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

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LIght **D**etection **I**n **N**oble **E**lements 2017

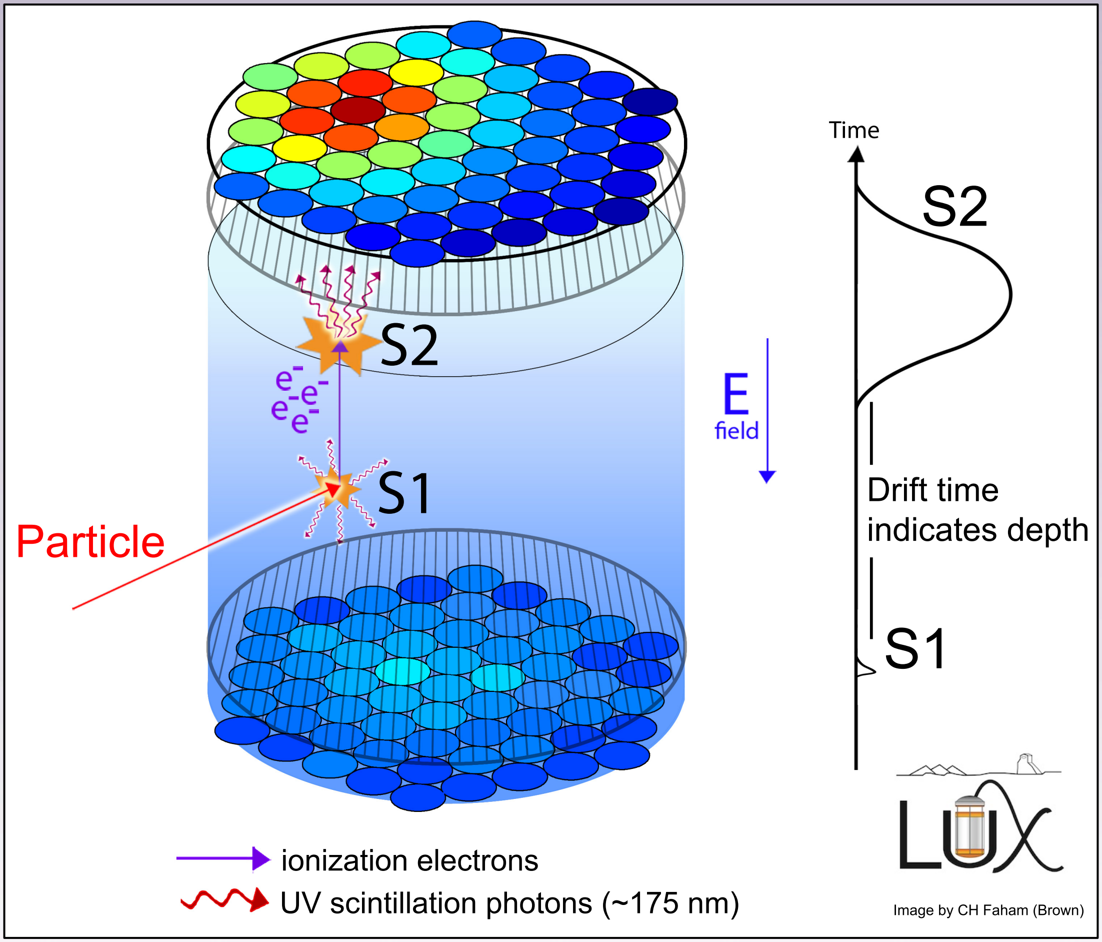
Direct Detection of Dark Matter

- Dark Matter searches hinge on the ability to understand the difference between electron and nuclear recoils
- Nuclear Recoils:
  - WIMPs (dark matter)
  - Neutrons
- Electron Recoils:
  - Neutrino-electron scatters
  - Gamma/X-ray scatters
  - Beta decay
- Other

- Use neutron single-scatters to simulate nuclear recoils from dark matter

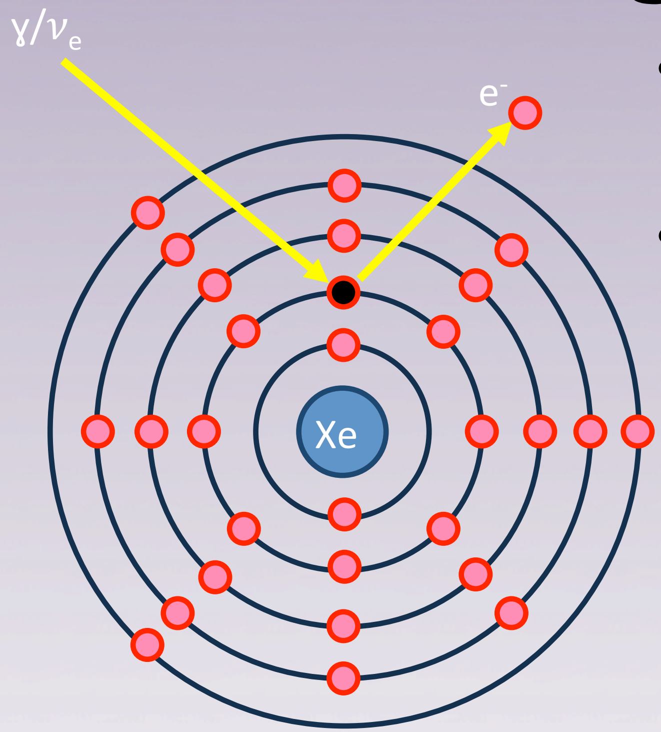
- Calibrate ER backgrounds using either external gamma-decays or internal beta-decays
- **Is it a valid assumption to say a beta decay and a neutrino-electron scatter look the same?**

