Background Suppression in the MAJORANA Demonstrator

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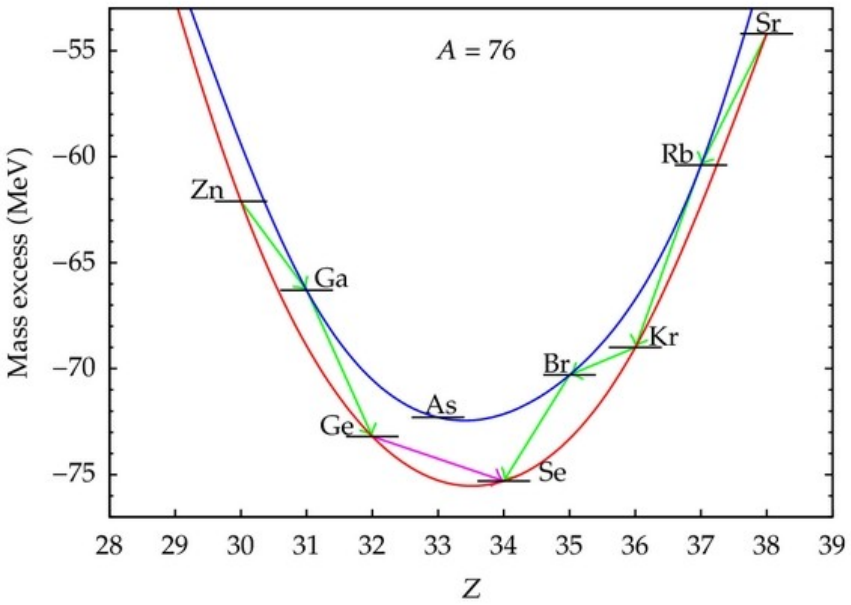
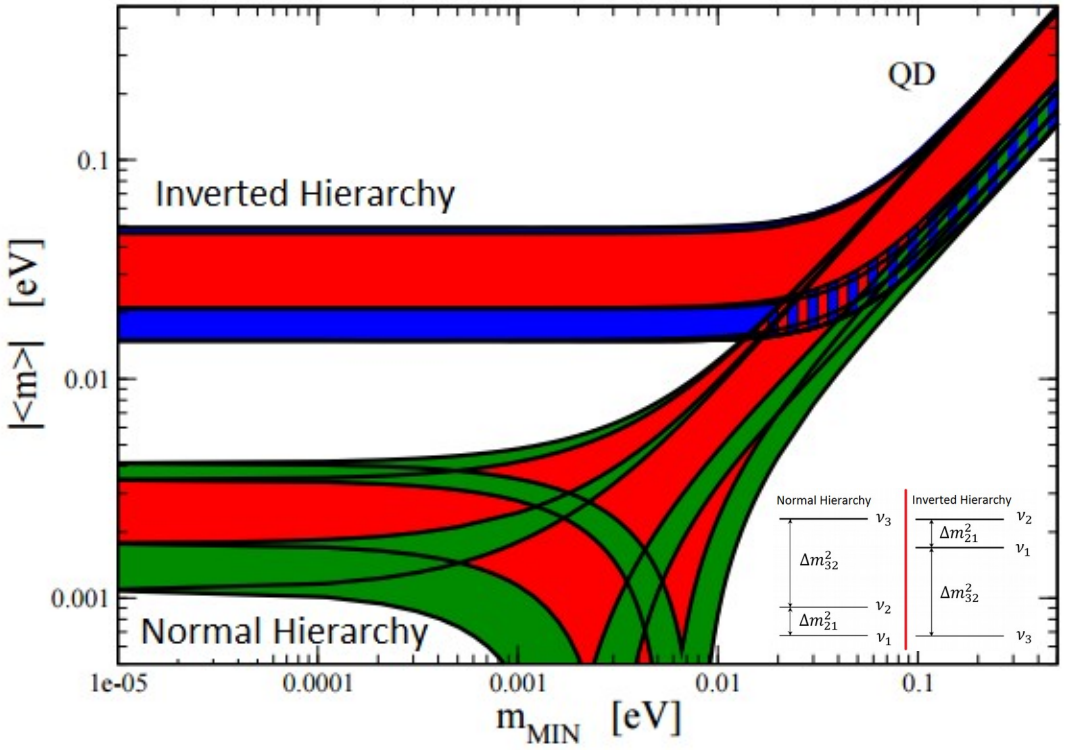
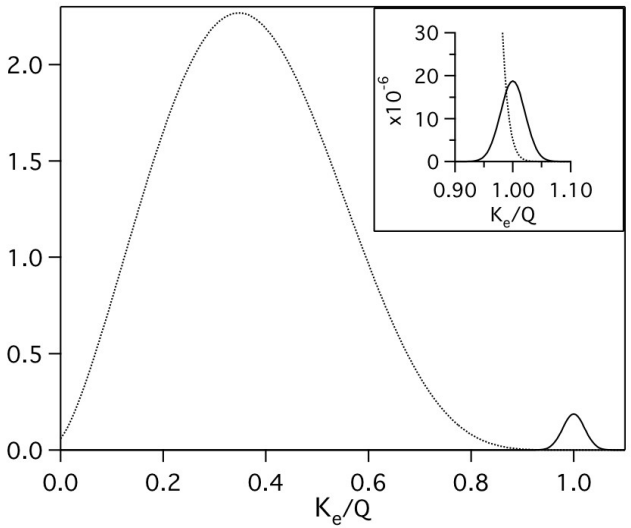
Physics 290E

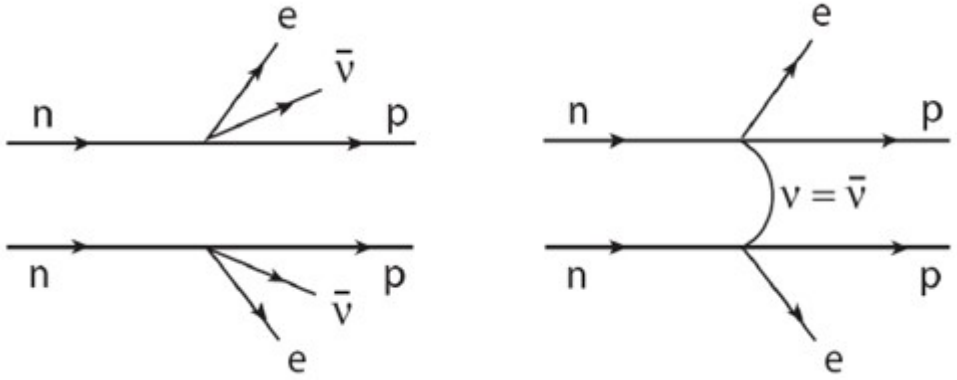
April 11, 2018

0νββ in 4,000 words



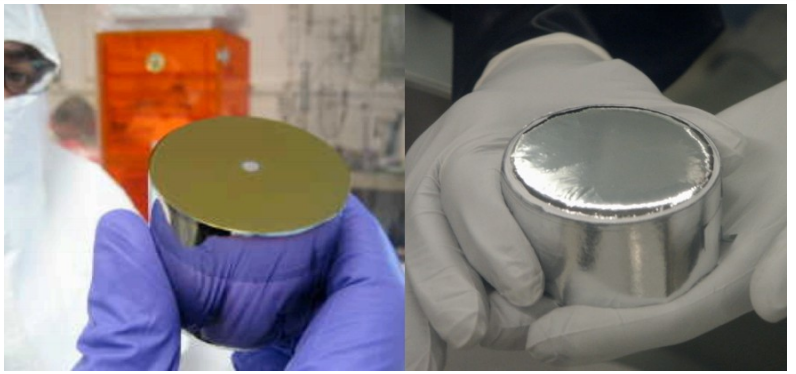


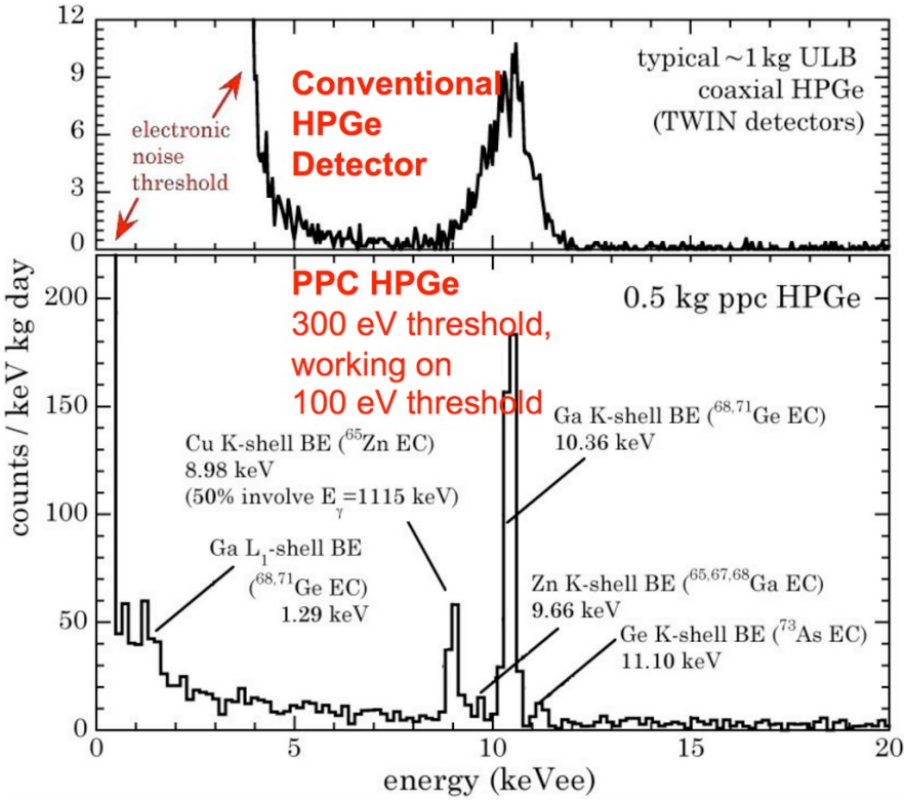




Why germanium?

