Results from the MAJORANA DEMONSTRATOR

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on behalf of the MAJORANA Collaboration

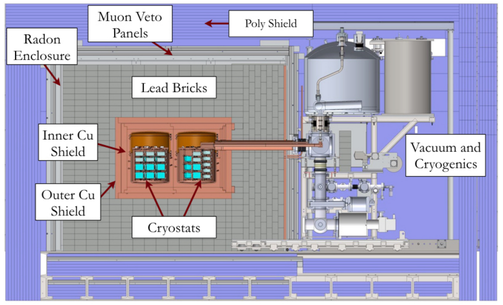
The MAJORANA DEMONSTRATOR

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

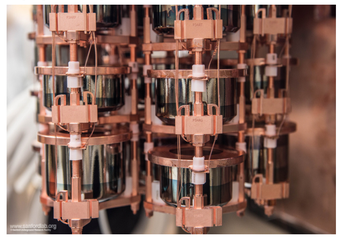
Source & Detector: Array of p-type point-contact (PPC) detectors
29.7 kg of 88% enriched ^{76}Ge crystals

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



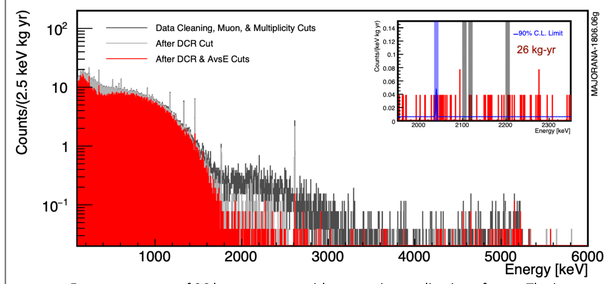
Close-packed array of PPC germanium detectors before insertion into vacuum cryostat

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

Now operating with single module of ^{nat}Ge PPC 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:
$T_{1/2} > 2.7 \cdot 10^{25}\mathrm{yr}$

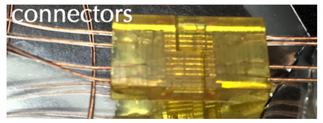
For analysis details, see S. I. Alvis *et al.* Phys. Rev. C **100**, 025501 (2019)

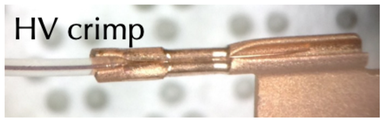
Improvements since last publication:
- Available exposure more than doubled, with ~75% of exposure blinded
- Improved event timing estimation resulting in improved energy linearity
- Higher-energy (^{56}Co) calibration of AvsE* multisite event rejection
- Electronics response deconvolution to stabilize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

AvsE and DCR are the primary pulse-shape analyses for background discrimination
- AvsE: removes gamma multisite events based on waveform rising edge
- DCR: removes passivated surface alpha backgrounds based on slow charge collection in waveform tail

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 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

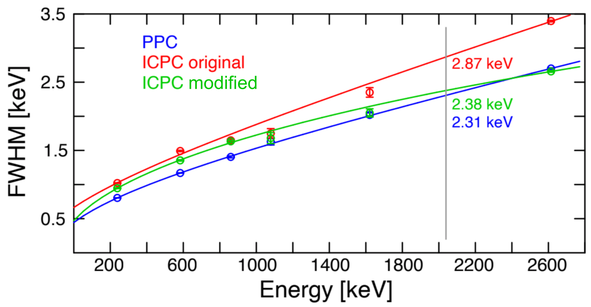
- 0νββ physics run concluded in March 2021
- All enriched detectors sent to Oak Ridge, TN en route to LNGS for incorporation in LEGEND-200 experiment
  - *See talk by C. Wiesinger (Neutrino Panel 2, next after break)*
- Natural detectors reconfigured into single module for continued background and BSM 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

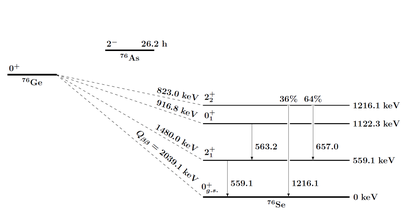
- First low-background physics operation of ORTEC-design inverted coaxial point contact (ICPC) detector geometry
  - Larger-mass ICPC detectors critical element of LEGEND experimental plan
    - Reduced backgrounds from electronics and cabling per sensitive exposure in larger detectors
- Longer drift 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

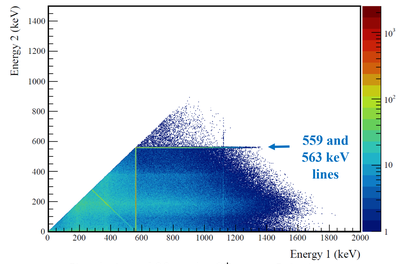


2020 hardware upgrade delivered on both improving robustness of connectors and also providing first low-background performance validation of the novel ORTEC ICPC detectors

Excited States Decay

- ^{76}Ge double-beta decay to ^{76}Se can also populate excited daughter states. These rare decay modes have never been observed, but are expected to have half-lives exceeding 10^{23} yr.
- Close packed array design of MAJORANA DEMONSTRATOR in vacuum cryostats, combined with world-leading energy resolution and low-background, gives world-leading sensitivity to these expected decay modes.