Xenon Time Projection Chambers (TPCs)

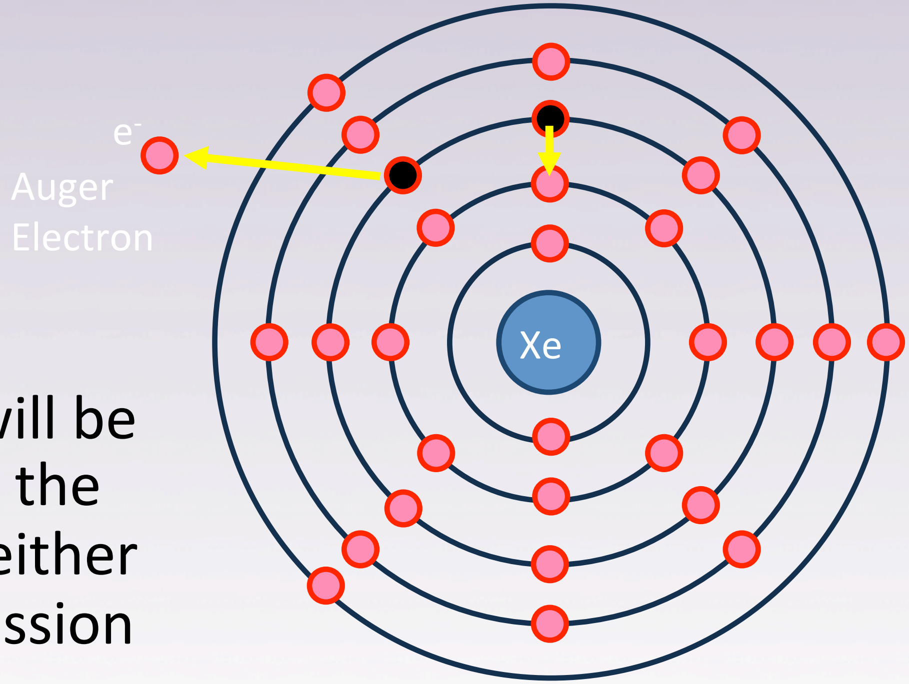


- An interaction generates a pulse of scintillation light (S1) and electrons
- The electrons are drifted to a liquid-gas interface, where they are extracted
- A high extraction field accelerates the electrons, producing a second burst of light (S2)
- The time difference between the pulses tells the height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

Auger Cascades

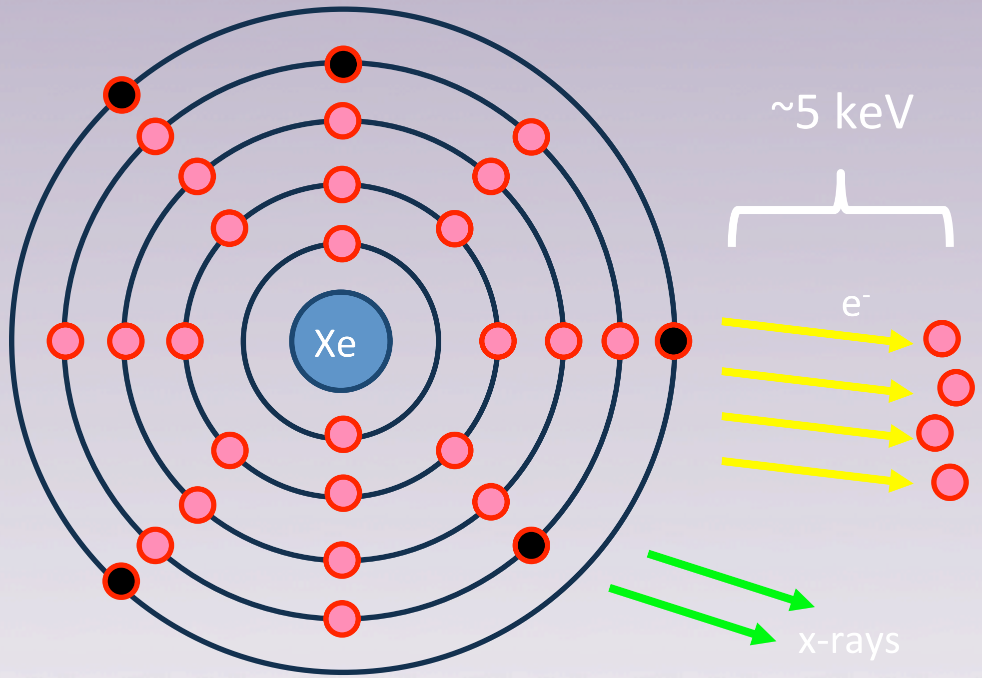


- Consider a neutrino or photon scattering off of the L-shell of xenon
- The initial electron kicked out loses its energy just like a beta decay



