Status and Results of MAJORANA DEMONSTRATOR Experiment

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On behalf of the MAJORANA Collaboration

The MAJORANA DEMONSTRATOR

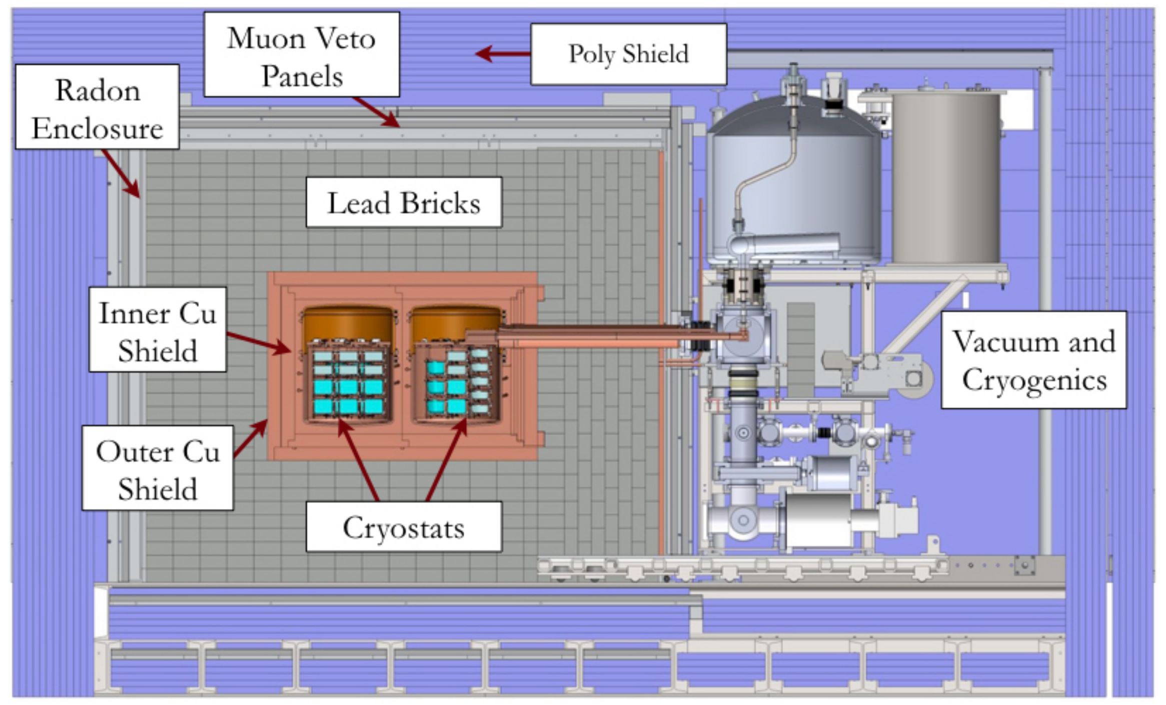
WHY USE GERMANIUM FOR MEASURING $0\nu\beta\beta$?

- Maximize source to total mass ratio
- Well-understood technologies
- Excellent energy resolution
- Demonstrated ability to enrich in ^{76}Ge from 7% to 88%
- Favorable nuclear matrix element
- Powerful background rejection

WHAT ARE THE GOALS?

- Demonstrating background low enough to justify building a tonne-scale experiment
- Establishing the feasibility of constructing & fielding modular arrays of Ge detectors
- Producing a currently competitive measurement of $0\nu\beta\beta$ in ^{76}Ge
- Searching for additional physics beyond the Standard Model

Operating at the 4850' level of the Sanford Underground Research Facility (SURF)



Scheme of the MAJORANA DEMONSTRATOR, N. Abgrall et al. Adv. High Energy Physics 2014

HOW DOES THE DEMONSTRATOR PERFORM THE MEASUREMENTS?