- The detector *is* the sample!
  - ^{76}Ge undergoes ββ, nat. abundance ~8%
  - "Easily" enriched to >80%
- Can achieve very high purity
  - Intrinisically low bkg
- Incredible energy resolution
  - Few keV possible!
- Fast sampling → PSD
  - Filter multi-site events (Compton), alphas, electronic noise…

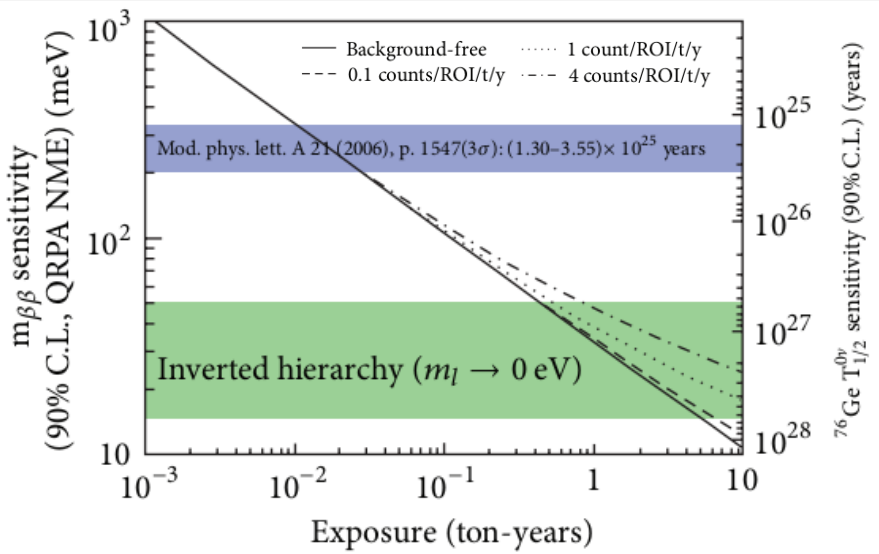


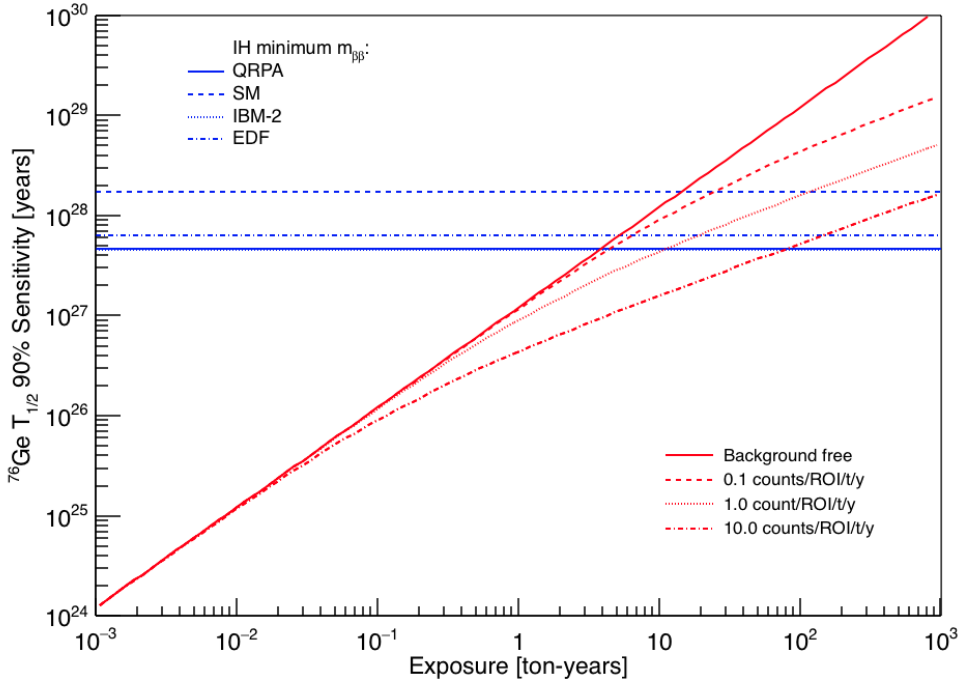


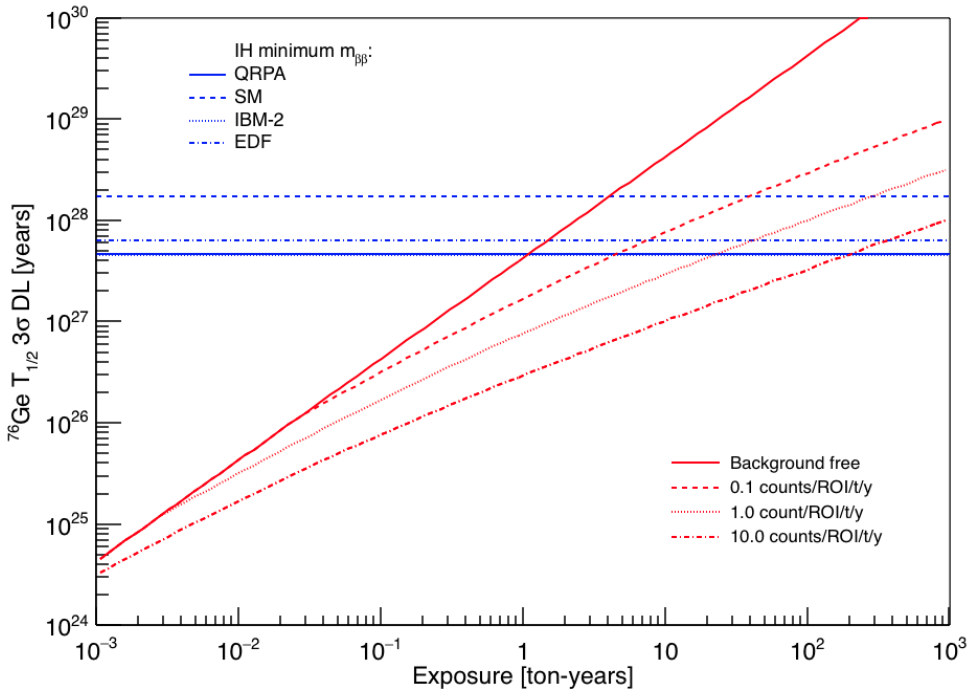
Sensitivity

To exclude Majorana+IH, need:

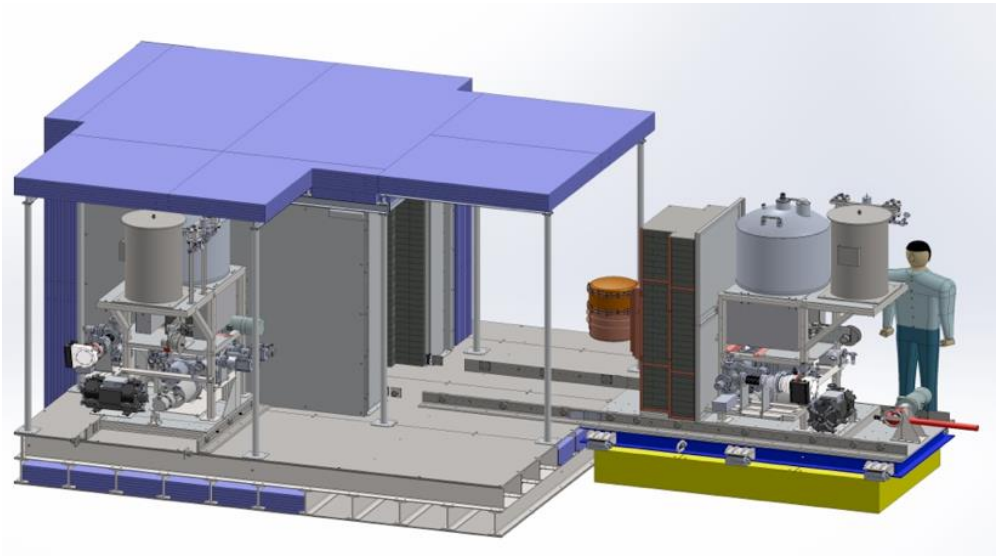
- Lots of **material** (ton-scale)
- Plenty of **time** (few years)
- **Clean signal**
  - Low background / high resolution







