using either external gamma-decays or internal beta-decays
- **Is it a valid assumption to say a beta decay and a neutrino-electron scatter look the same?**

- Not going to talk about these…

PICO Bubble Chambers



- Superheat any liquid such that it has a ~keV energy threshold to boil
- Need energy deposited within a critical radius to make a bubble (dE/dx threshold)

See the following talks for more information:

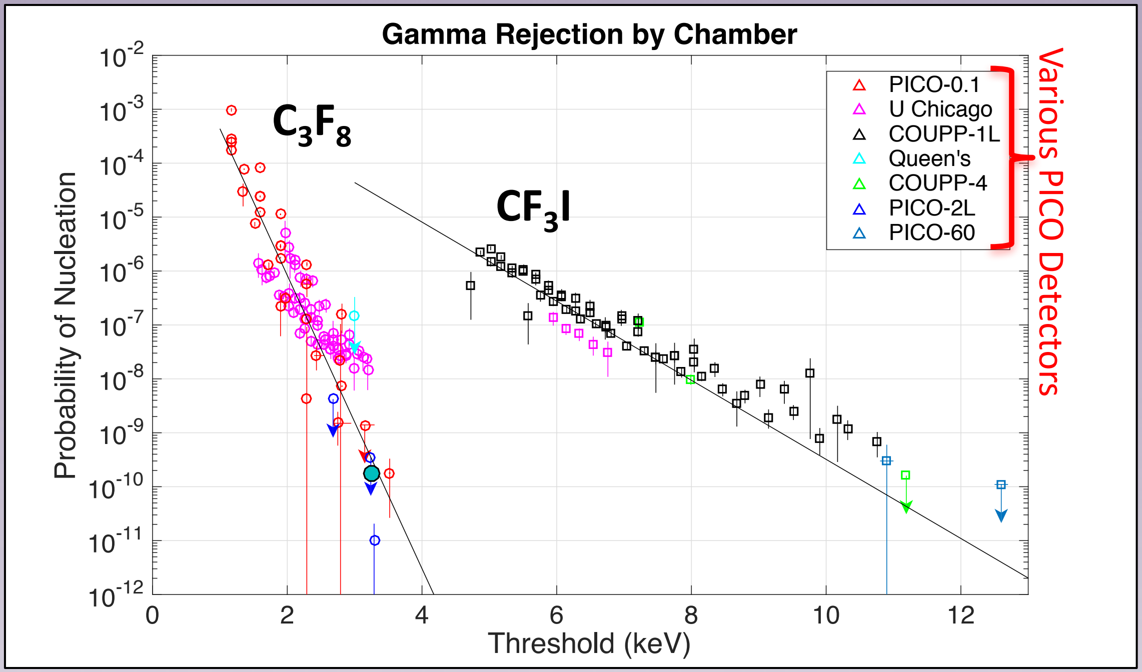
PICO Talks

- First demonstration of a scintillating xenon bubble chamber for dark matter and CEνNS detection (J. Zhang) Mon 1:15pm
- Threshold verification in the PICO-60 detector and study of the growth and motion of nucleation bubbles (P. Mitra) Mon 2:45pm
- PICO Results and Outlook *plenary (C. Krauss) Tue 9:50am
- PICO-500: Simulations for a 500L bubble chamber for dark matter search (E. Vázquez Jáuregui) Tue 4:30pm

PICO Posters

- Nuclear recoil calibration for PICO bubble chambers (M. Jin)
- PICO-60: World's largest bubble chamber for dark matter detection (U. Chowdhury)
- The PICO-40L detector design (B. Loer)