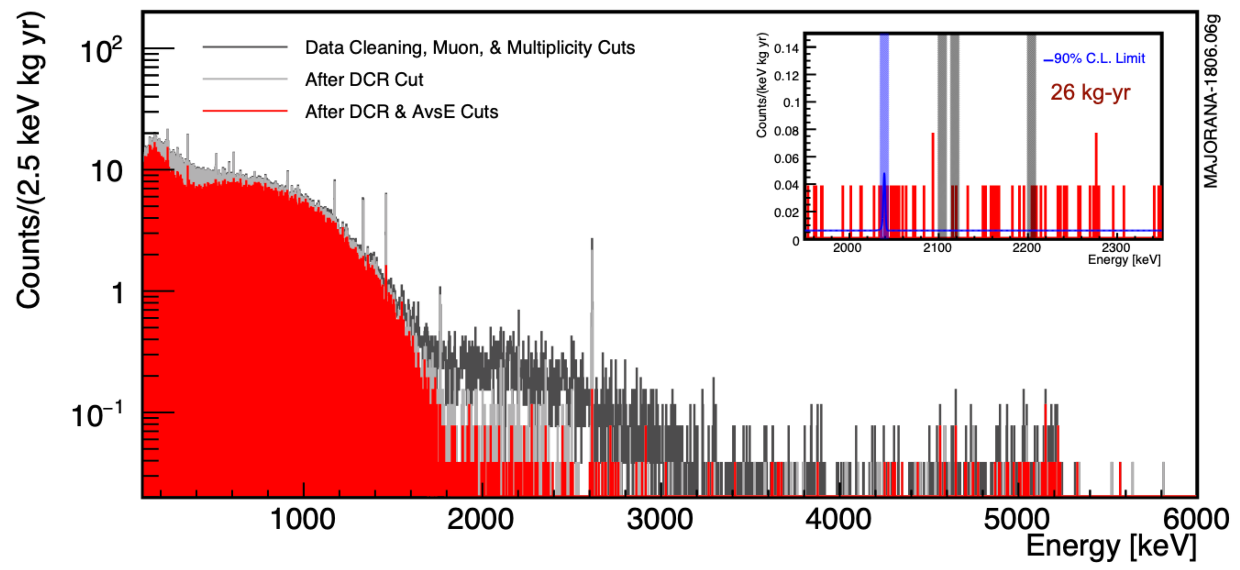
✓ 44.1 Kg of Ge detectors
- ➢ 29.7 kg enriched to 88% on ^{76}Ge
- ➢ 14.4 kg of natural Ge
- ➢ p-type Point Contact (PPC) geometry

✓ 2 independent cryostats
- ➢ Naturally scalable
- ➢ Ultra-clean (electroformed Cu)

✓ 2 Compact shield + muon veto
- ➢ Low-background passivated Cu and Pb shield

2019 analysis (Phys. Rev. C **100**, 025501 (2019))

- Data divided into data sets, due to different configurations of the DEMONSTRATOR
- Energy determined at a fixed pickoff after applying a trapezoidal filter to the waveform. Pole-zero and charge trapping corrections are included. The DEMONSTRATOR is calibrated weekly using data from a ^{228}Th source.
- Only data from enriched detectors after data cleaning and muon veto is used to generate the energy spectrum, but data from both enriched and natural detectors is used to remove high multiplicity processes.
- Pulse shape analysis removes multi-site events (AvsE) and alphas from the surface (DCR)
- Limit obtained using an unbinned extended profile likelihood method



Energy spectrum above 100 keV from all 26 kg-y exposure with only data cleaning and muon veto applied (black) and after all cuts (red). The inset shows the same spectra in the background estimation window, with regions excluded due to gamma backgrounds shaded in grey and the 10 keV window centered on $Q_{\beta\beta}$ shaded in blue.