MAJORANA Demonstrator

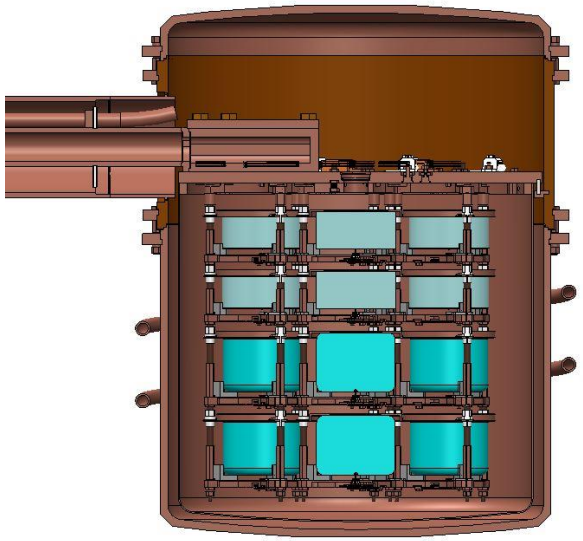


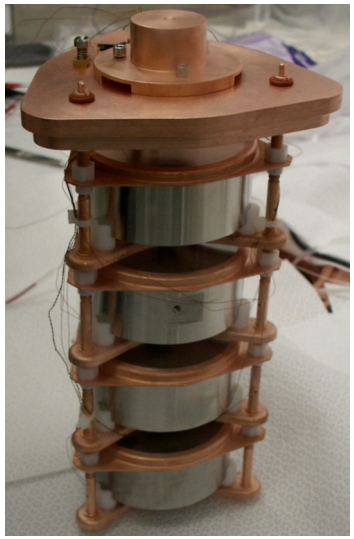
4,850’ underground @ SURF

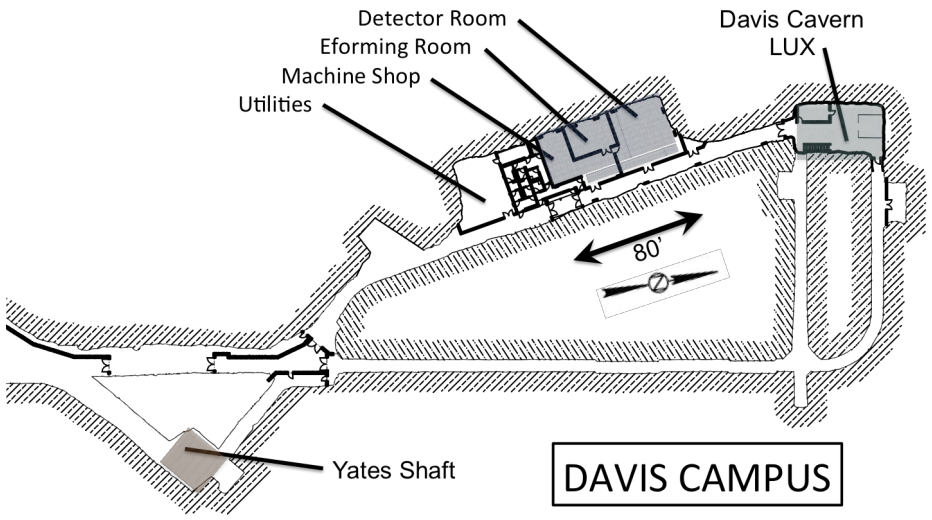
~30 kg of ^{76}Ge

Goal: Show low background

- Justify ton-scale experiment







Grandma's secret recipe

For oven-fresh low-background samples:

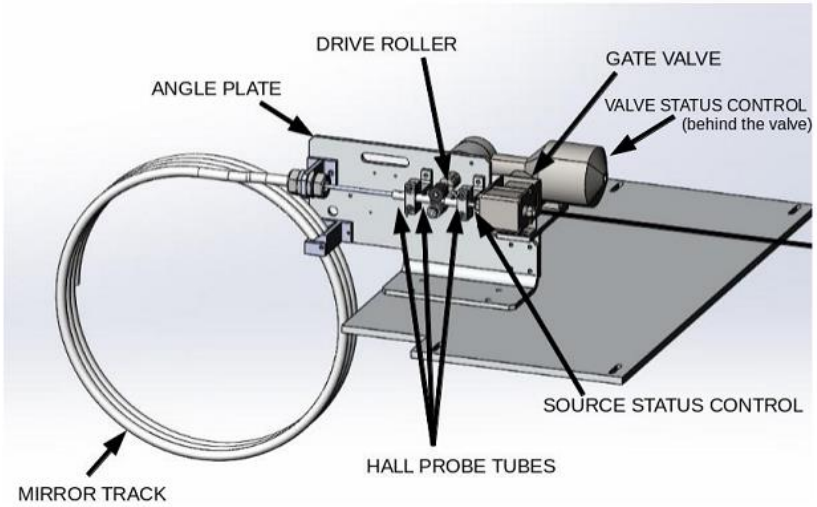
- **Calibrate** the hell out of your detector
  - High resolution, good linearity
- Use pure-as-hell **materials**
- **Shield** the hell out of your detector
- **Ground** the hell out of your electronics
- **Reject** the hell out of bad data
- **Process** the hell out of your waveforms
  - PSD → Background rejection

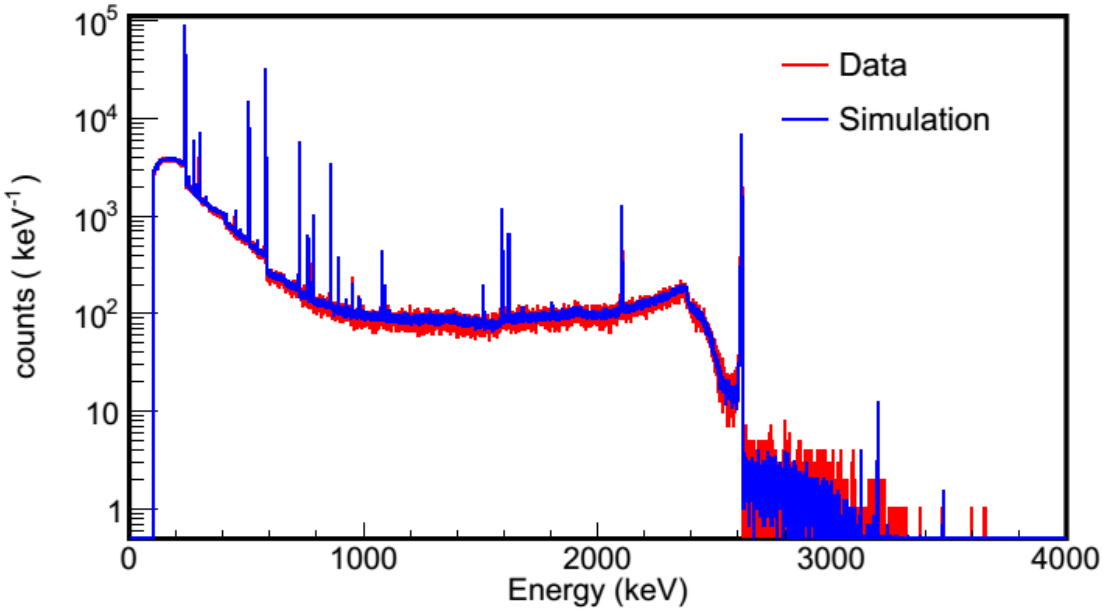
Calibration

Regularly study detector response using ^{228}Th source scans:

- Correct for time-dependence of energy scale
- Correct for position-dependent response (charge capture)
- Determine dead regions

Result: Fantastic resolution & stability





Purity

Use extremely pure, oxygen-free, electro-formed copper for:

- Support structures, cryostat, inner shielding

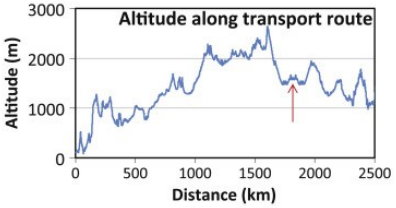
As much as possible, fabricate and assemble underground, in a glovebox