- 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



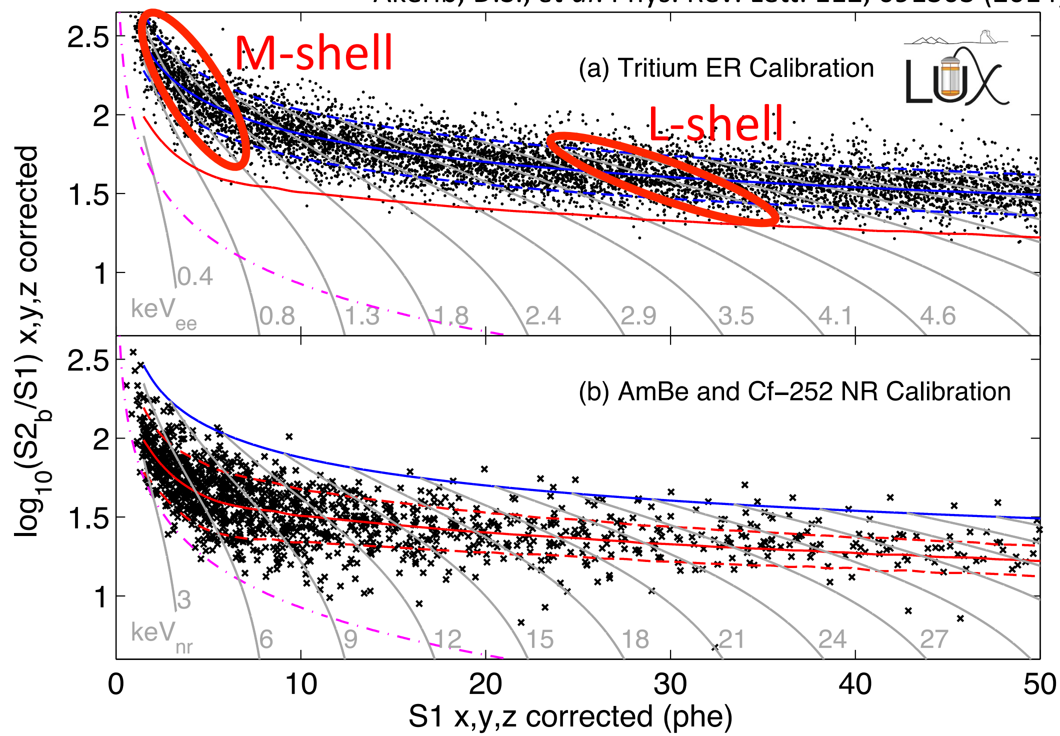
- This will propagate outwards until the full binding energy of the original electron is released
- Because the constituents are all very low energy, the net dE/dx is larger than for a single 5keV piece

- These constituent pieces form one effective interaction that deposits its energy very locally, similarly to a nuclear recoil
- Current models assume that dE/dx should not be important at energy ranges used in dark matter searches

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)

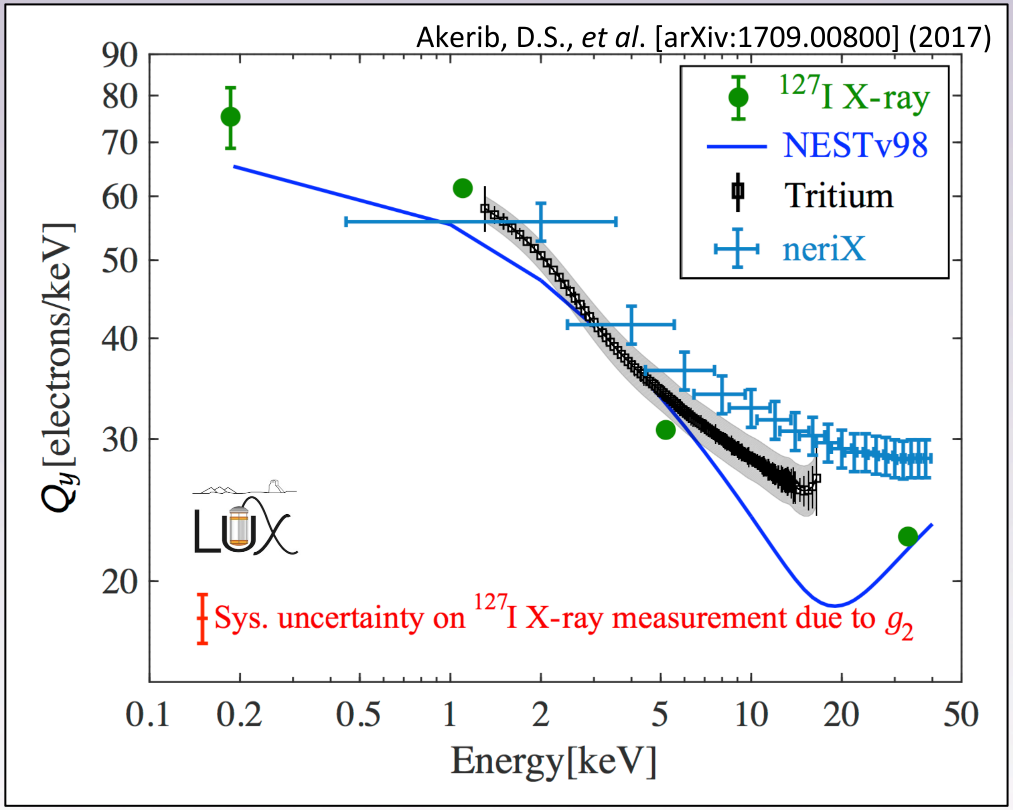


Implications

- 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**

How do you calibrate this?