Simulation of ββ to the 0^+_1 state: Coincident energy spectrum for events with two detectors

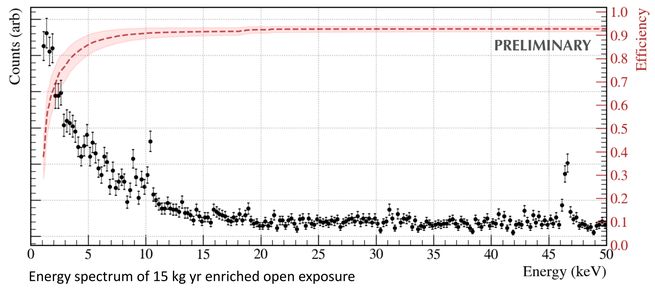
- Search performed with 41.9 kg yr exposure (20.6 kg yr blind)
- Results consistent with background-only, improving previous limits for all decay channels by x2-700

Decay Mode	Det. efficiency (M1, M2)	$T_{1/2}$ prev. limit (90% CI)	$T_{1/2}$ new limit (90% CI)	$T_{1/2}$ sensitivity (90% CI)
$0^+_{g.s.} \xrightarrow{2\nu\beta\beta} 0^+_1$	2.4%, 1.0%	$> 3.7 \cdot 10^{23} y$ [5]	$> \mathbf{7.5 \cdot 10^{23} y}$	$> \mathbf{10.5 \cdot 10^{23} y}$
$0^+_{g.s.} \xrightarrow{2\nu\beta\beta} 2^+_1$	1.4%, 0.6%	$> 1.6 \cdot 10^{23} y$ [5]	$> \mathbf{7.7 \cdot 10^{23} y}$	$> \mathbf{10.2 \cdot 10^{23} y}$
$0^+_{g.s.} \xrightarrow{2\nu\beta\beta} 2^+_2$	2.2%, 0.8%	$> 2.3 \cdot 10^{23} y$ [5]	$> \mathbf{12.8 \cdot 10^{23} y}$	$> \mathbf{8.2 \cdot 10^{23} y}$
$0^+_{g.s.} \xrightarrow{0\nu\beta\beta} 0^+_1$	3.0%, 1.2%	$> 1.3 \cdot 10^{22} y$ [6]	$> \mathbf{39.9 \cdot 10^{23} y}$	$> \mathbf{39.9 \cdot 10^{23} y}$
$0^+_{g.s.} \xrightarrow{0\nu\beta\beta} 2^+_1$	1.6%, 0.7%	$> 1.3 \cdot 10^{23} y$ [7]	$> \mathbf{21.2 \cdot 10^{23} y}$	$> \mathbf{21.2 \cdot 10^{23} y}$
$0^+_{g.s.} \xrightarrow{0\nu\beta\beta} 2^+_2$	2.3%, 1.0%	$> 1.4 \cdot 10^{21} y$ [8]	$> \mathbf{9.7 \cdot 10^{23} y}$	$> \mathbf{18.6 \cdot 10^{23} y}$

New ^{76}Ge double beta decay to excited states results recently published:
See I. J. Arnquist *et al.* Phys. Rev. C **103**, 015501 (2021)

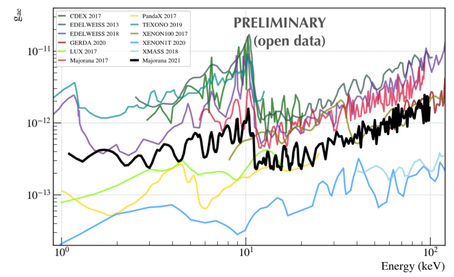
Beyond-Standard Model (BSM) Searches

- MAJORANA DEMONSTRATOR has rich low-energy physics program due to low-noise detectors and electronics, low backgrounds, and excellent energy resolution
- Significant exposure for *both* natural and enriched detectors
- Energy threshold of 1 keV achieved for analysis, with data-derived efficiency determination



Energy spectrum of 15 kg yr enriched open exposure

- Leading germanium limit for bosonic dark matter, leading direct LIPs search, plus other BSM searches



1 keV analysis threshold achieved enabling forthcoming sensitivity in BSM searches

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