Results from the MAJORANA DEMONSTRATOR

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on behalf of the MAJORANA Collaboration

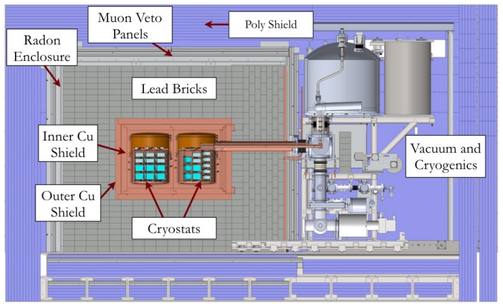
The MAJORANA DEMONSTRATOR

Searching for neutrinoless double beta decay of ^{76}Ge and additional physics beyond the Standard Model

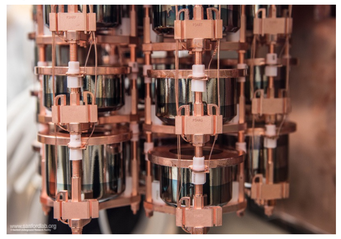
Source & Detector: Array of p-type point-contact (PPC) detectors
29.7 kg of 88% enriched ^{76}Ge crystals

Excellent Energy Resolution: 2.5 keV FWHM at 2039 keV ($Q_{\beta\beta}$)
Best of any 0νββ experiment

Low Background: Two modules within a compact graded shield and active muon veto using ultra-clean materials
Modules operate independently or in tandem to optimize exposure



Schematic of the MAJORANA DEMONSTRATOR Experiment



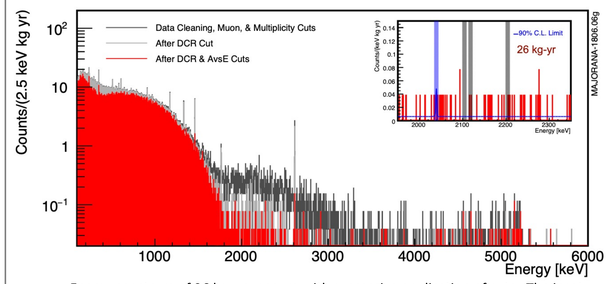
Close-packed array of PPC germanium detectors before insertion into vacuum cryostat

Operating at the 4850' level of SURF (Sanford Underground Research Facility) from 2015 until 2021

Now operating with single module of natural Ge detectors

See also N. Abgrall *et al.*, Adv. High Energy Phys. **2014**, 365432 (2014)

0νββ Physics Results



Energy spectrum of 26 kg-y exposure with successive application of cuts. The inset shows the spectrum of the background estimation window; 10 keV windows are excluded around known gamma lines (gray) and $Q_{\beta\beta}$ (blue).

Exposure:
$26\ \mathrm{kg \cdot yr}$

Energy resolution (FWHM):
$2.5 \pm 0.1\ \mathrm{keV}$

Background index :
$11.9 \pm 2.0\ \mathrm{cts/(FWHM \cdot t \cdot yr)}$

Median sensitivity:
$4.8 \cdot 10^{25}\mathrm{yr}$

Full exposure Limit:
$T_{1/2} > 2.7 \cdot 10^{25}\mathrm{yr}$

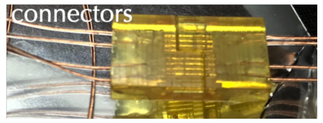
For analysis details, see S. I. Alvis *et al.* Phys. Rev. C **100**, 025501 (2019)

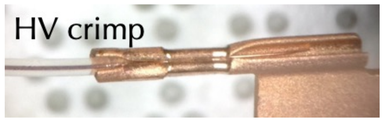
Improvements since last publication:
- Available exposure more than doubled, with ~75% of exposure blinded
- Improved event timing estimation resulting in improved energy linearity
- Higher-energy (^{56}Co) calibration of multisite event rejection
- Electronics response deconvolution to stabilize alpha rejection
- Improved understanding of detector stability and impact on analysis

A new result, with combined total of **~65 kg-yr** from the complete dataset and analysis improvements, is being prepared for release

2020: Hardware Upgrade

- Complete rebuild of Module 2
- 5 original PPC detectors removed and shipped to LNGS for LEGEND-200 testing
- 4 new ORTEC enriched ICPC geometry LEGEND detectors incorporated to study performance in the MAJORANA DEMONSTRATOR
- Newly developed signal and HV connectors provide ultra-clean, low-mass, high-reliability design
- Additional cross-arm shielding added and modified cable routing to address known issues with original design





2021: End of 0νββ Run

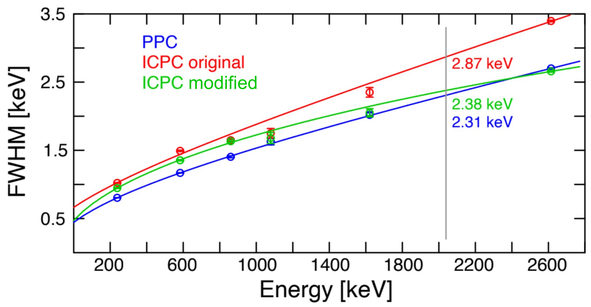
- 0νββ physics run concluded in March 2021
- All enriched detectors sent to Oak Ridge, TN en route to LNGS for incorporation in LEGEND-200 experiment
- Natural detectors reconfigured into single module for continued background and BSM physics studies