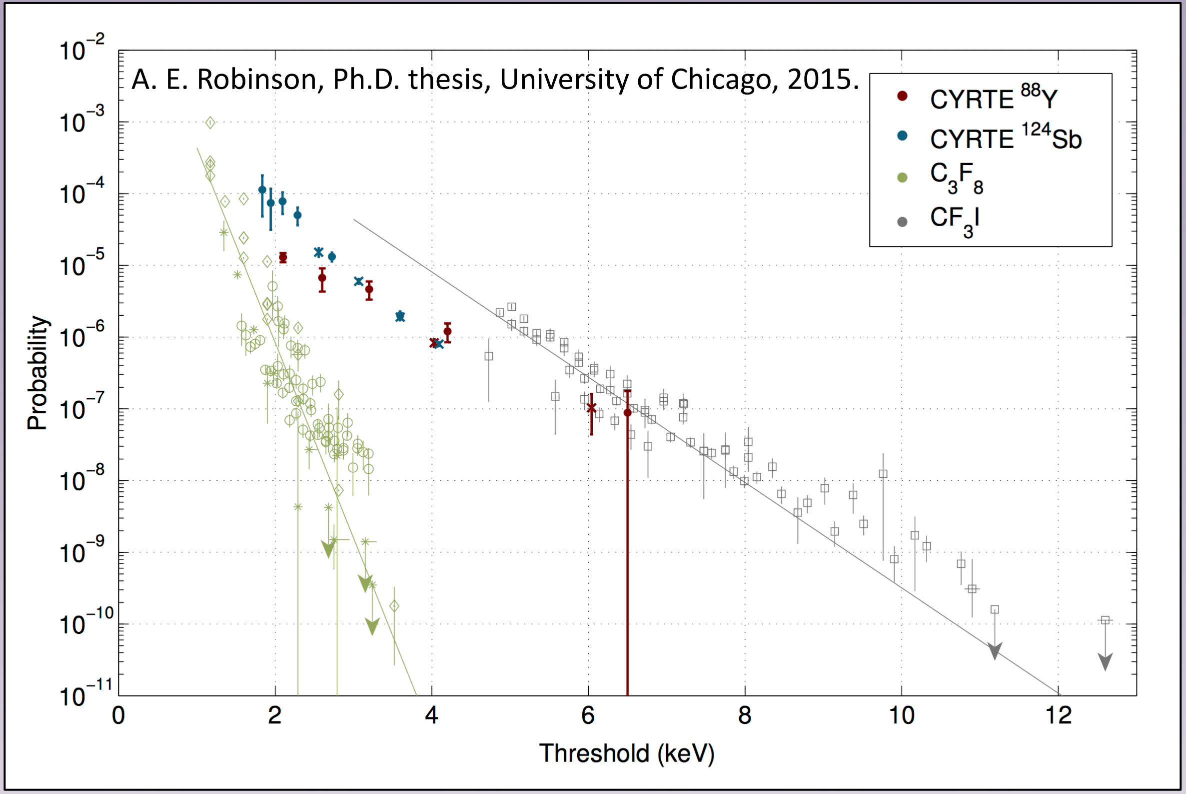
PICO Electron Recoils



- Electrons have a low dE/dx, making them very inefficient at nucleating bubbles
- Use external gamma sources to calibrate the probability of electron recoils to make an event
- Rejection depends largely on choice of target fluid

The difference is from the iodine, and we hypothesize that heavy target fluids have a higher probability to nucleate a bubble.

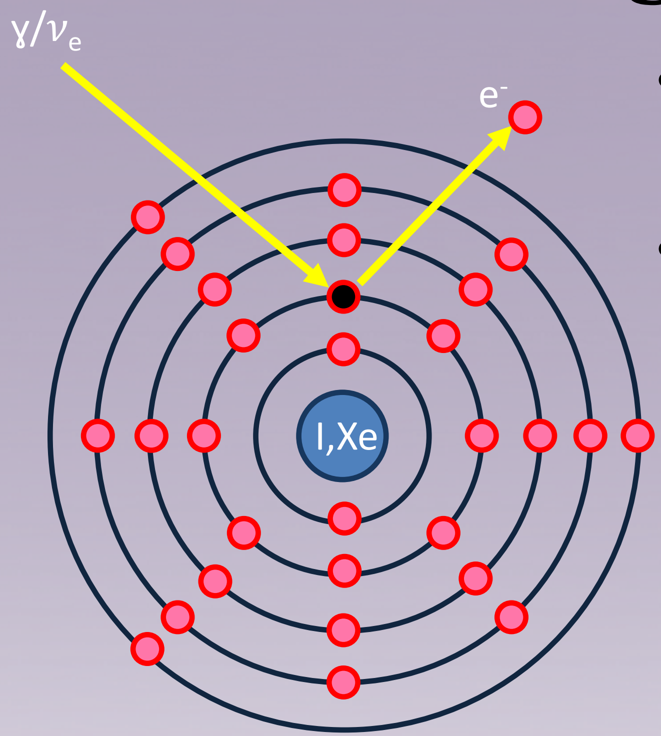
Why the difference?



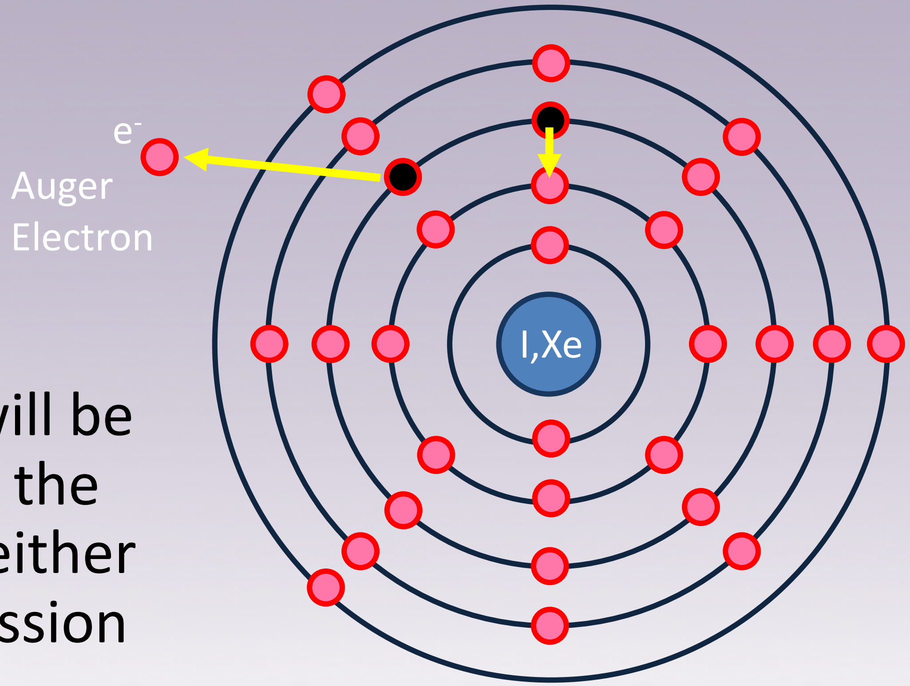
- 'CYRTE' detector was previously filled with CF3I before being filled with C3F8
- Electron recoil rejection completely dominated by interactions on iodine despite residual abundance…
- Effect is atomic and not fluid dependent

We need a mechanism. Why is iodine (or other heavy elements) so much more sensitive to electron recoils?

