Modeling Backgrounds in the MAJORANA DEMONSTRATOR

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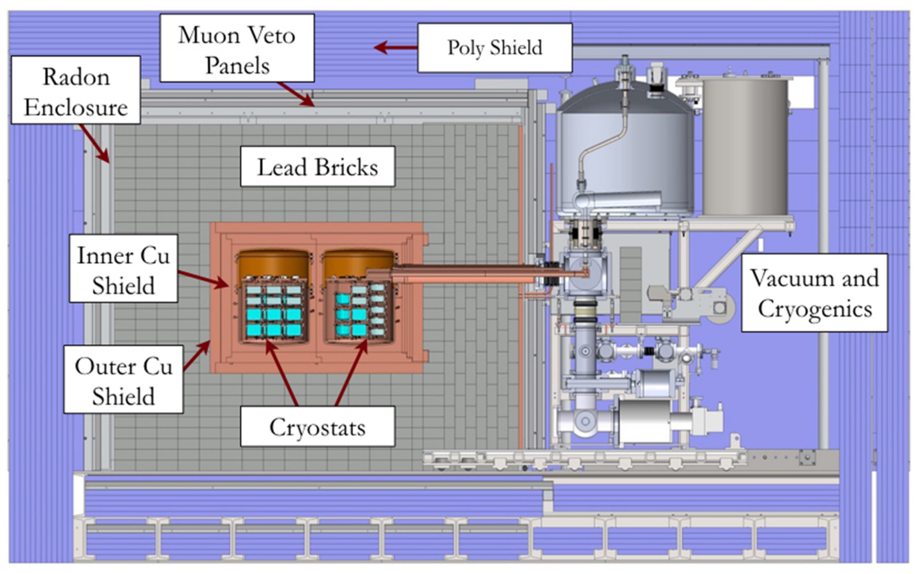
Introduction

The MAJORANA DEMONSTRATOR was a neutrinoless double-beta ($0\nu\beta\beta$) decay experiment that ran with 44 kg of HPGe p-type point contact (PPC) detectors, of which 30 kg were enriched in ^{76}Ge. The experiment operated at the Sanford Underground Research Facility in Lead, SD until March 2021.

Key Features

- 2 high vacuum modules, each containing 7 strings of HPGe PPC detectors
- Compact graded shield and active muon veto
- Radiopure materials
- Excellent energy resolution: 2.5 keV FWHM at $Q_{\beta\beta}$ (2039 keV)
- Ultra-low background rate and flat spectrum near $Q_{\beta\beta}$ after cuts

Cross-section of the MAJORANA DEMONSTRATOR



Motivation

Rate in the background estimation window (BEW) around $Q_{\beta\beta}$ after all cuts:

Assay-based projection: 1.17 ± 0.04 cts/(keV t yr)

Measured background: 6.23 ± 0.55 cts/(keV t yr)

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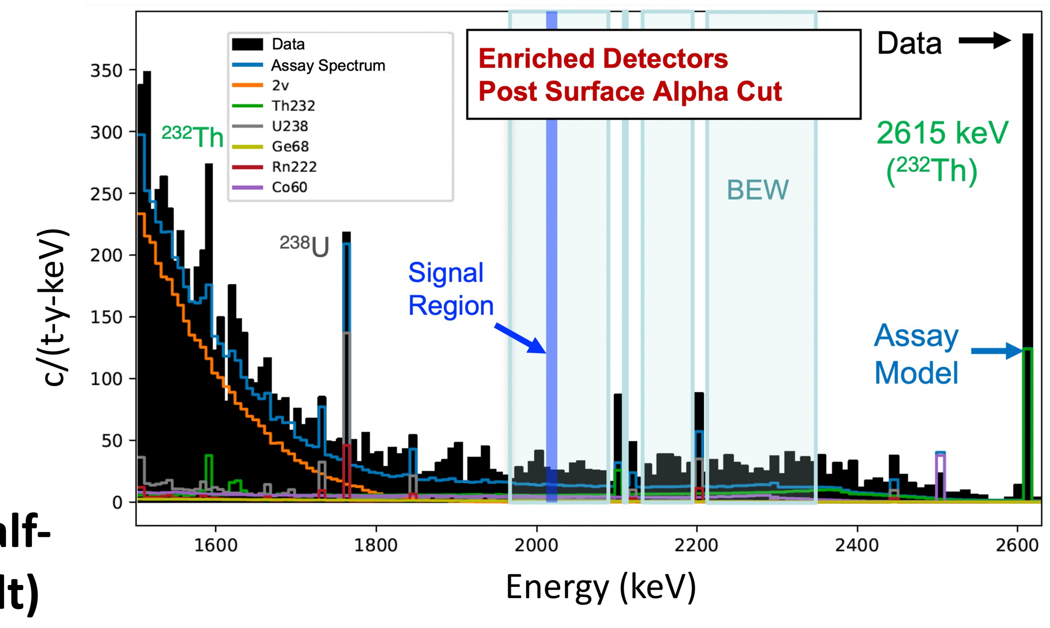