Exposure:

$26\,\text{kg-yr}$

Energy resolution:

$2.5 \pm 0.1\,\text{keV}$

Background index in the lower background configuration:

$11.9 \pm 2.0\,\text{cts}/(\text{FWHM t yr})$

Median sensitivity:

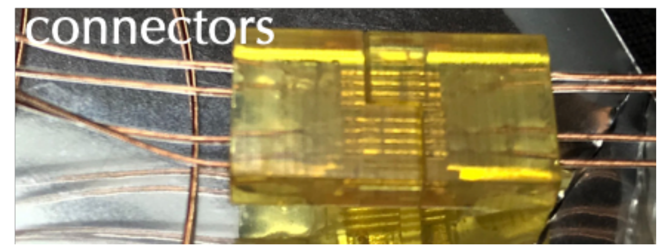
$4.8 \times 10^{25}\text{yr}$

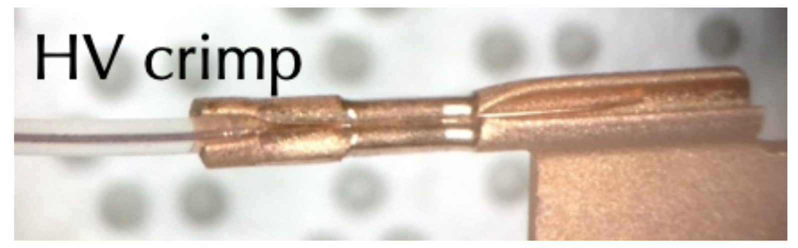
Full Exposure Limit:

$$T_{1/2} > 2.7 \times 10^{25}\ \text{yr}$$

2020 Upgrade

- The 2020 upgrade has improved the robustness of both signal and HV connections with a newly developed ultra-clean, low-mass, and high-reliability design
- 5 PPC detectors removed and shipped to LNGS for LEGEND-200 testing
- Careful bundling of cables and installation of extra cross-arm shielding
- Good signal connections and HV connection improved to 95% each
- The 2 failures will be diagnosed in the next warm-up





Outlook and next result

- New analysis, with improvements applied to old + new data, will **be released this year**
- Add 3-4 ORTEC ICPC detectors for post-upgrade running. Run for 6+ months to measure performance. Ultimate integrated exposure: around 60 kg-y
- Stop as-late-as-possible to ship enriched detectors to LNGS for installation in LEGEND-200, and continue background studies with natural detectors

More information about MAJORANA at:

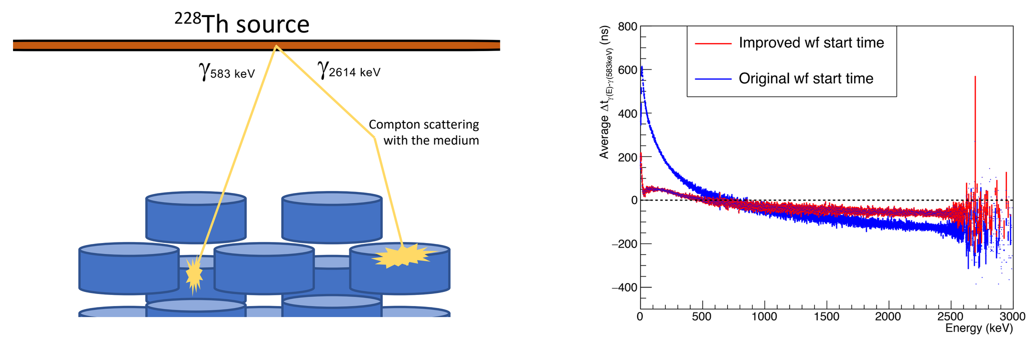
- Wed, July 1: GERDA, MAJORANA and LEGEND – towards a background free ton-scale Ge76 experiment (Y. Kermaidic)
- Poster 254: New results from MAJORANA DEMONSTRATOR's for Double-Beta Decay of ^{76}Ge to Excited States of ^{76}Se (I. Guinn)
- Poster 257: An improved background model for the MAJORANA DEMONSTRATOR (A. Reine and C. Haufe)

ANALYSIS IMPROVEMENTS FOR THE UPCOMING RELEASE

Exposure improvement: From 26 kg-y to about 50 kg-y (adding new data from April 2018 to Nov 2019)