- One option is with Xe-127 electron capture decay
- Recent LUX analysis used different positions of EC gamma and cascade to tag and isolate S2 from the cascade



- Why is our measurement different?
  - Small detector means gammas escape, letting us resolve <u>both</u> S1 and S2
  - Simultaneous injection of Xe-127 and tritium to remove systematic errors
  - Rn-220 injection allows for comparison to K-shell
  - Full cascade of Auger electrons has small (order 1%) probability, so we need more statistics
    - LUX result had 542 L-shell EC decays

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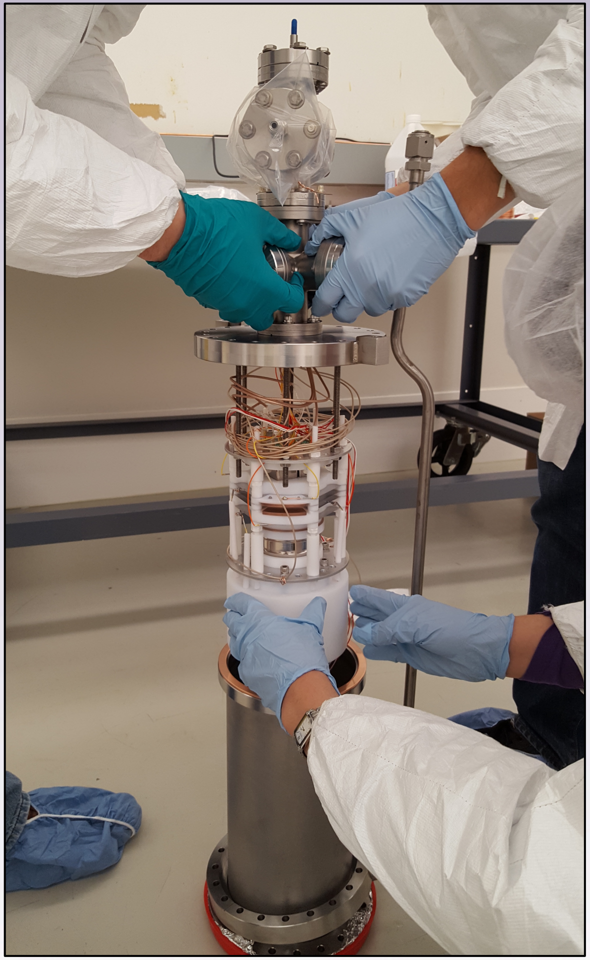
XELDA detector

(<u>**X**</u>enon <u>**E**</u>lectron-recoil <u>**L**</u>-shell <u>**D**</u>iscrimination <u>**A**</u>nalyzer)

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



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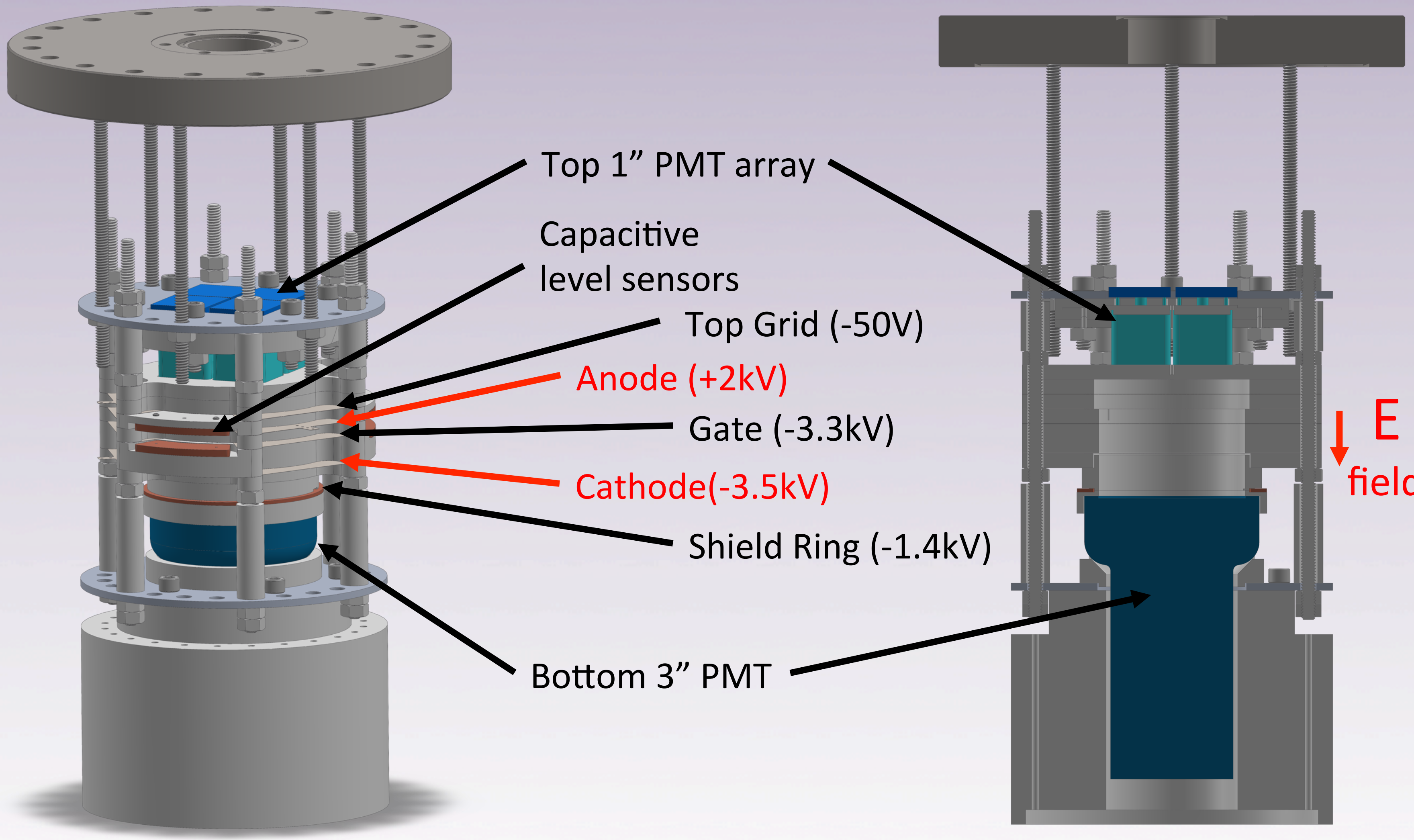
XELDA detector