Fitting Goals:

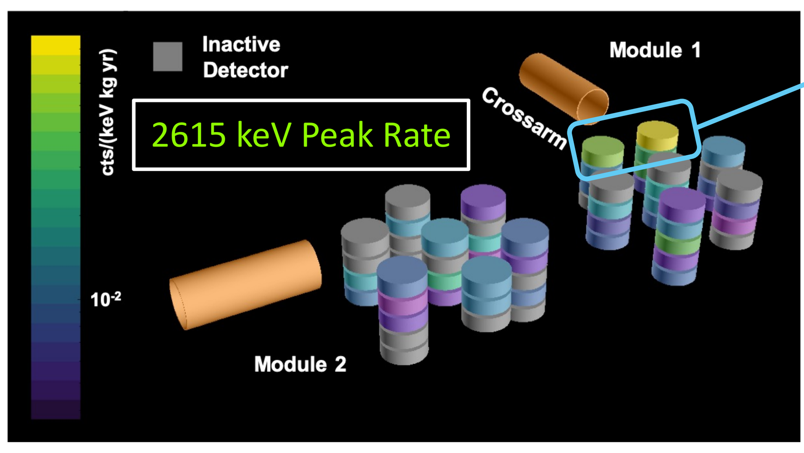
- ✓ **Measure the $2\nu\beta\beta$ half-life of ^{76}Ge (new result)**
- ✓ Determine the source of excess ^{232}Th backgrounds not accounted for in assay-based model
- ✓ Model backgrounds across wide energy range for use in searches for BSM processes
- ✓ Inform design decisions of the next-generation experiment LEGEND