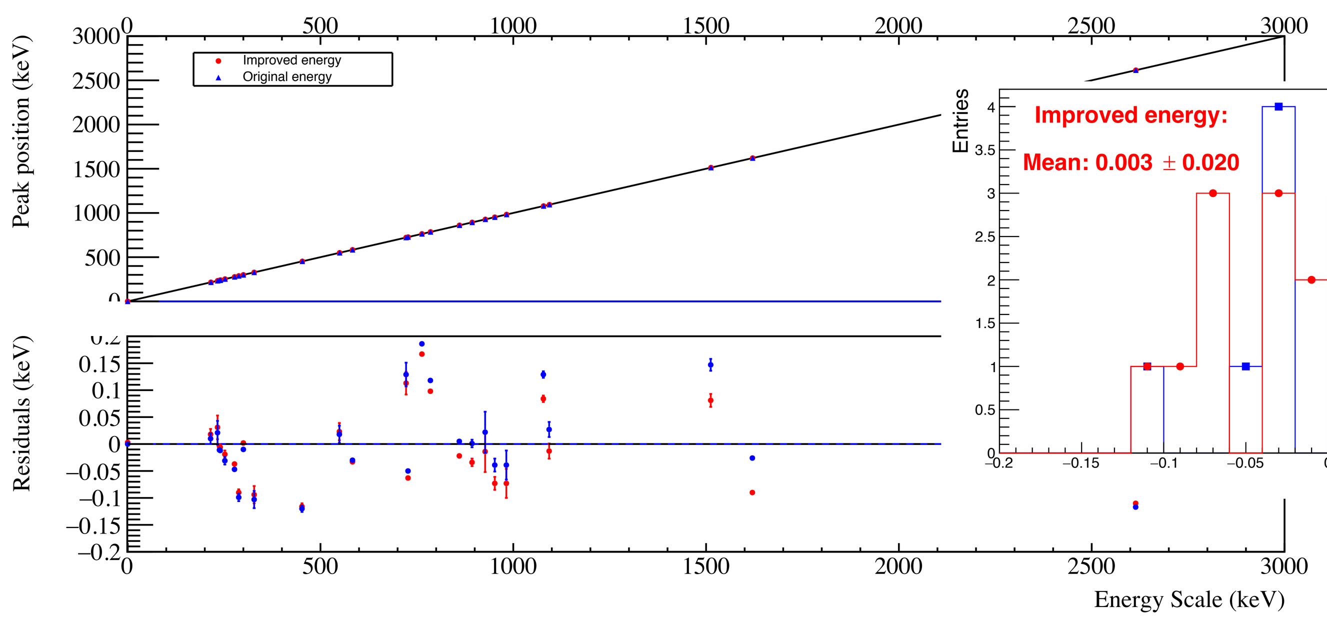
Energy calibration

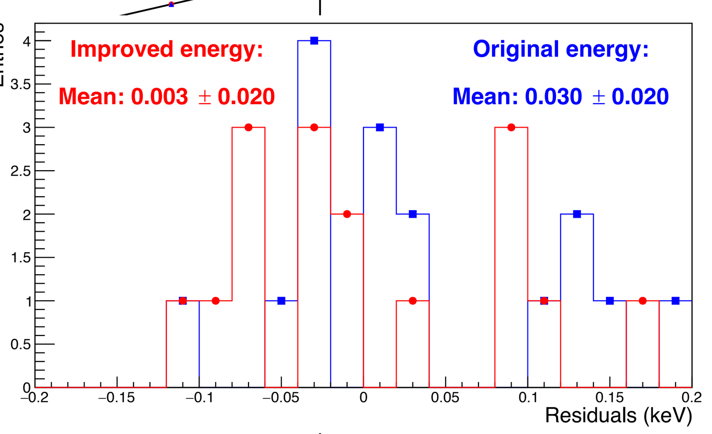
- New energy estimator with a correction applied to the waveform start time
- The correction is obtained from ^{228}Th calibration data through coincidences between 583 keV γ with other γ