Auger Cascades

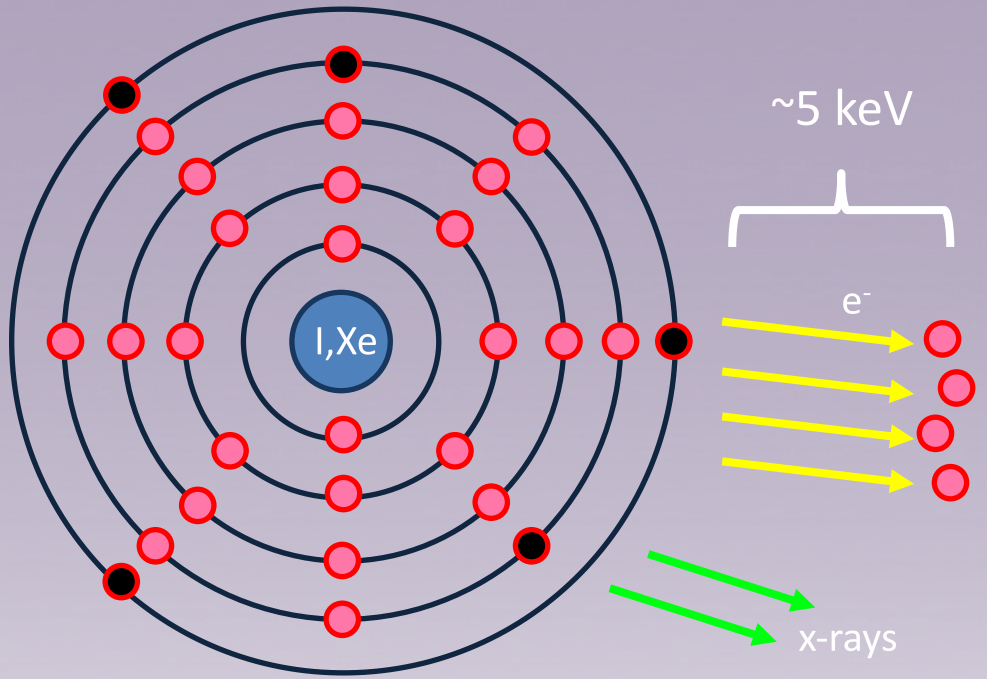


- Consider a neutrino or photon scattering off of the L-shell of iodine or xenon
- The initial electron kicked out loses its energy just like a beta decay



- The vacancy it leaves behind will be filled by another electron with the energy difference released in either an x-ray or Auger electron emission