Comprehensive inventory database, parts tracking, surface radiation exposure records

Maintain detector in radon-purged environment

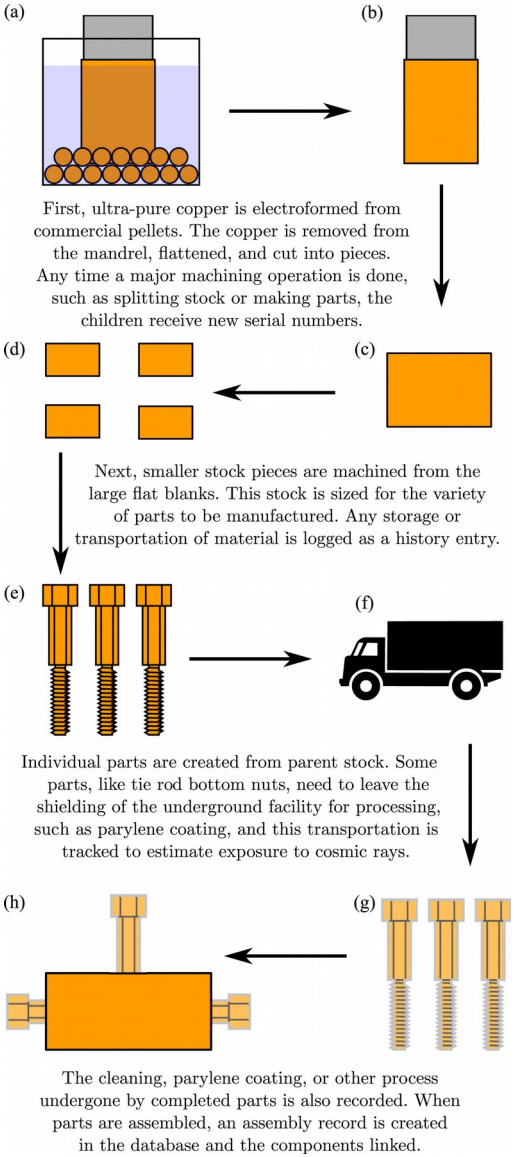
FedEx Tracking data (reverse chronological order)

Date, Time	Activity	Location
Jun 13, 12:06	Delivered	Lead, SD
Jun 13, 10:37	Out for delivery	Rapid City, SD
Jun 13, 8:50	At local facility	Rapid City, SD
Jun 13, 5:00	At local facility	Rapid City, SD
Jun 12, 21:10	In transit	Denver, CO
Jun 11, 8:32	In transit	Boise, ID
Jun 9, 2:50	In transit	Hermiston, OR
Jun 8, 20:45	Left FedEx origin	Pasco, WA
Jun 8, 14:23	Picked up	Richland, WA



Parts Tracking Database records information (chronological order)

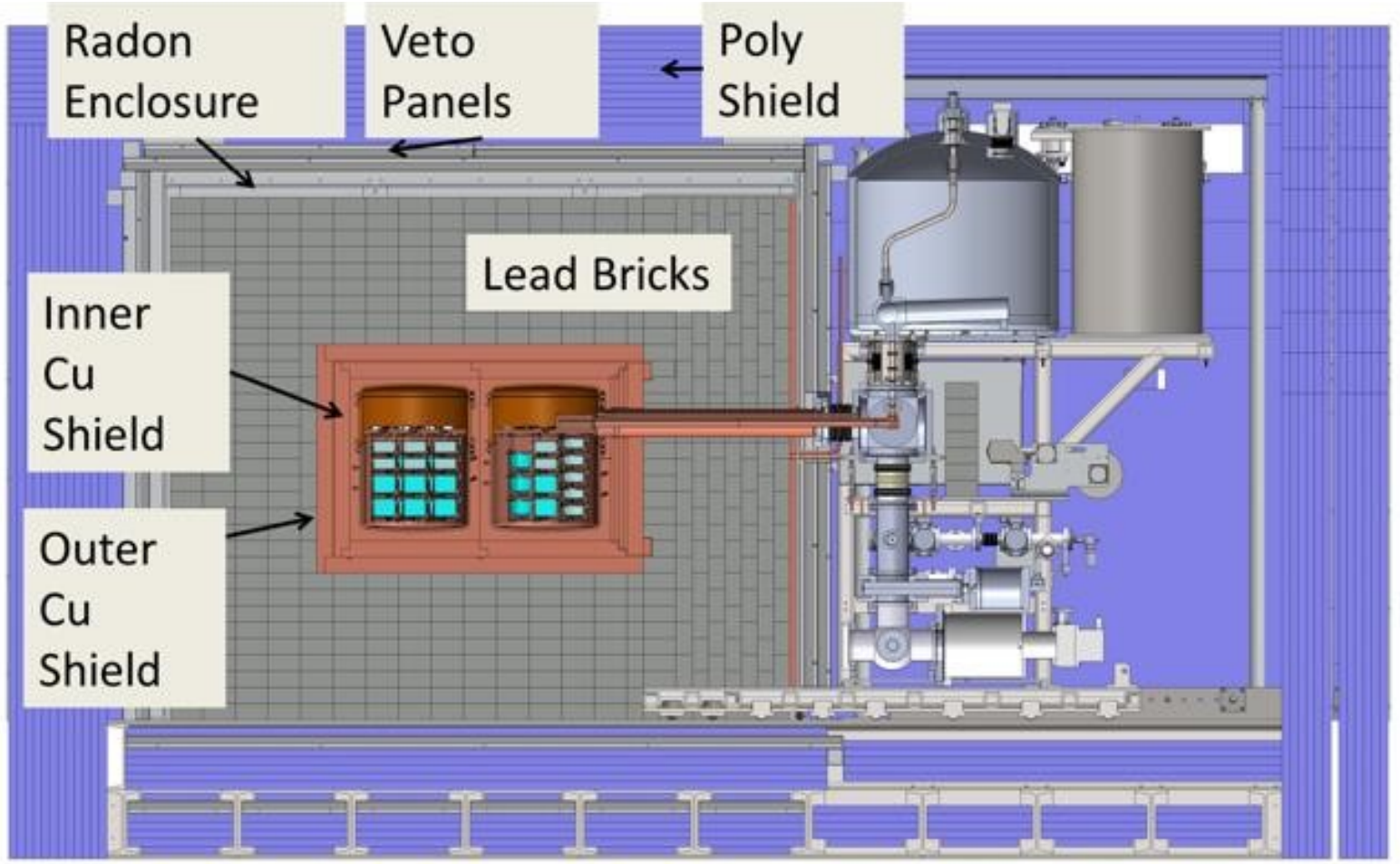
Record Type	Start – End (Date, Time) – (Date, Time)	Movement or Location (City, State)	Exposure calculation Sea-level Equivalent Exposure (hours)
Transport	Jun 8, 14:23 PDT – Jun 8, 14:43 PDT	Richland, WA → Pasco, WA	0.4
Storage	Jun 8, 14:43 PDT – Jun 8, 20:45 PDT	Pasco, WA	4.6
Transport	Jun 8, 20:45 PDT – Jun 8, 21:30 PDT	Pasco, WA → Hermiston, OR	0.9
Storage	Jun 8, 21:30 PDT – Jun 9, 2:50 PDT	Hermiston, OR	6.2
Transport	Jun 9, 2:50 PDT – Jun 9, 8:03 MDT	Hermiston, OR → Boise, ID	11.2
Storage	Jun 9, 8:03 MDT – Jun 11, 8:32 MDT	Boise, ID	114.9
Transport	Jun 11, 8:32 MDT – Jun 11, 20:42 MDT	Boise, ID → Denver, CO	95.2
Storage	Jun 11, 20:42 MDT – Jun 12, 21:10 MDT	Denver, CO	133.5
Transport	Jun 12, 21:10 MDT – Jun 13, 3:12 MDT	Denver, CO → Rapid City, SD	29.8
Storage	Jun 13, 3:12 MDT – Jun 13, 10:37 MDT	Rapid City, SD	21.1
Transport	Jun 13, 10:37 MDT – Jun 13, 11:34 MDT	Rapid City, SD → Lead, SD	2.9
Storage	Jun 13, 11:34 MDT – Jun 13, 12:06 MDT	Lead, SD	2.7