Left: Graphical representation of the analyzed events. Right: Time difference between the two hits of the signal with correction (red) and without correction (blue)

- The expected time difference between the 2 hits of the event is 0
- The distribution is used to obtain an energy dependent correction
- A quadratic function, instead a linear one, is applied to the corrected raw energy to get the final energy scale



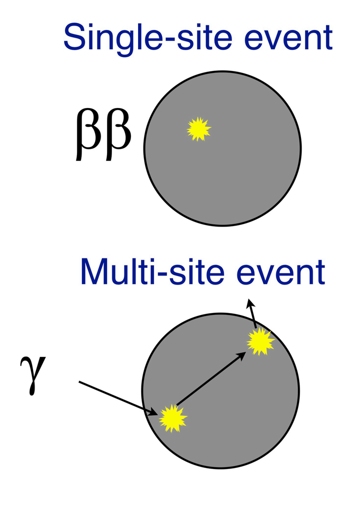


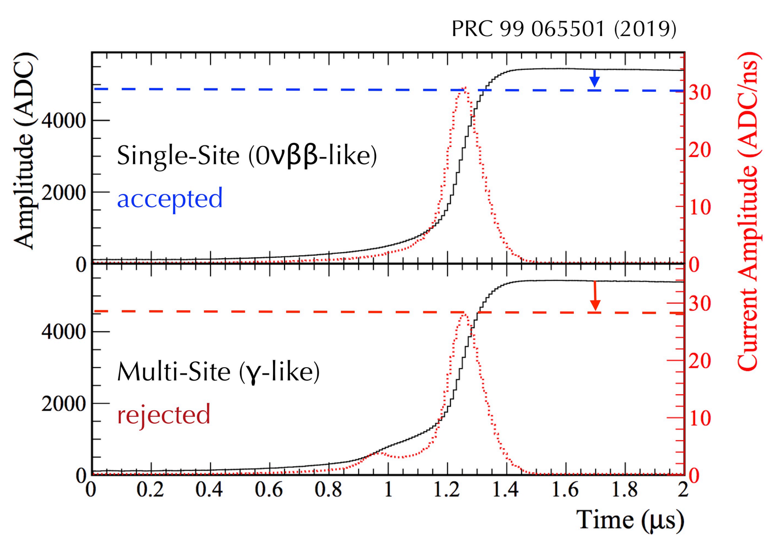
Top: Peak position of 26 γ peaks from the ^{228}Th source versus the energy scale of Majorana Demonstrator for the original energy (blue) and the improved energy (red) for DS6b dataset. Bottom: Residual of the peak position for the same energy parameters. Right: Residuals for peaks with energy higher than 500 keV.

The waveform start time correction reduces the non-linearity in the energy scale, which improves the energy parameter, especially at low energies but also at high energies, where the $0\nu\beta\beta$ peak is expected

Multi-site Rejection

- Pulse shape analysis used to identify multi-site background
- Cut is applied to keep 90% of known single-site event populations
- 50% reduction of Compton continuum background
- Results in a factor of three suppression in the background averaging window

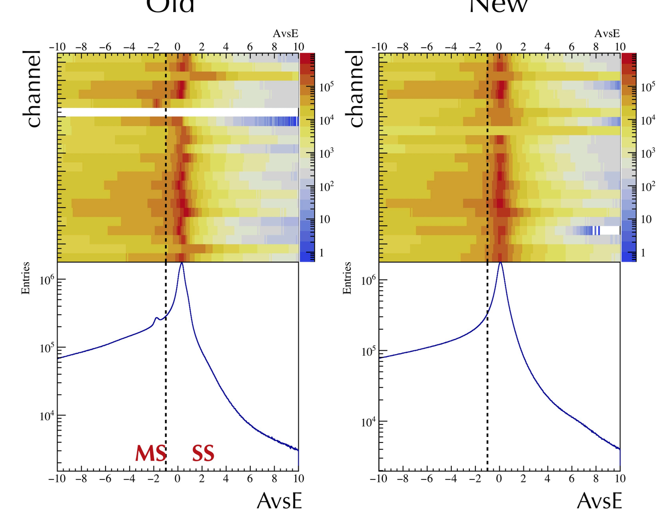




Left: Graphical representation of single-site and multi-site events. Right: Corresponding current amplitudes (A) and waveforms for equal energy depositions (E)