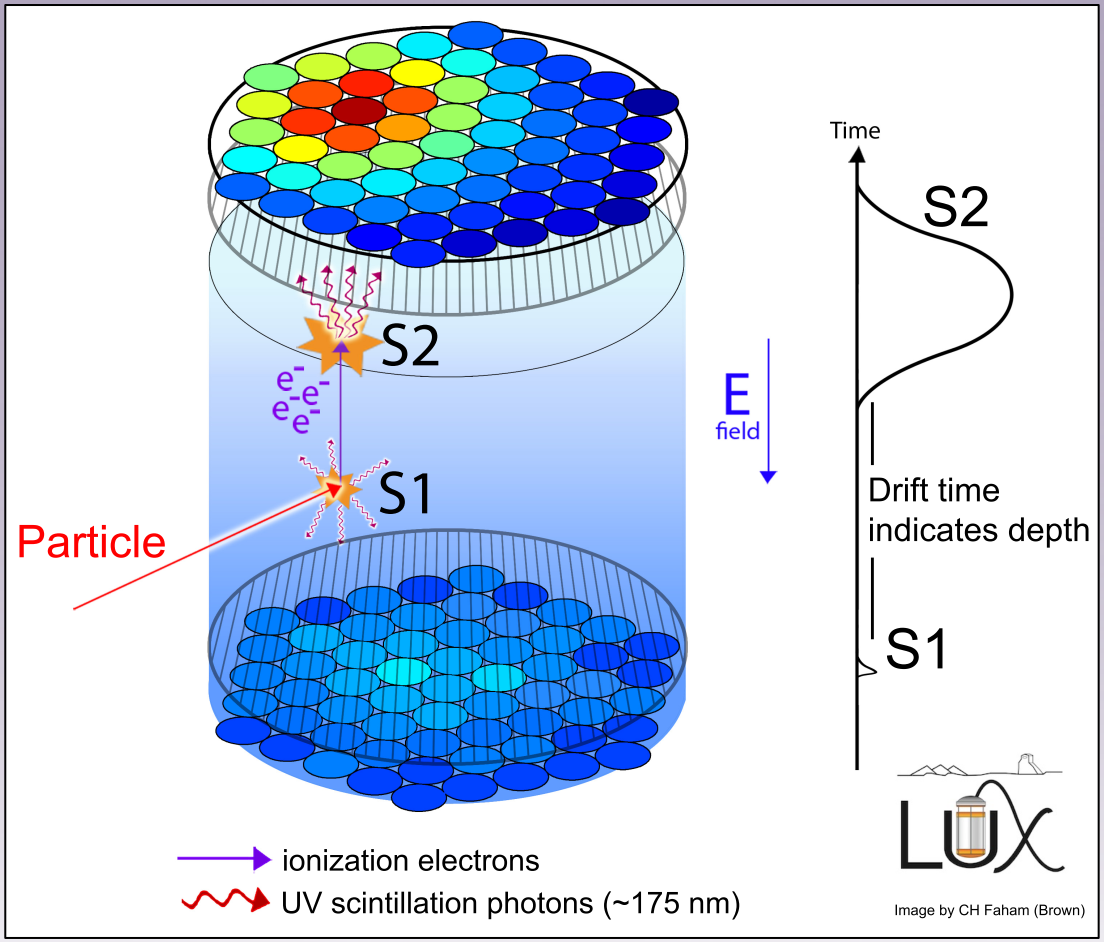
Auger Cascades



- This will propagate outwards until the full binding energy of the original electron is released
- Because the constituents are all very low energy, the net dE/dx is larger than for a single 5keV piece

- This is significant enough to yield a many orders of magnitude higher probability of nucleating a bubble in the bubble chambers
- **What does it mean for other types of detectors?**

Xenon Time Projection Chambers (TPCs)

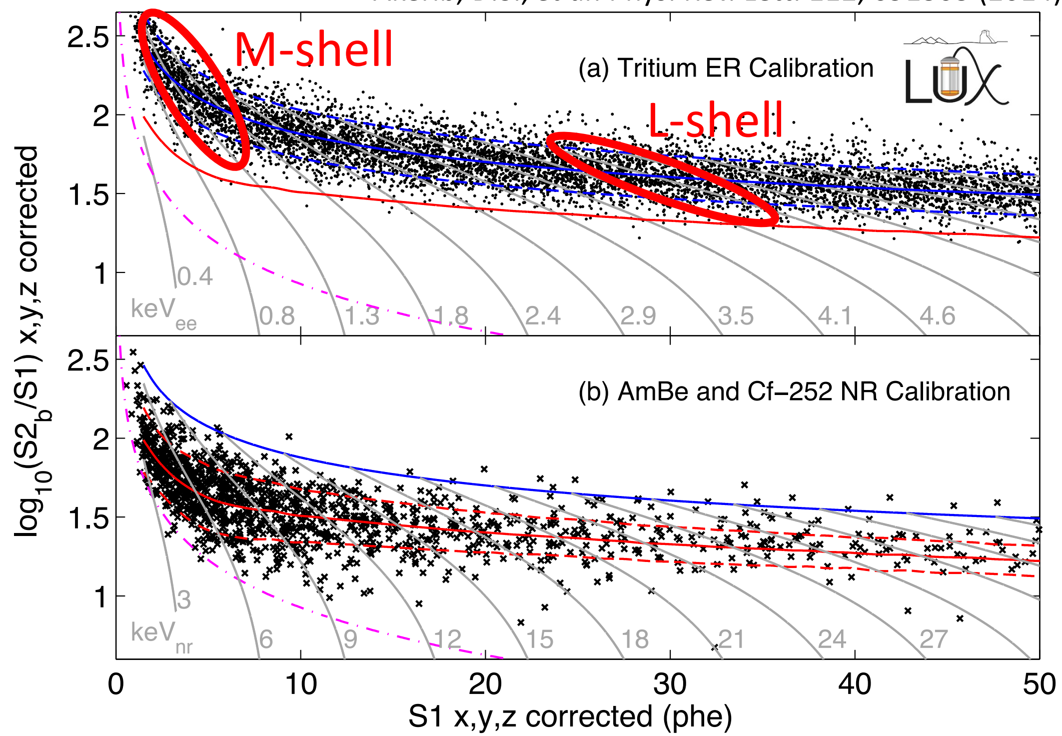


- An interaction generates a pulse of scintillation light (S1) and electrons
- The electrons are drifted to a liquid-gas interface, where they are extracted
- The high extraction field accelerates the electrons, producing a second burst of light (S2)
- The time difference between the pulses tells the height of the event.

TPC Calibration

- The collaborations using xenon TPCs (LUX, XENON1T, PandaX-II) calibrate their detectors using injected beta decays from tritium or radon
- A significant fraction of the background budget for LZ is neutrino-electron and Compton scatter events, which include an inner-shell component
- L- and M- shell binding energies fall within the energy range of interest
- **Beta-decay isotopes do not calibrate for this effect**

Akerib, D.S., *et al*. Phys. Rev. Lett. 112, 091303 (2014)