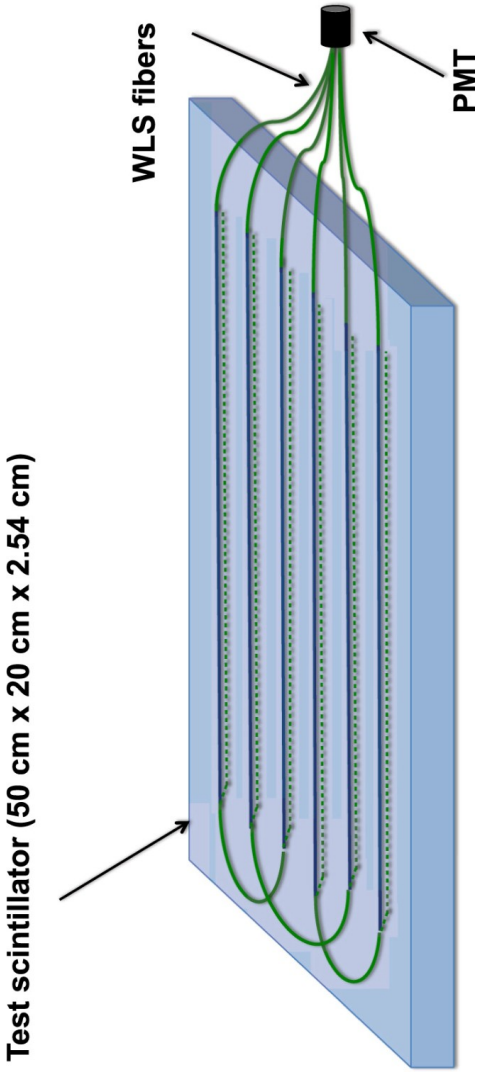


Shielding

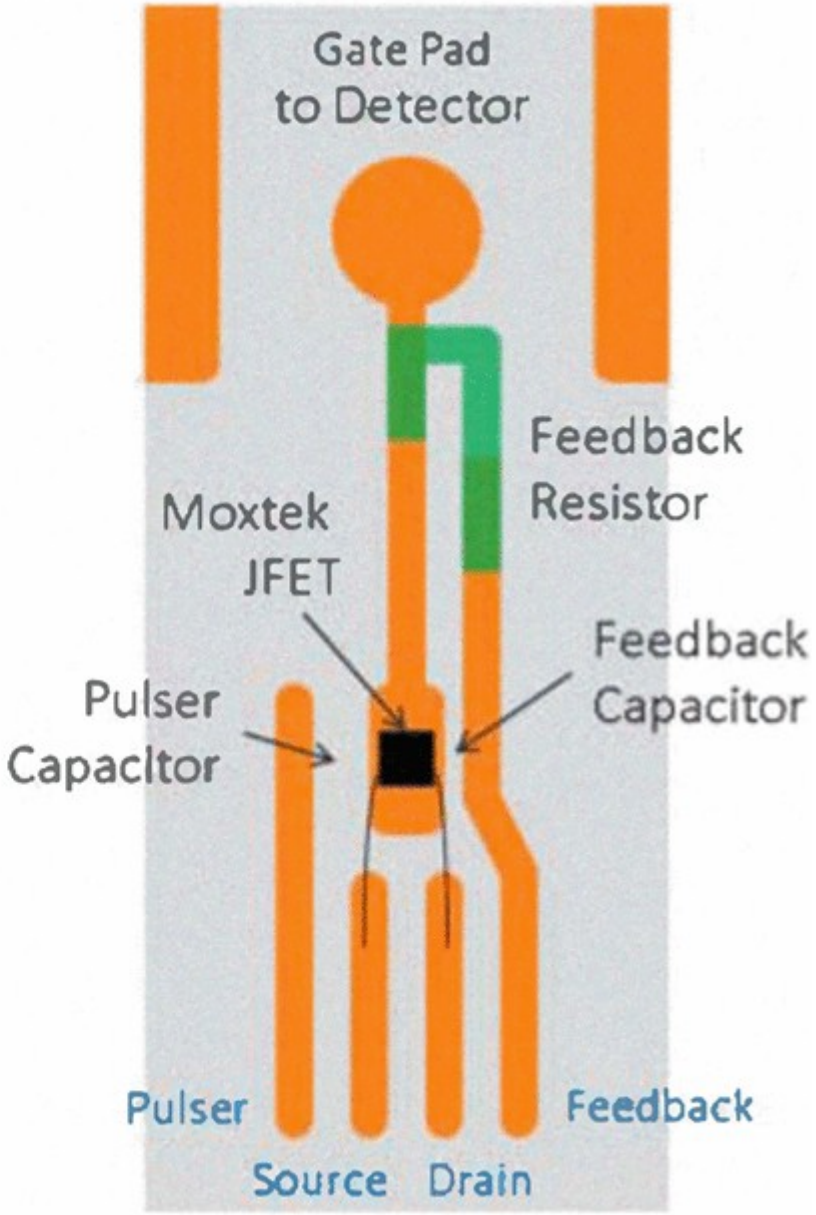
Don’t forget the most important shield of all:

4,850’ of solid rock!



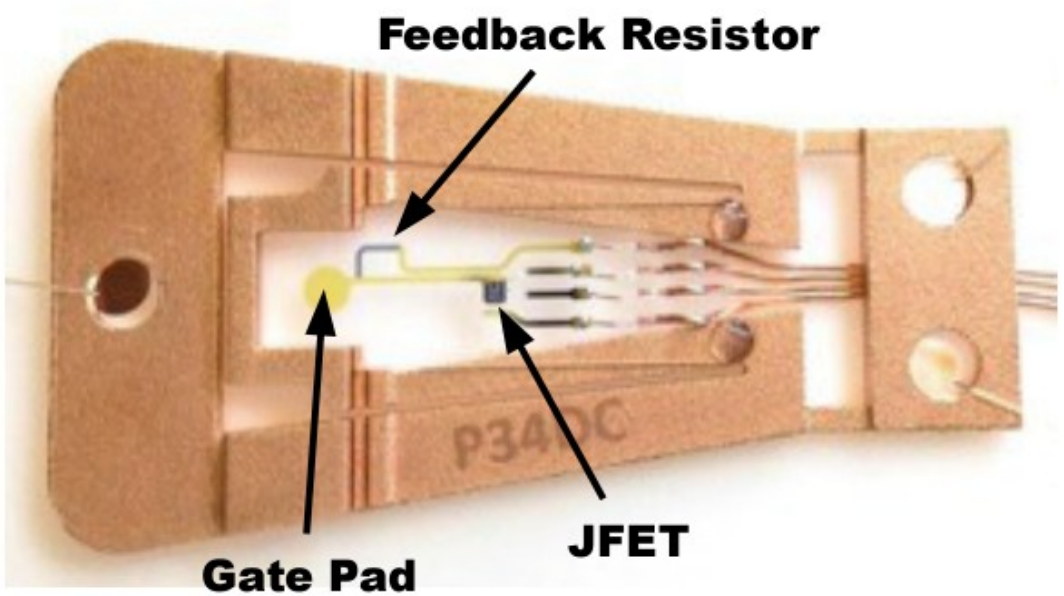


Grounding

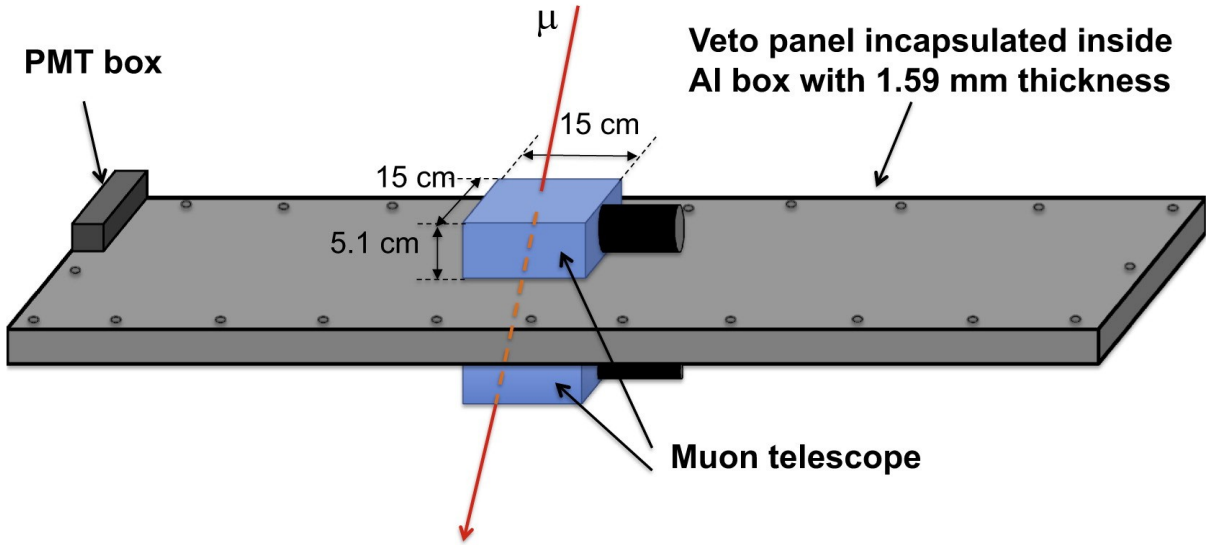


Keeping it quiet:

- Custom, low-noise readout electronics
- Robust grounding scheme to isolate electronics from environment



Livetime rejection



Reject periods of noise/instability (microphonics)

- LN_2 filling, construction, etc.