Improvements to the multi-site parameter (AvsE)

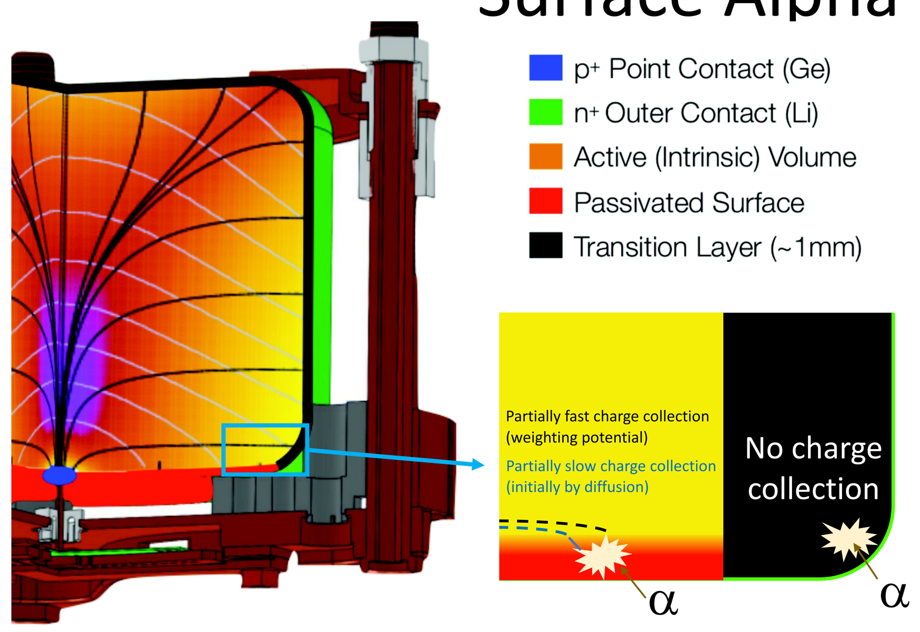
1. Refined alignment of the distribution center to produce a more precise cut
2. Introduced a width-energy dependence correction that improves the single-site acceptance at higher energies
3. Adjusted for correlations with event drift-time



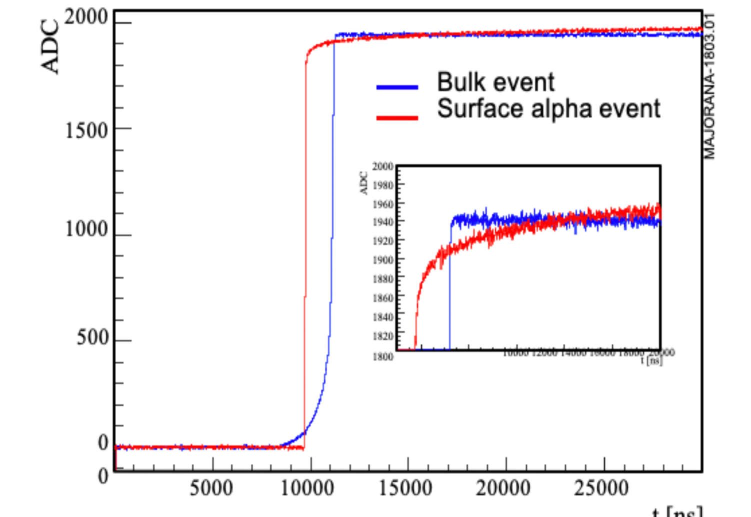
Measurements of the AvsE parameter, before and after analysis improvements, on calibration data