modeled after the MiX detector

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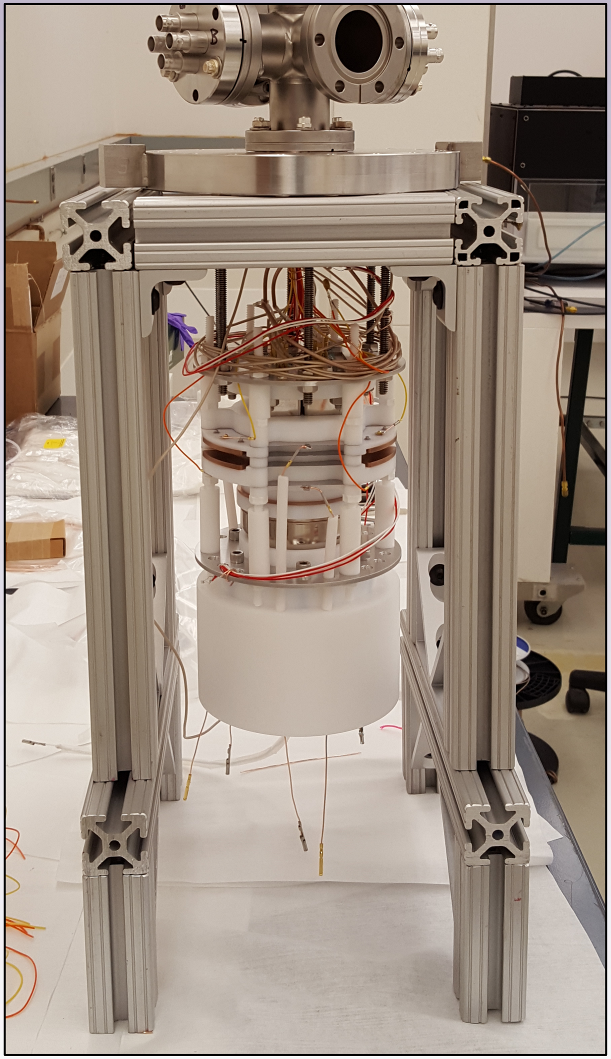
Detector Design



- Use bottom PMT for pulse finding
- Use top PMT array for S2, XY, and trigger
- Use sum of all PMTs for 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