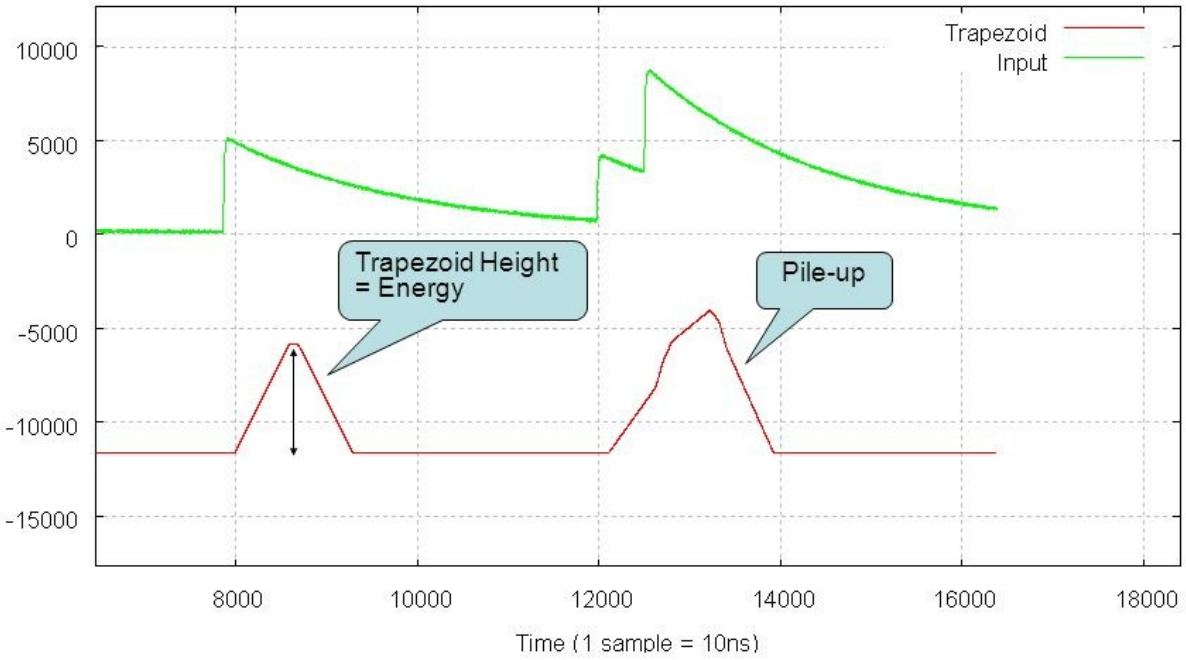
Reject events where multiple detectors trigger within 4 μs

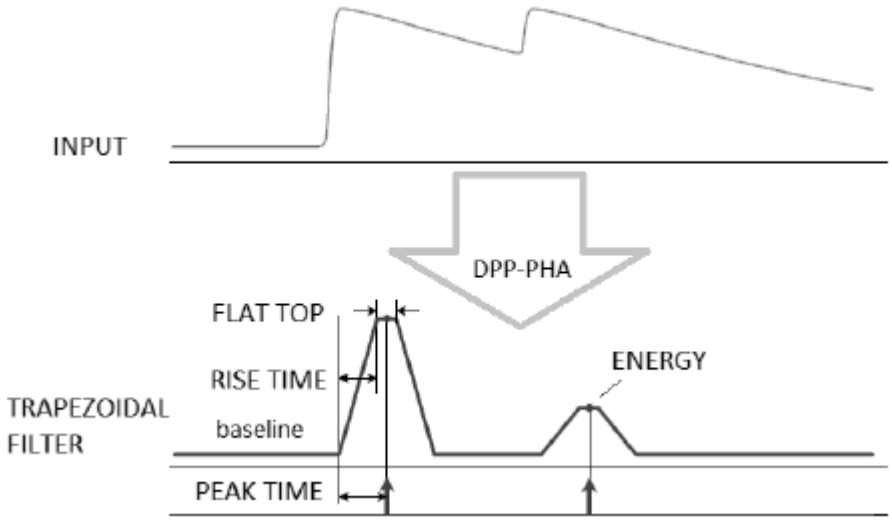
- ββ decays are localized!

Reject 1s after muon

- Give cosmogenics a chance to decay

Waveform processing





First, filter out noise-induced nonphysical waveforms

- 99.9% efficiency for true physics events

Use **trapezoidal filter** to go from "decaying step functions" to Gaussian-like pulses

- Amplitude ∝ energy

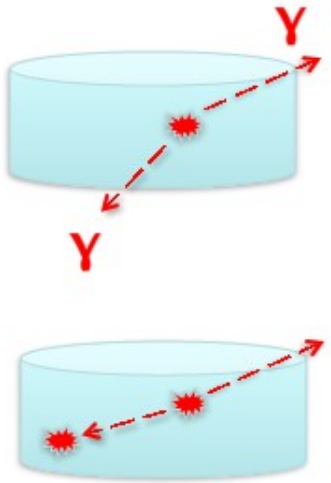
Further background removal using **pulse shape discrimination…**