The new AvsE parameter offers better stability and uniformity across all detectors, while accounting for acceptance degradation at higher energies. The result is a better multi-site discriminating parameter

Surface Alpha Rejection

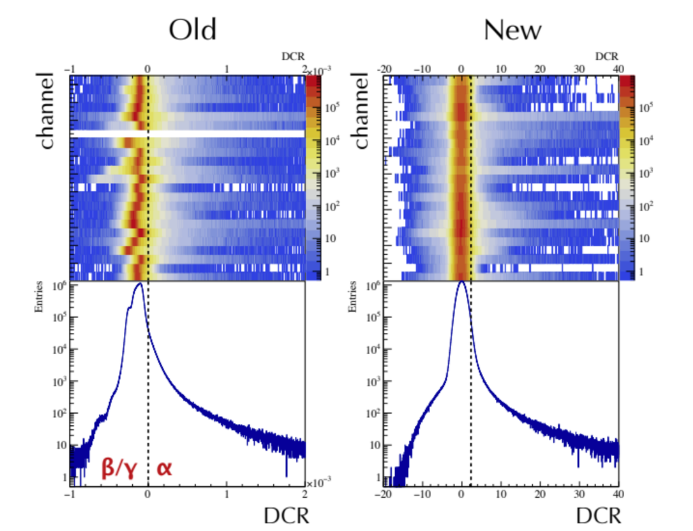


Graphical representation of alpha interactions in the surface of a PPC detector



An example of pole zero corrected waveforms for an interaction in the bulk (blue) and an alpha incident on the passivated surface (red). For alphas, there is both fast charge collection (sharp rising edge) and delayed charge collection (slow rise in waveform)

- The delayed charge recovery (DCR) parameter, which estimates the slope of the waveforms after the rising edge to identify alpha-like events with a delayed charge collection component while retaining 99% of the signal, has been improved since the last analysis using:
  1. Electronics' transfer function deconvolved waveforms
  2. Parameters converting the slope of the waveform into DCR, whose distribution is designed to have a mean of 0 and a standard deviation of 1
  3. Charge trapping, or drift time, correction



DCR parameter, before and after improvements, in calibration data

The new DCR parameter provides better stability across time and across detectors as well as increased exposure. Better discrimination between normal bulk events and alphas is expected.

The Majorana Collaboration: Isaac Arnquist, Frank Avignone, Alexander Barabash, CJ Barton, Ethan Blalock, Tobias Bode, Brady Bos, Matthew Busch, Micah Buuck, Tom Caldwell, Yuen-Dat Chan, Cabot-Ann Christofferson, Pinghan Chu, Morgan Clark, Jeannie Cox, Clara Cuesta, Jason Detwiler, Brandon DeVries, Maria-Laura di Vacri, Trevor Edwards, David Edwins, Yuri Efremenko, Hiroyasu Ejiri, Steven Elliott, Aaron Engelhardt, Rushabh Gala, Graham Giovanetti, Matthew Green, Julieta Gruszko, Ian Guinn, Vincente Guiseppe, Chris Haufe, Charles Havener, Reyco Henning, David Hervas, Eric Hoppe, Alexandru Hostiuc, Mary Kidd, Inwook Kim, Richard T. Kouzes, Thomas Lannen, Andrew Lopez, Mariano Lopez, Eric Martin, Ryan Martin, Ralph Massarczyk, Samuel Meijer, Susanne Mertens, Jordan Myslik, Tupendra Oli, Gulden Othman, Abigail Otten, Laxman Paudel, Walter Pettus, Alan Poon, David Radford, Ben Ranson, Anna Reine, Keith Rielage, Nicholas Ruof, Tyler Ryther, Bade Sayki, Matthew Stortini, David Tedeschi, Jared Thompson, Robert Varner, Sergey Vasilyev, John Wilkerson, Clint Wiseman, Wenqin Xu, Chang-Hong Yu

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