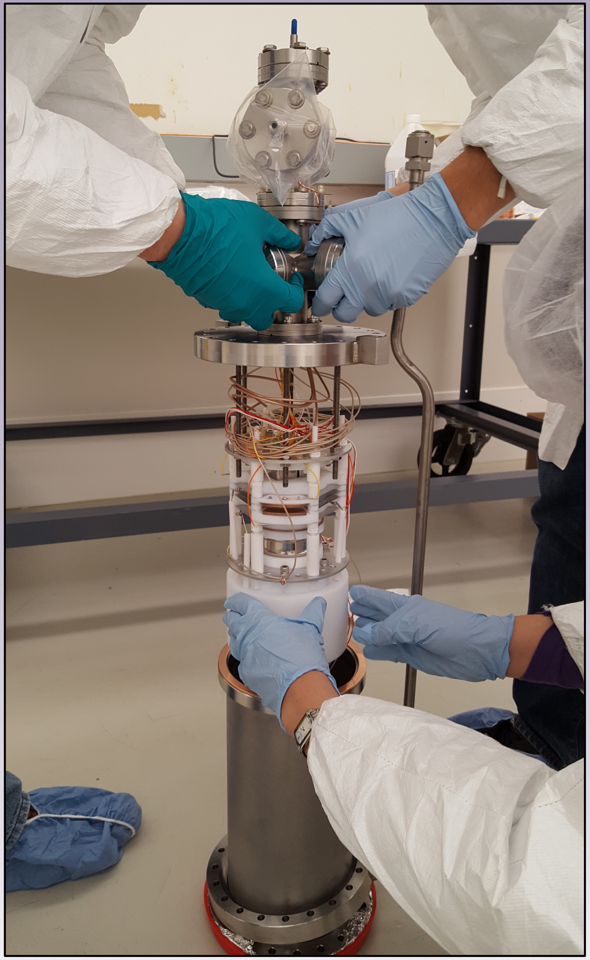
Implications

- The standard profile-likelihood analysis relies on tritium beta decays accurately simulating <u>all</u> electron-recoil backgrounds
- Differences in energy deposition due to Auger cascades could lead to second-order deviations from the calibrated model
- **The profile likelihood analysis *could* interpret this difference as a WIMP signal**

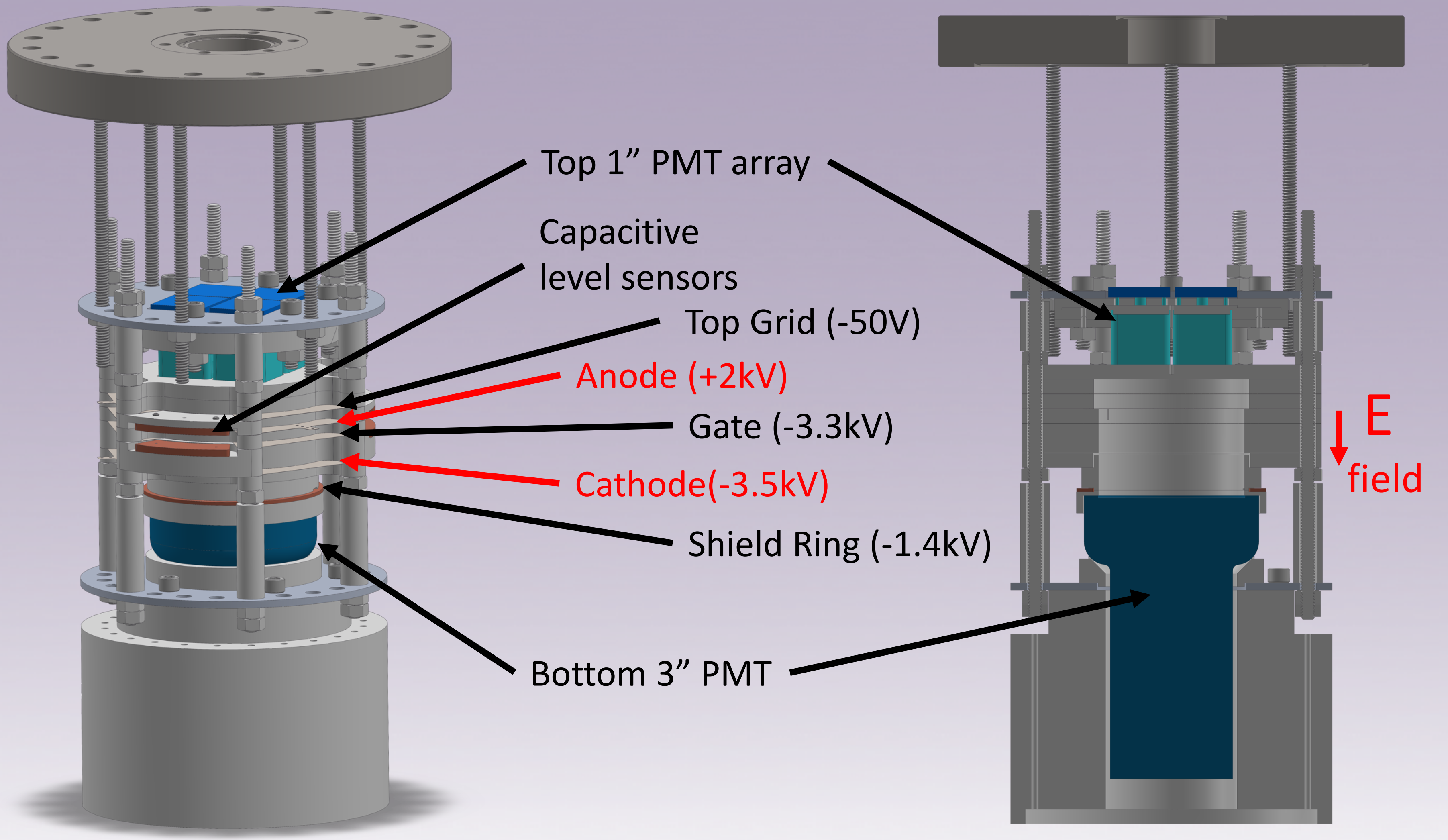
XELDA detector

(**X**enon **E**lectron-recoil **L**-shell **D**iscrimination **A**nalyzer)