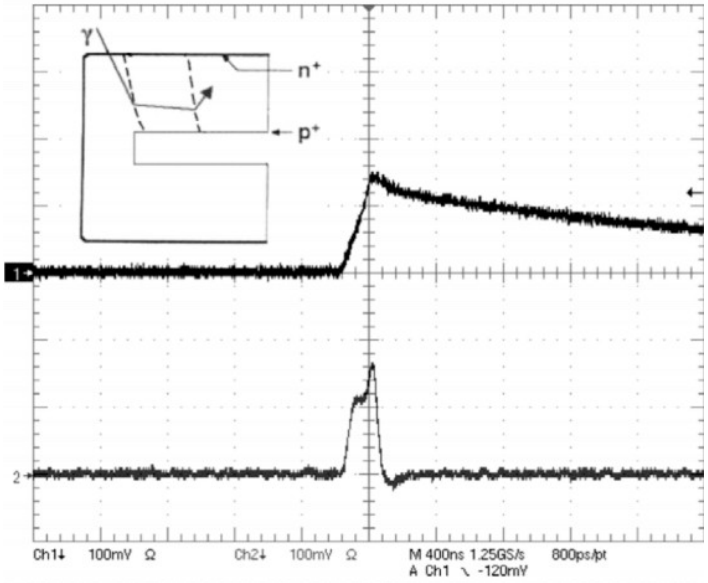
PSD: Single-site events

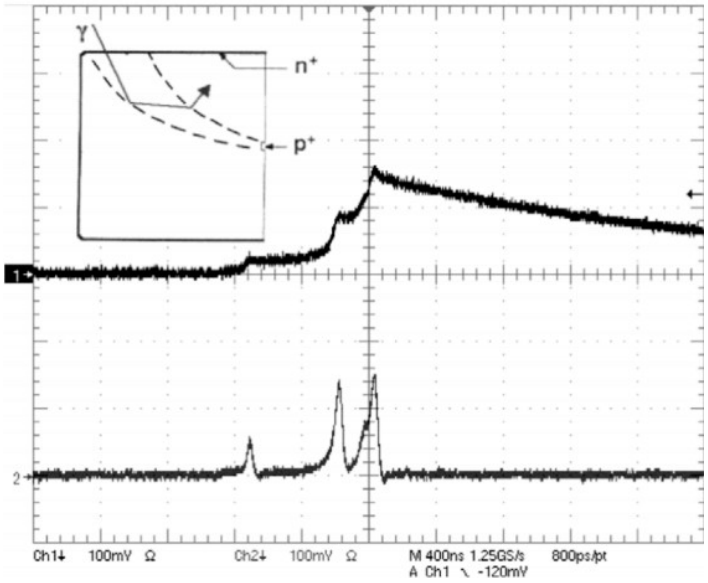
Already reject multi-detector events

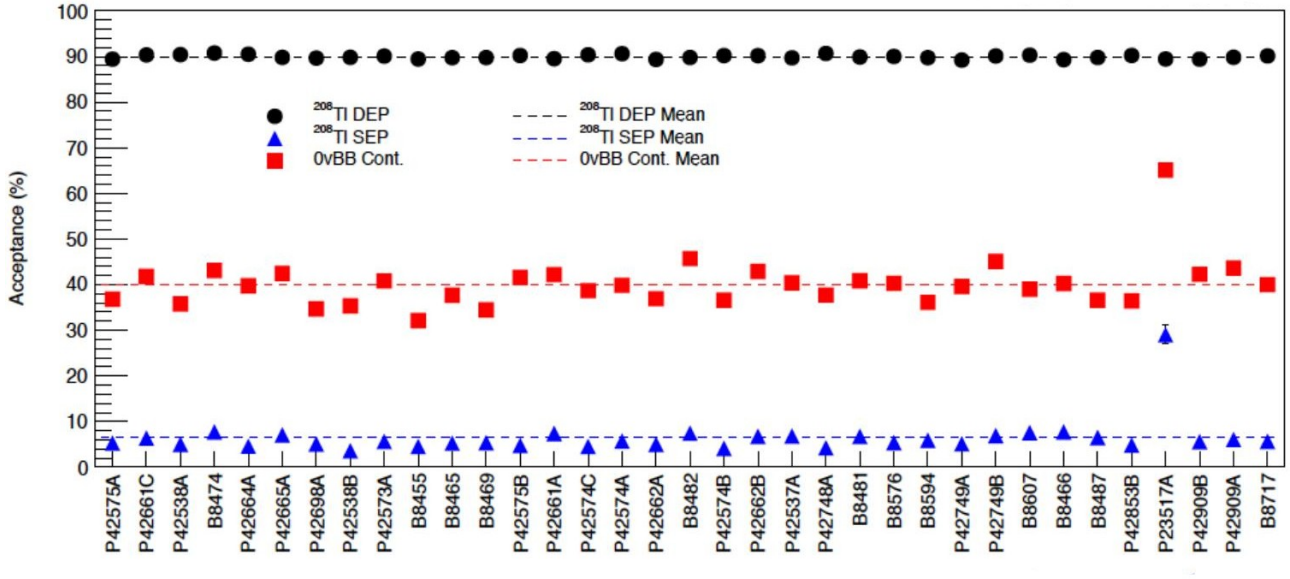
- What about single-detector, multiple-site (e.g. Compton)?

Use time structure of pulses to discriminate!









PSD: Removing surface α's

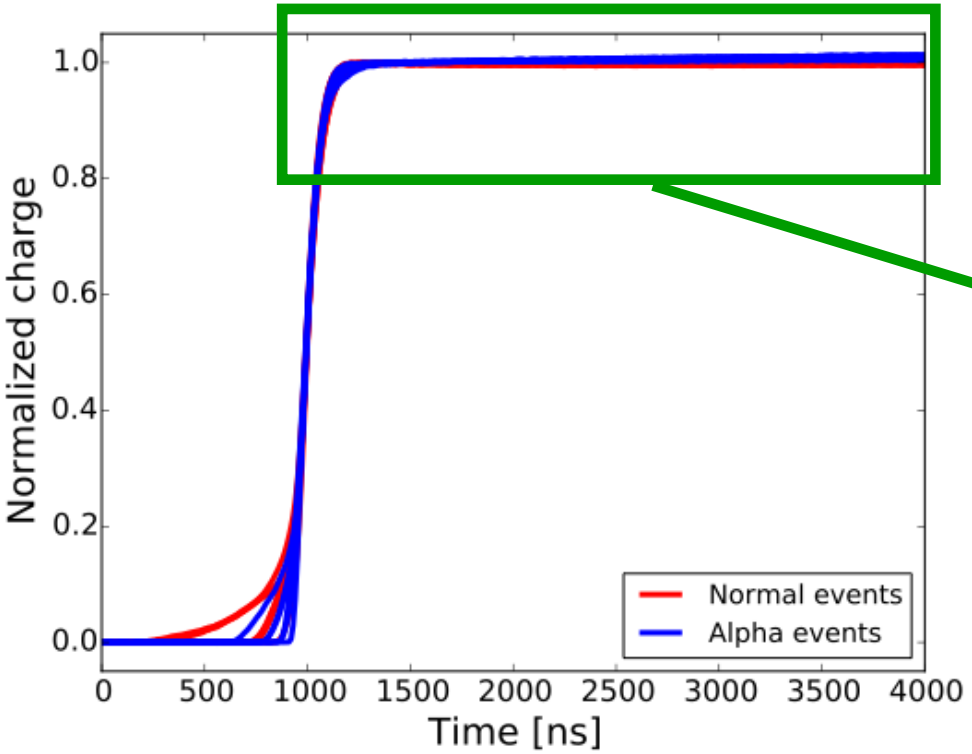
"Dead" layer near surface:

- Charge trapping for α events → Energy degradation → Filth and grime in 0νββ window
- "Delayed charge recovery" very apparent in waveform!

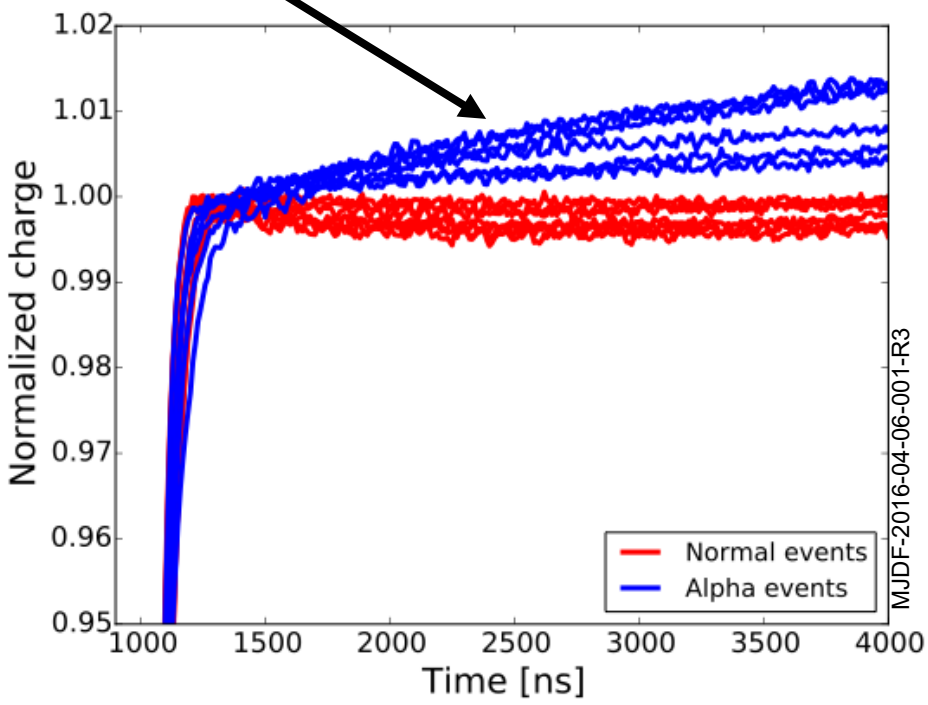
PSD cut based on tail slope:

- ~100% α rejection
- 99% efficiency for bulk events

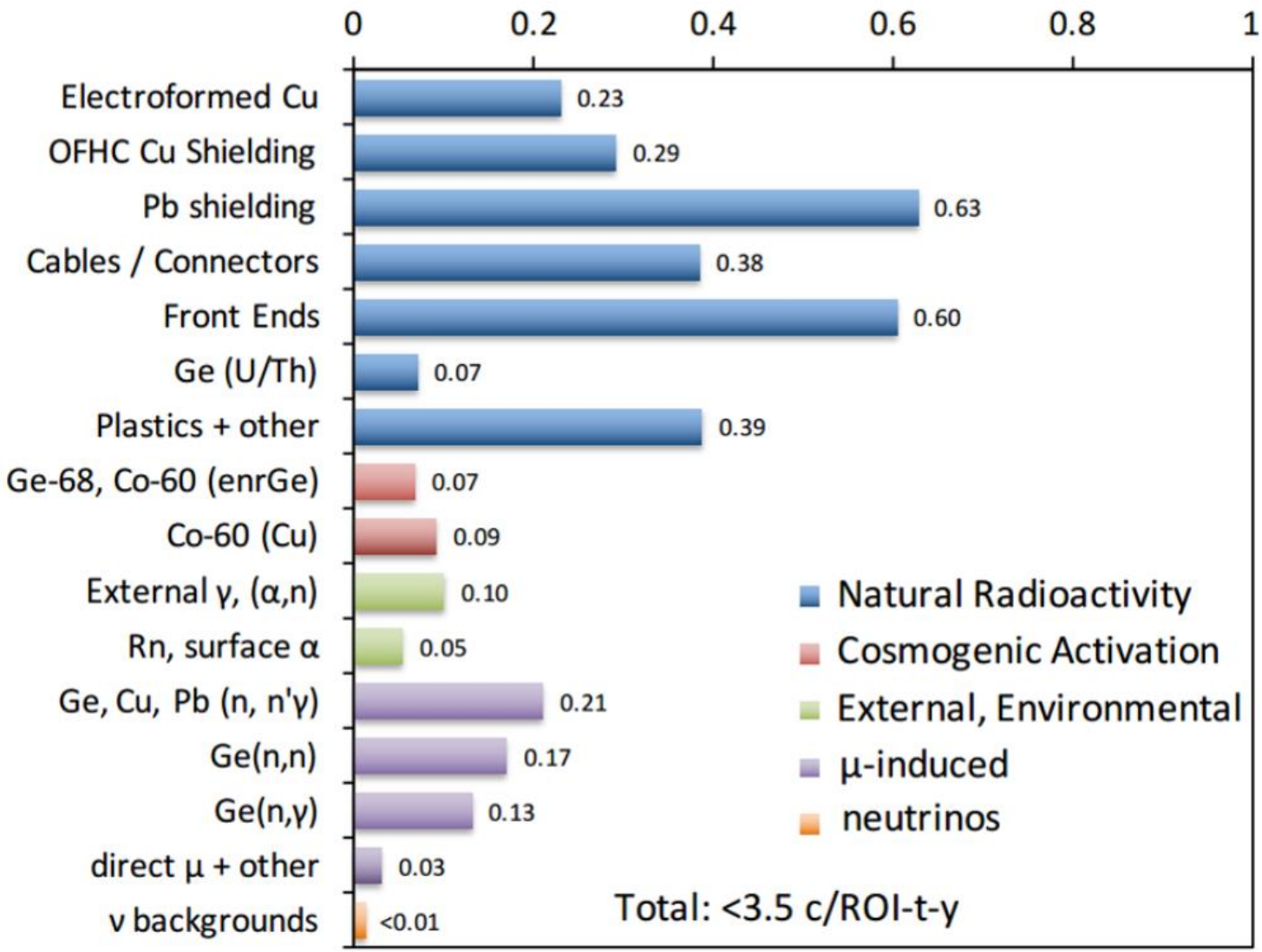
Example pole-zero corrected waveforms



Slow drift of charges along passivated surface results in very slow signal component



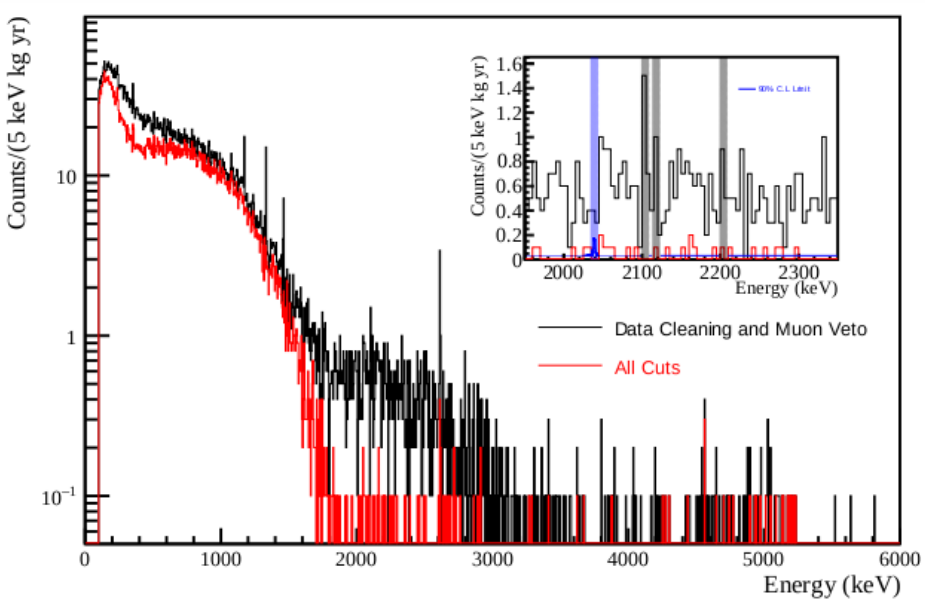
Background budget

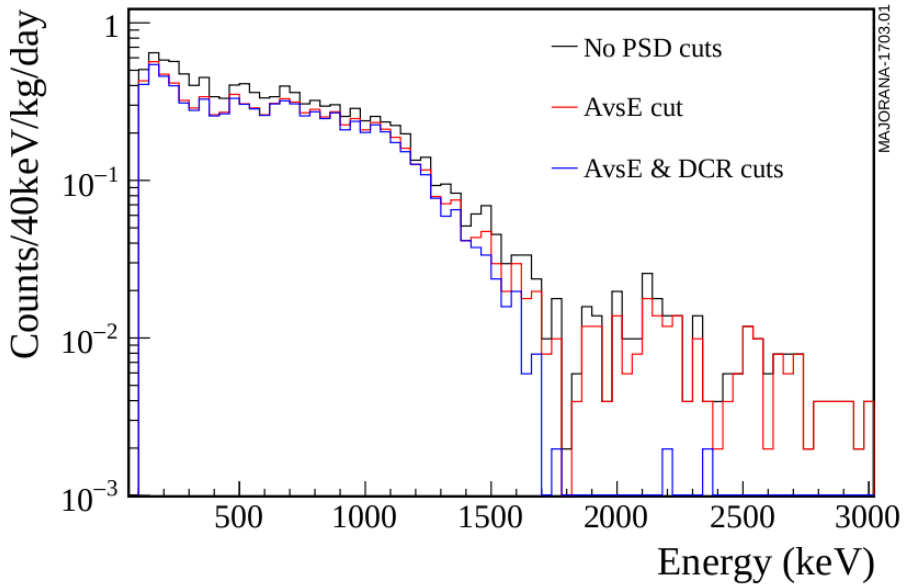


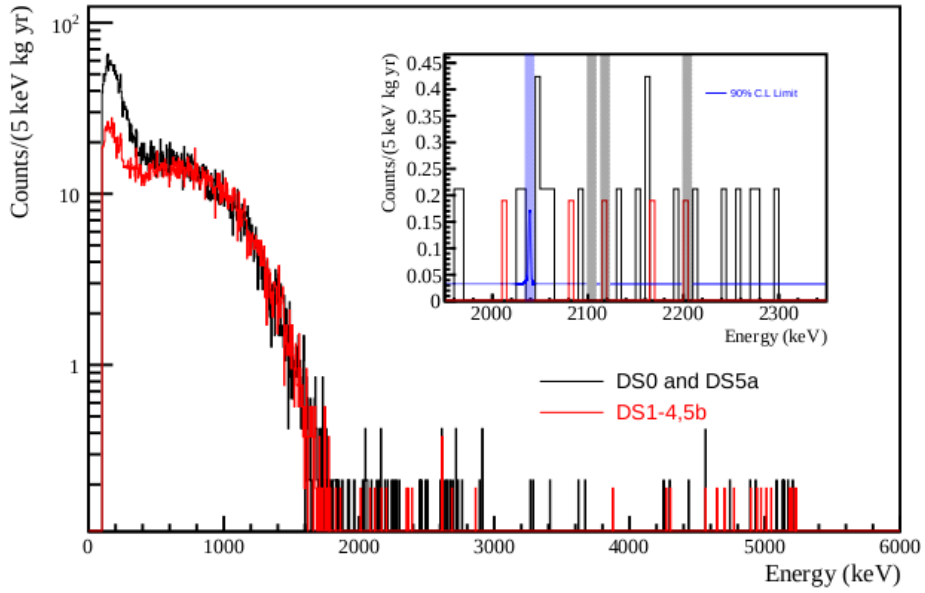
Measured result: $4.0^{+3.1}_{-2.5}$ c/FWHM·t·yr!

Great Job!

Results!







9.95 kg yr

$T^{0\nu}_{1/2} > 1.6 \times 10^{25}$ yr

$m_{\beta\beta} < 240\text{-}520$ meV

Data set	Window counts	BI $\times 10^{-3}$	ROI (keV)	ROI BG (counts)
DS0	11	$24.3^{+8.4}_{-7.0}$	3.93	0.120
DS1	3	$04.6^{+3.5}_{-2.9}$	4.21	0.035
DS2	0	< 12.3	4.34	0.000
DS3	0	< 3.6	4.39	0.000
DS4	0	< 12.7	4.25	0.000
DS5a	10	$08.0^{+3.1}_{-2.6}$	4.49	0.125
DS5b	0	< 1.9	4.33	0.000
Total	24	$06.7^{+1.4}_{-1.4}$	4.32	0.288
DS1-4,5b	3	$01.6^{+1.2}_{-1.0}$		0.036

Conclusion

- MAJORANA has achieved their background goals while demonstrating the best energy resolution of any existing 0νββ experiment
- Background level of $4.0^{+3.1}_{-2.5}$ c/FWHM·t·yr is consistent with the $2.9^{+1.8}_{-1.2}$ achieved by GERDA, MAJORANA's "rival" in the ^{76}Ge arena
- Now that feasibility has been proven, MAJORANA and GERDA have joined forces to build the LEGEND ton-scale experiment!

Thanks!

Care to learn more?

- Recent results: 10.1103/PhysRevLett.120.132502 (arXiv: 1710.11608)
- Andrew Lopez @ DPF ‘17
- Steve Elliot @ Neutrino ‘16
- Vic Gehman, UVA seminar