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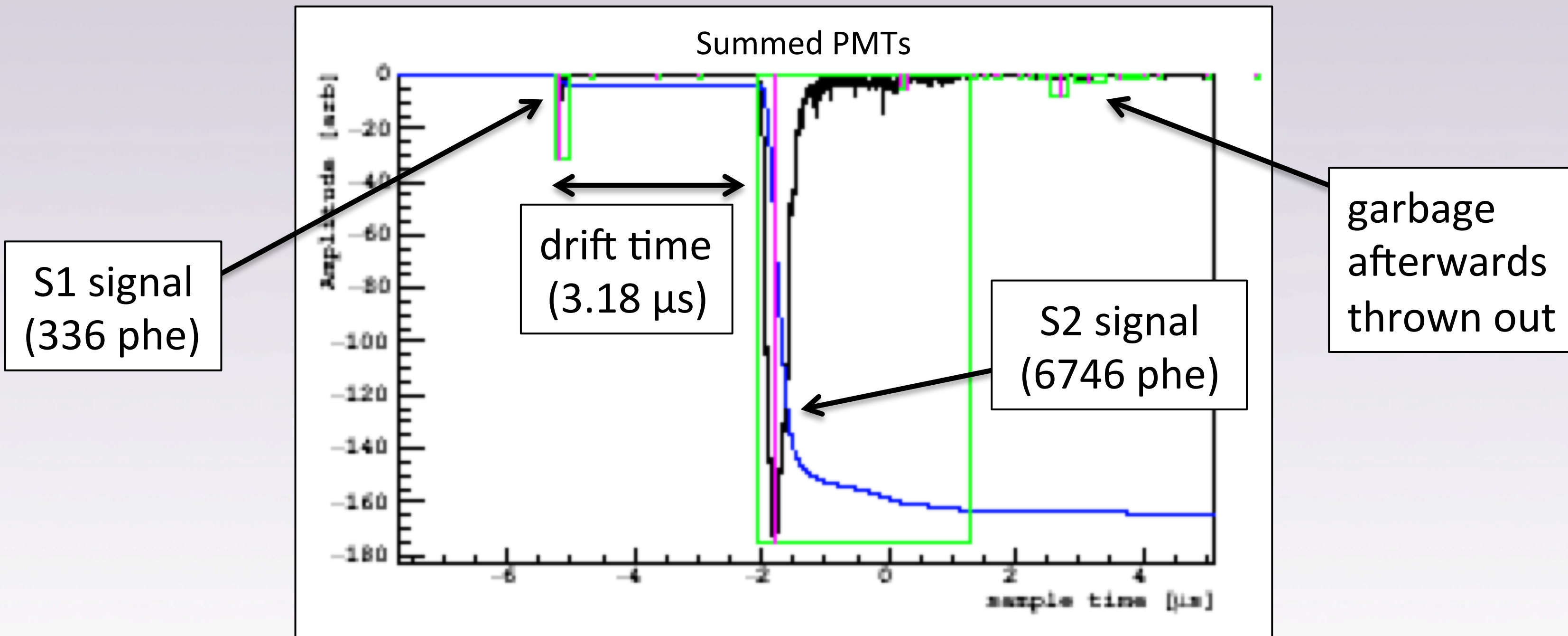
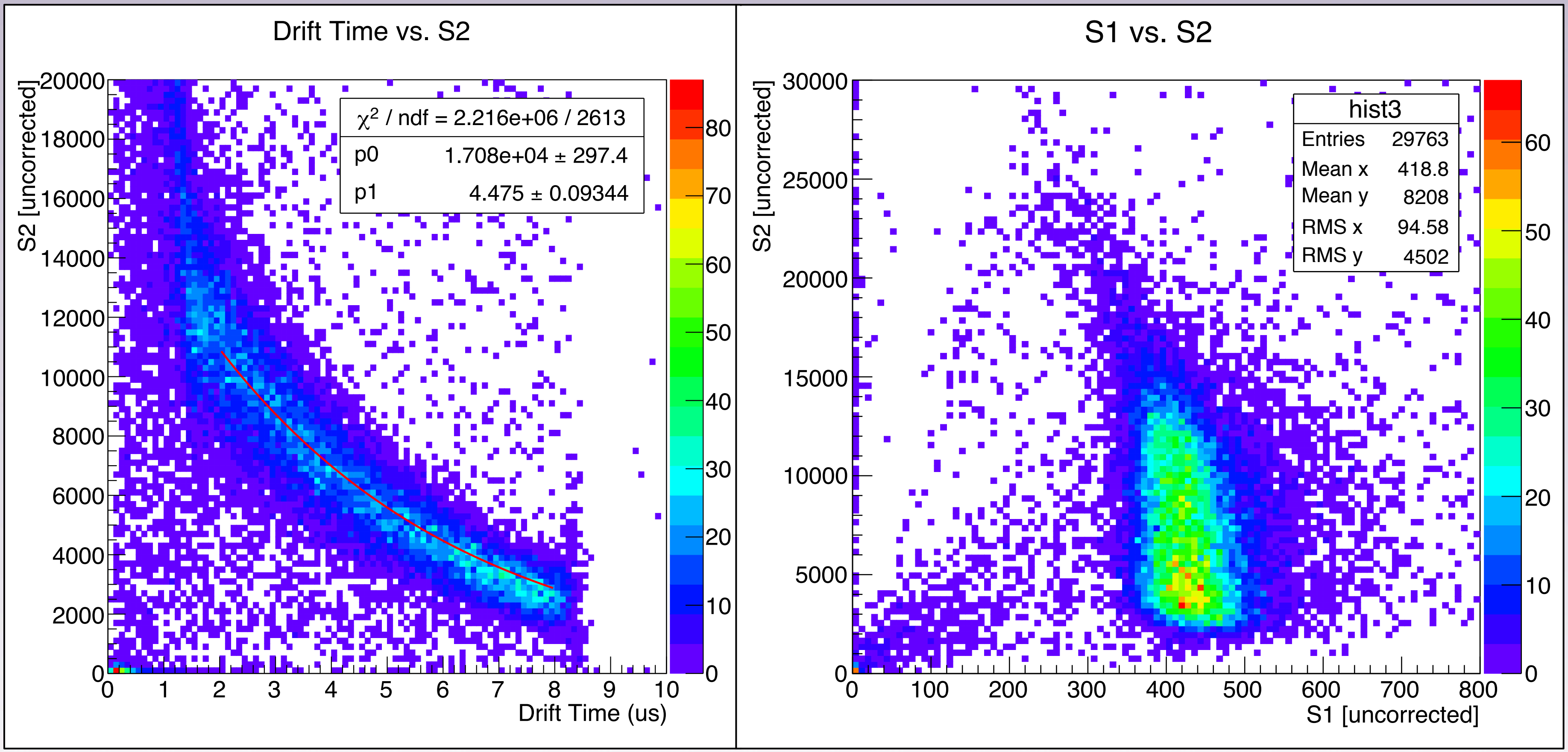
Sample Event

- We use the DAQMAN package (by Ben Loer) for both our DAQ and analysis framework
- Green boxes represent the ‘found’ pulses
- Blue line is the cumulative integral