- Goal: Build a detector to perform a direct, high-statistics cross calibration of tritium beta decay against the relaxation following inner-shell scatters
- How: Xe-127 decays by electron capture. In a small detector, the associated gammas are lost, leaving ONLY the energy deposited by the resulting cascade.
- **Plan: Simultaneous tritium and Xe-127 will allow us to look for small deviations without systematics**

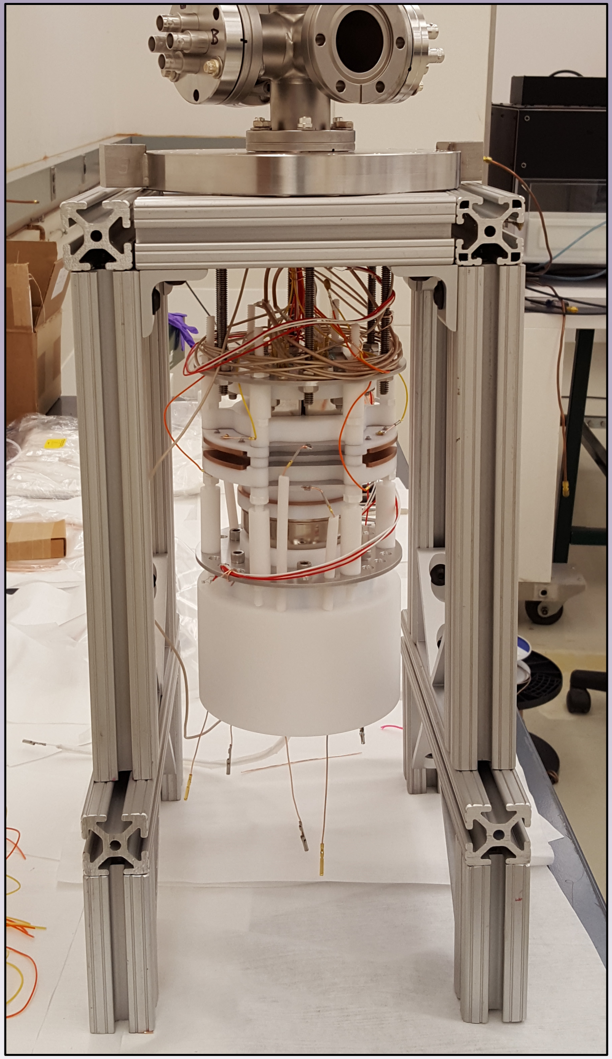


XELDA detector



modeled after the MiX detector

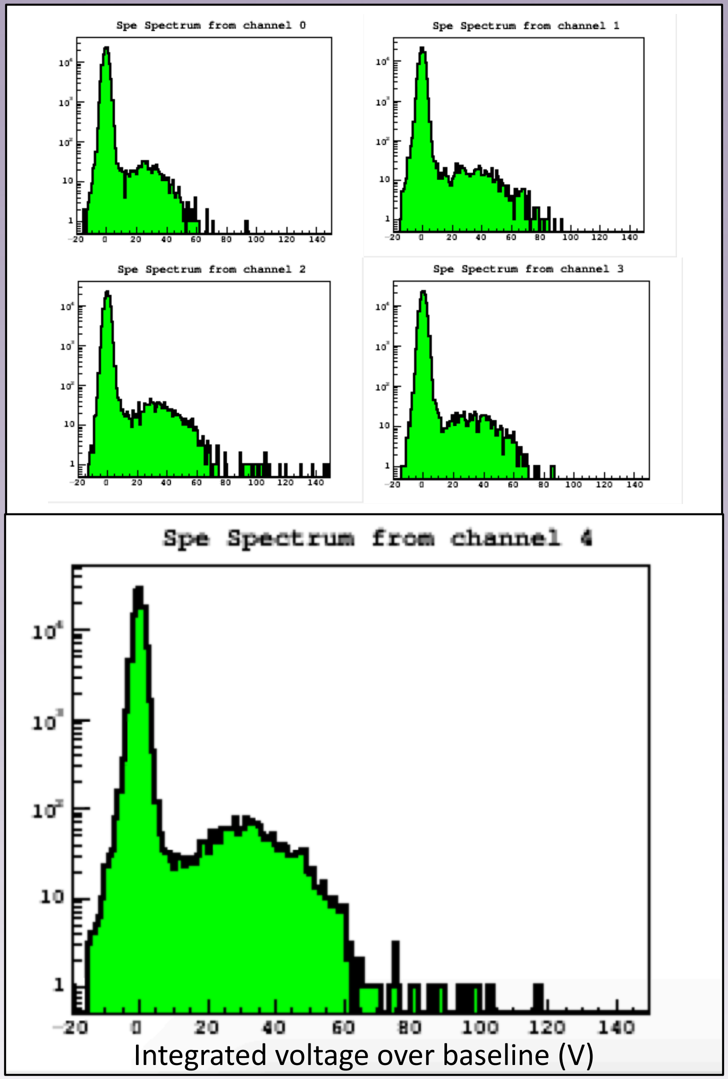
Detector Design



- Use top PMT array for XY and trigger
- Use bottom PMT to see small S1
- Detector dimensions:
  - Diameter: 63.5mm
  - Cathode to Gate: 12.7mm
  - Gate to Anode: 6.4mm
- Operating conditions:
  - Drift field: 300 V/cm
  - Extraction field: 10 kV/cm