2020 Upgrade Performance

- Significant improvement in design robustness and operational detector fraction with new HV and signal connectors, and improved cable routing

	Before Upgrade	After Upgrade
Working signal	24/29 (82%)	27/27 (100%)
Working HV	19/24 (79%)	27/27 (100%)
Operational	18/29 (62%)* Used for final analysis	27/27 (100%)** Final selection pending

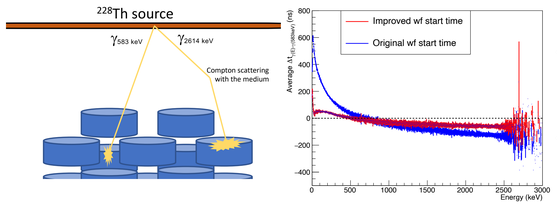
- First low-background physics operation of ORTEC-design inverted coaxial point contact (ICPC) detector geometry
  - Larger-mass ICPC detectors critical element of LEGEND experimental plan
    - Reduced backgrounds from electronics and cabling per sensitive exposure in larger detectors
- Longer drift time of ICPC detectors require modified charge trapping algorithm for optimal performance
  - Comparable energy performance to the smaller PPC detectors comprising rest of array
- Gain stability and PSA performance also validated with 6 months of data for these detectors



2020 hardware upgrade delivered on both improving robustness of connectors and also providing first low-background performance validation of the novel ORTEC ICPC detectors

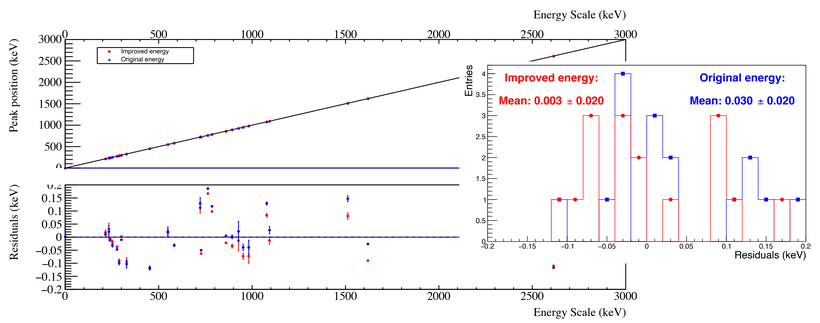
Energy Calibration

- Energy estimated via an optimized trapezoidal filter of ADC-nonlinearity-corrected waveforms in addition to corrections for charge-trapping and the fixed-time pickoff from "t_0"
- Recent improvements: correction for the start time of the waveform, and a quadratic correction for charge recombination



- ^{228} Th calibration data used to estimate waveform start time by calculated coincidences between 583 keV γ with other γ
- New quadratic correction is applied to the corrected raw energy to get the final energy scale

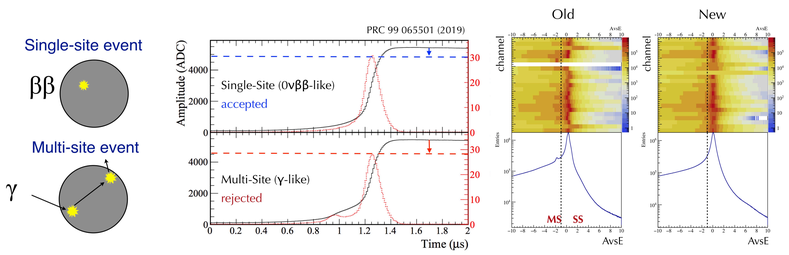
Left: Graphical representation of coincident calibration events. Right: Time difference between the two hits of the signal with correction (red) and without correction (blue)



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.

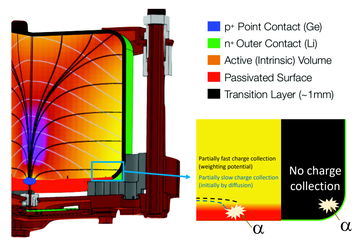
The waveform start time correction reduces the non-linearity in the energy scale, which improves the energy resolution, especially at low energies but also at high energies, where the 0νββ peak is expected

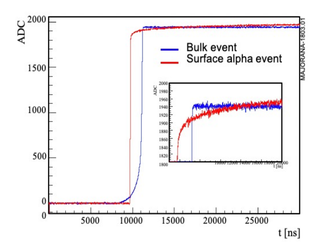
Multi-Site Rejection



- Pulse shape analysis used to identify multi-site background, tuned cut to keep 90% of known single-site event population
- 50 %reduction in the Compton background and a factor of three suppression of the background averaging window

Surface Alpha Rejection





- Identify alpha-like events with delayed charge collection by calculated waveform slope after the rising edge
- Surface alpha rejection is responsible for the majority of suppression in the background averaging window

New improvements to the multi-site and surface alpha rejection provide better stability across all detectors. Multi-site rejection has improved energy dependence correction and surface alpha has electronics transfer deconvolution and a new parameter transform that provides uniformity across detectors

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