Detector Calibration

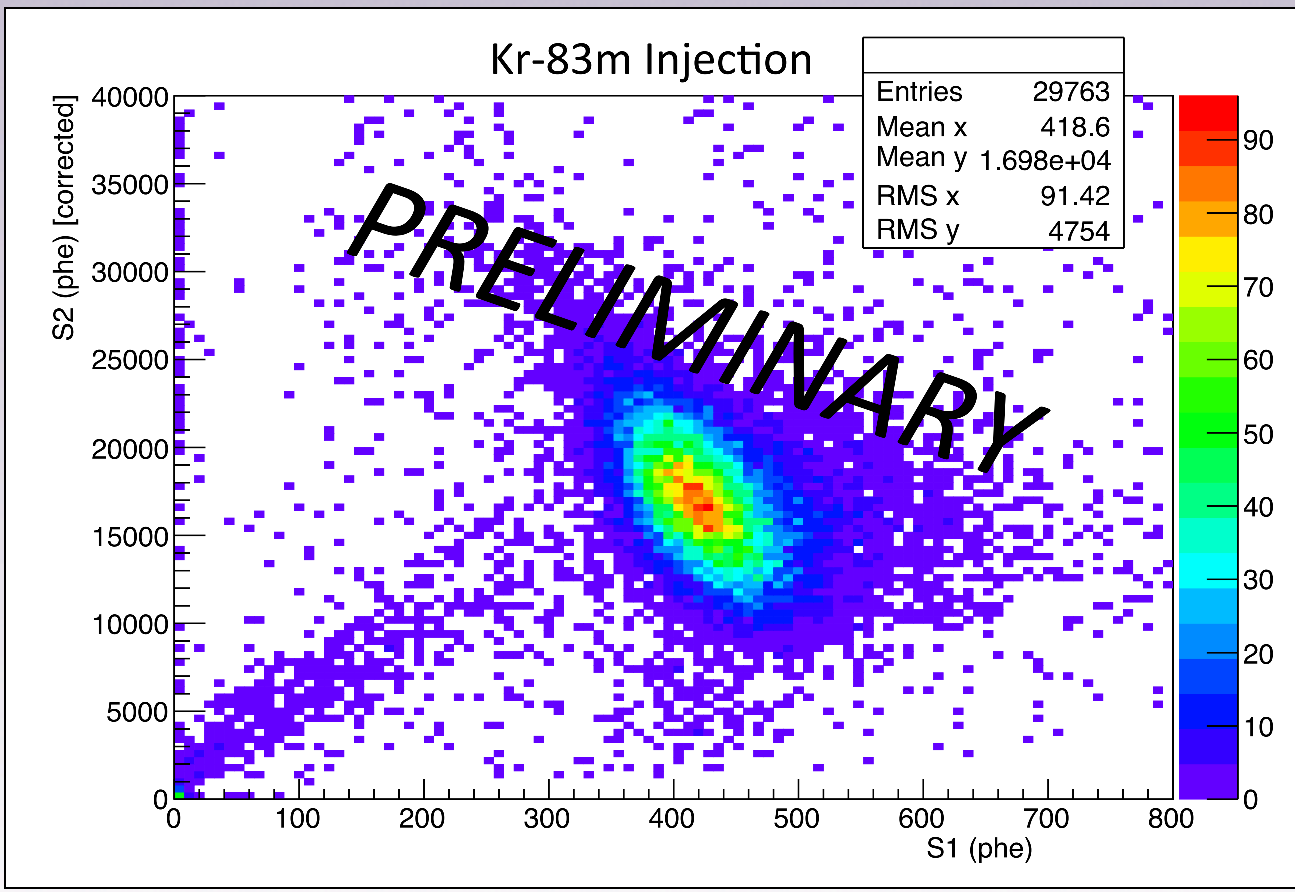
- Use Kr-83m mono-energetic decay for energy calibration