Detector Calibration

- Use blue LED to calibrate single photon sensitivity
- Seeing single phe peak in all five PMTs
- Definitely still room for noise reduction



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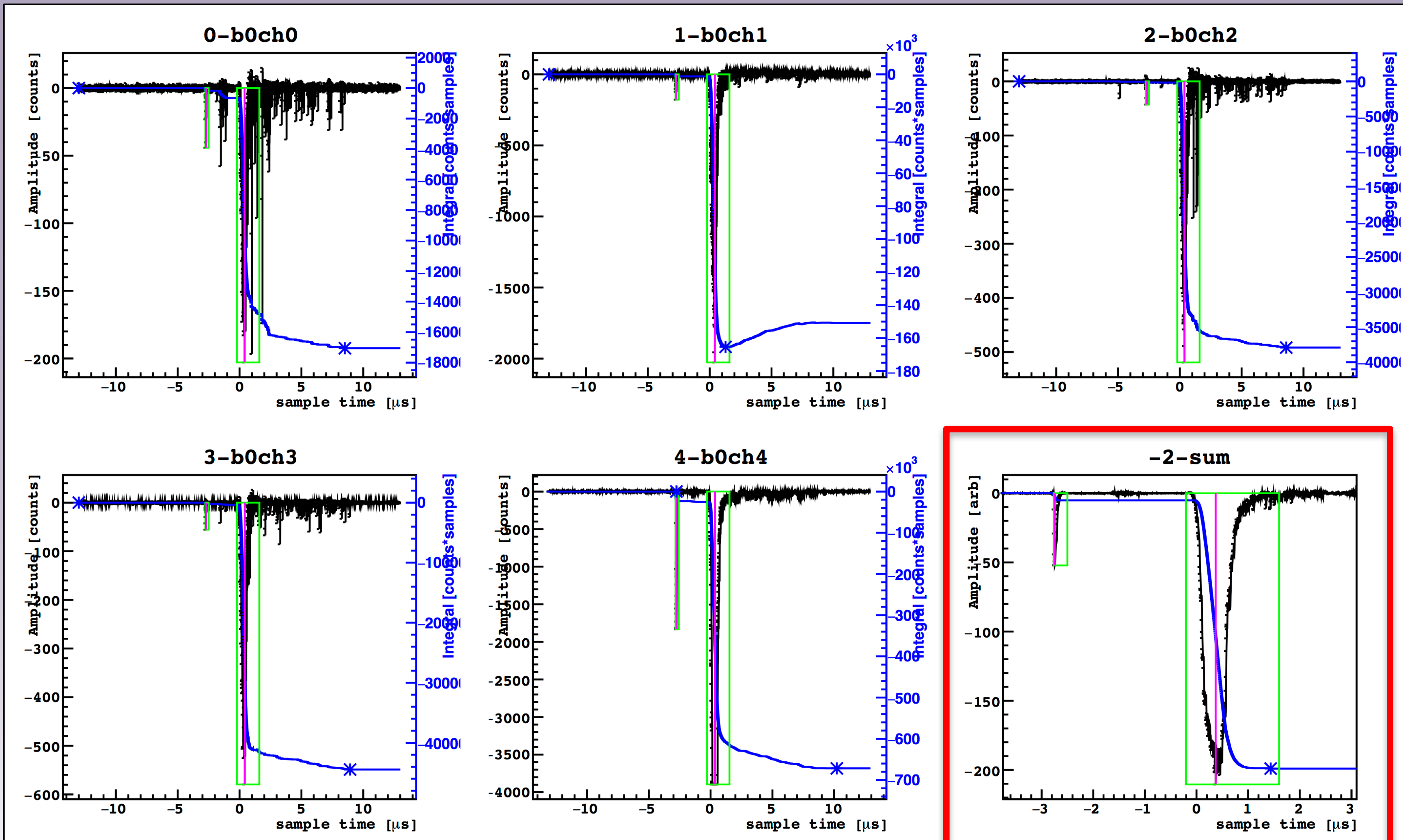
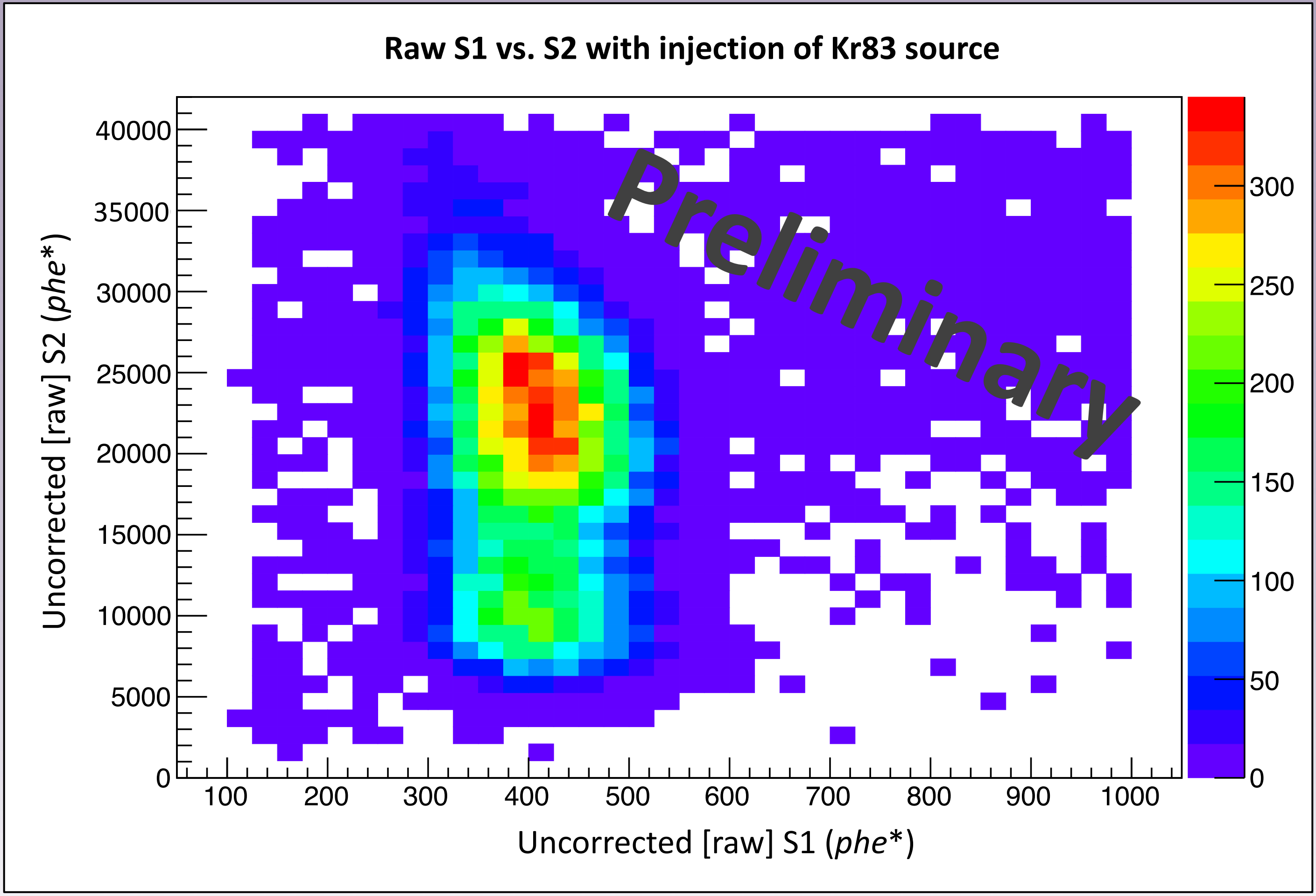
Sample Event



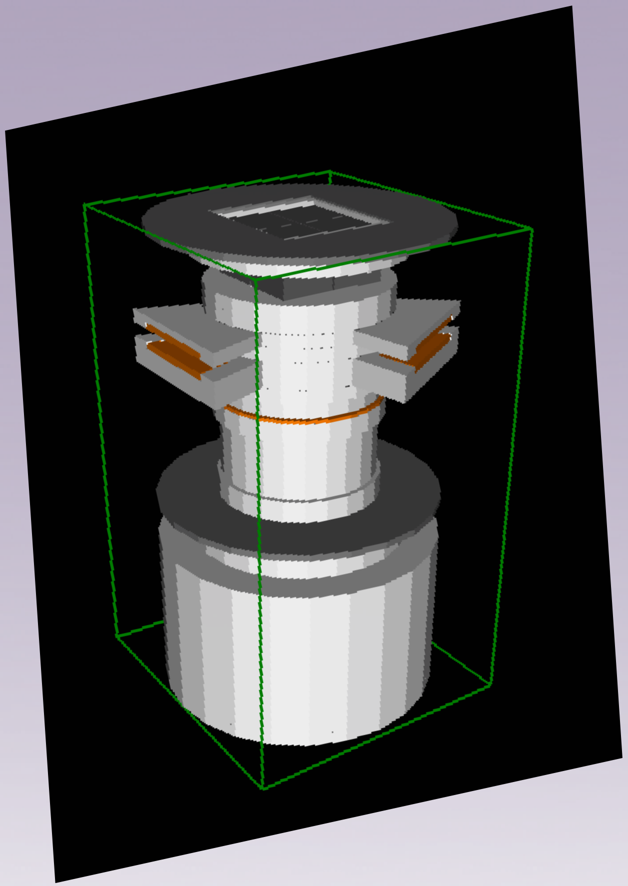
Energy Calibration

- Inject Kr-83m to look at S1/S2 response of 42keV line



Conclusions

- Inner-shell electron recoils could contribute important corrections to existing background model
- XELDA detector works!
- Now completing analysis chain
- Light simulation will allow XYZ corrections and fiducialization (soon)
- Tritium and Xe-127 ready to inject
- **Need to challenge the assumption that all electron recoils are alike**



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Thank you!

- **DoE SCGSR Fellowship Program (for paying me)**

- XELDA group: **Hugh Lippincott**, **C. Eric Dahl**, Amy Cottle, Dylan Temples, Makayla Trask
- Fermilab technicians: William Miner, Kelly Hardin, Ronald Davis

- University of Michigan LUX group (especially Scott Stephenson): XELDA detector is modeled after the MiX detector
- Ben Loer for daqman software package and related assistance
- Luca Grandi for Kr-83 calibration source
- Carter Hall for tritium calibration source
- PICO and LZ collaborations for continued support