- Initial data has electron lifetime of 4.48 microseconds

Energy Calibration

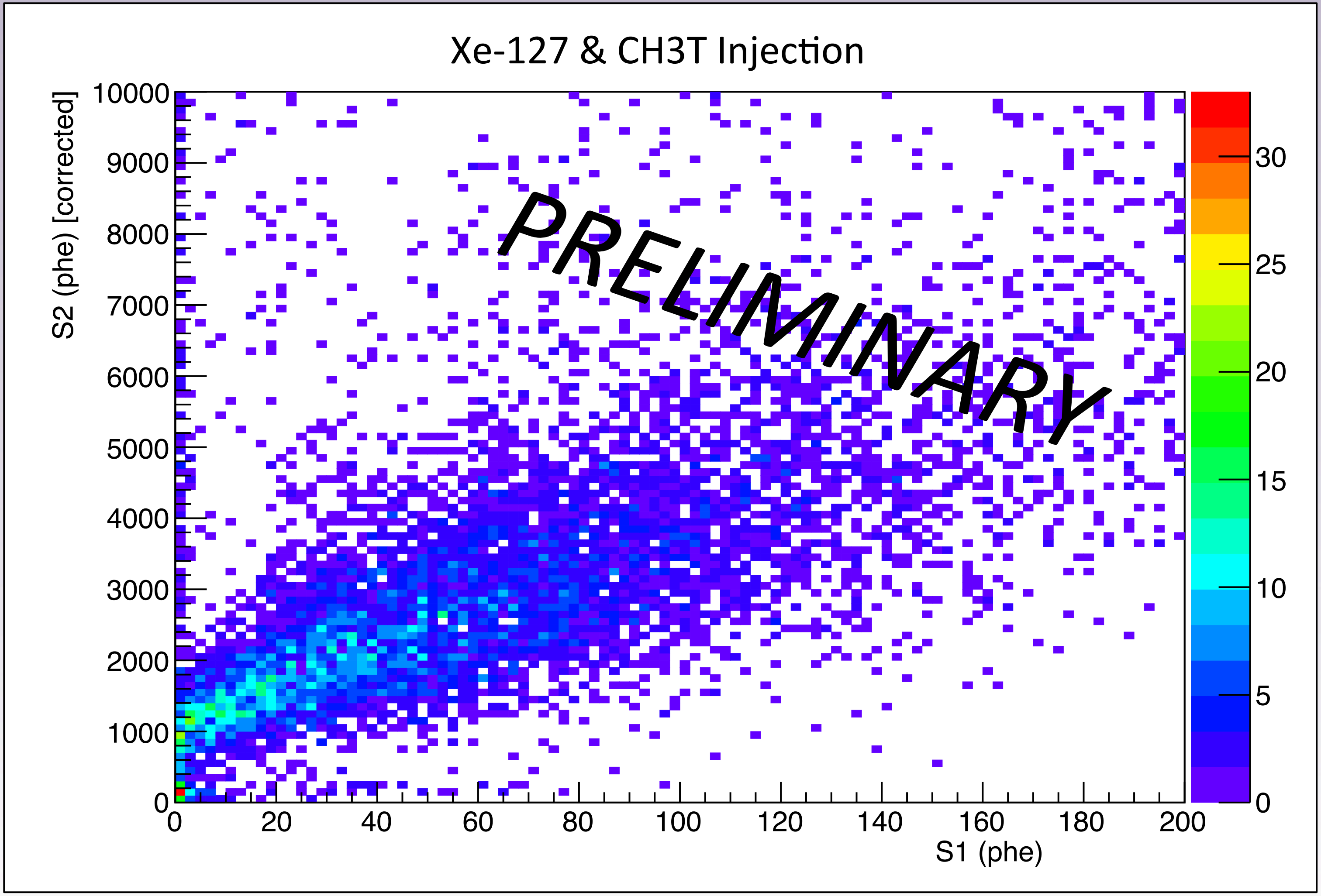
- We can correct S2 for this lifetime to zero drift time



- 41.6 keV energy decay of Kr-83m shows up as a peak
- Use this to calibrate our detection efficiency
  - g2 ~ 20
  - g1 ~ 0.2

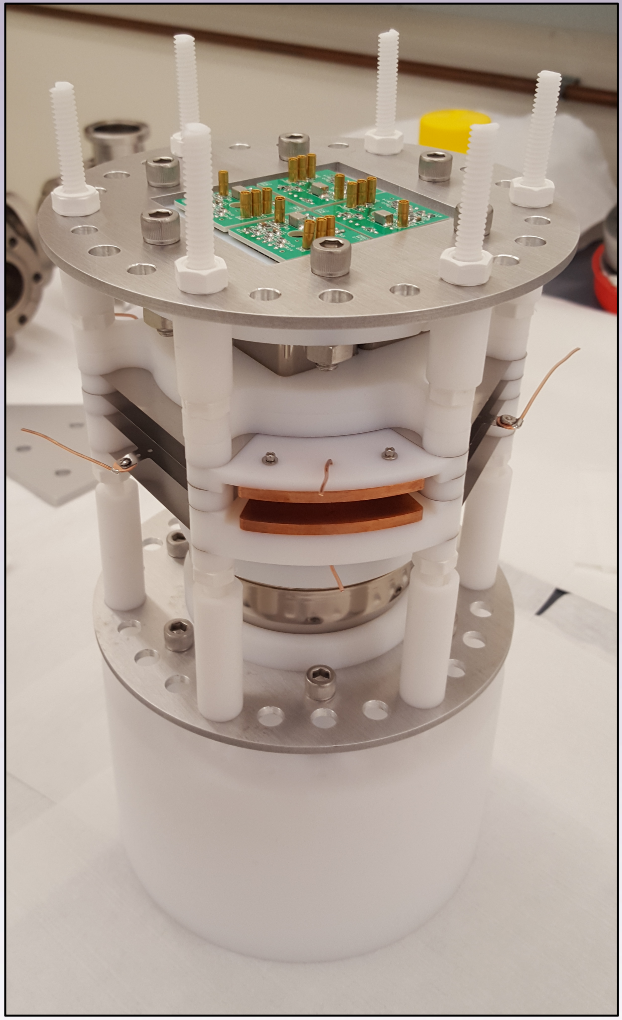
Calculation based on Manalaysay et al. (2010) [arXiv:0908.0616]

Initial Measurements



Conclusion

- Differences between the energy deposition of ionization tracks and (L-shell) binding energy release have calibrated to the 4% level
- Second order differences due to Auger cascades could result in small deviations (order 1%) from the S2/S1 profile of beta decay
- XELDA is going to look at a simultaneous (systematic-free) comparison of tritium (and Rn-220) to Xe-127 EC decay



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
- Luca Grandi for Kr-83m calibration source
- Carter Hall for tritium calibration source
- PICO and LZ collaborations for continued support