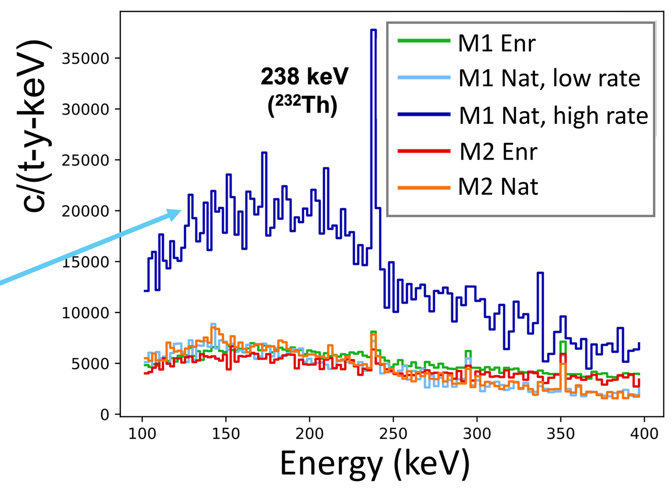
Background Model Development

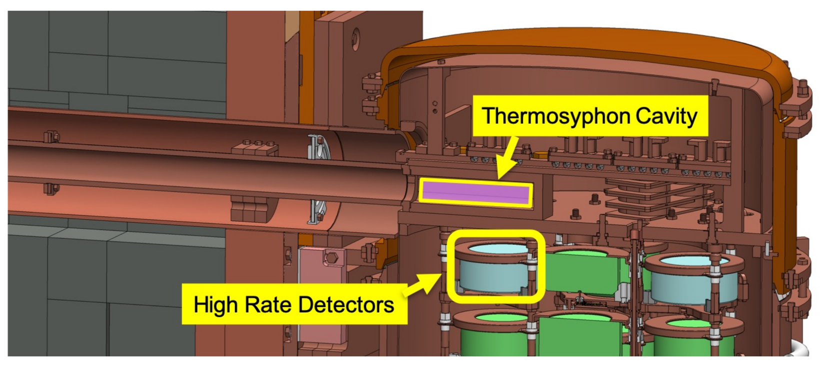
Enriched Background Index (All cuts):

Module 1: 7.38 ± 0.71 cts/(keV t yr)

Module 2: $3.33^{+0.75}_{-0.67}$ cts/(keV t yr)







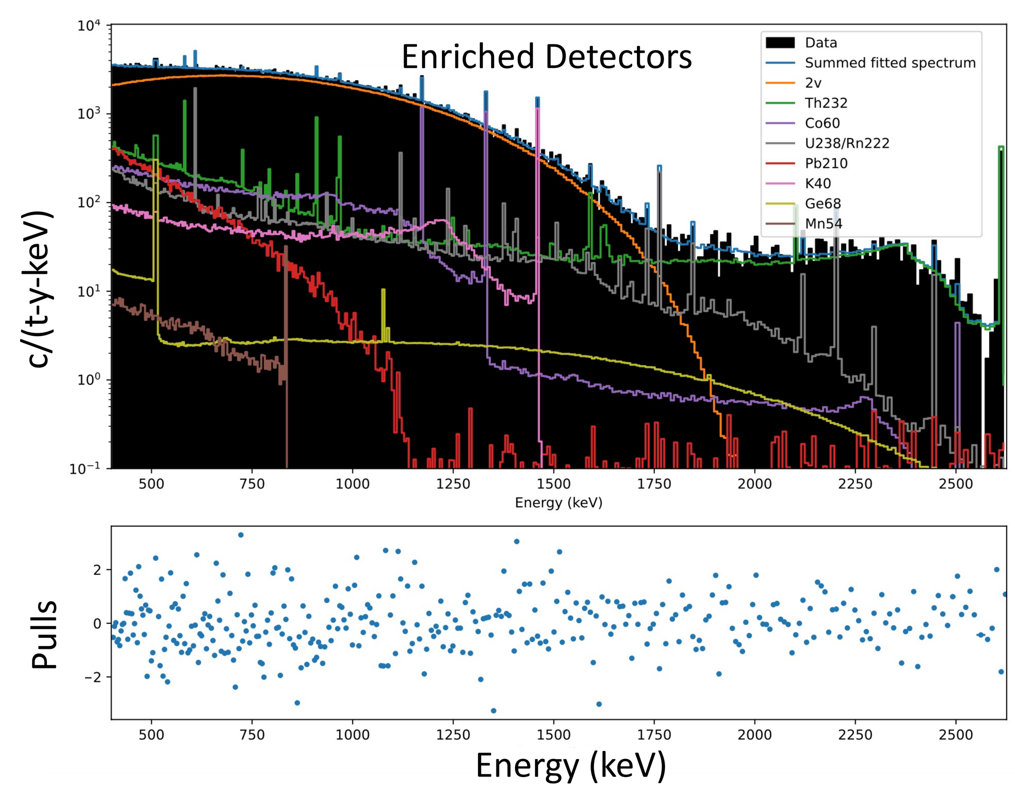
Studies of spatial non-uniformity of backgrounds informed spectral fits:

- Optimized detector grouping
- Led to identification of candidate hot spot in Module 1 thermosyphon cavity

Frequentist spectral fits

- 114 activities floated
  - Up to 9 decay chains
  - 32 component groups
- Data cleaning and primary surface alpha cut applied to data
- 51.9 kg-yr enriched + 22.4 kg-yr natural exposure
- Fit range: 400-2630 keV
- Bin width increases as function of energy to contain ~99% of peak counts in single bin

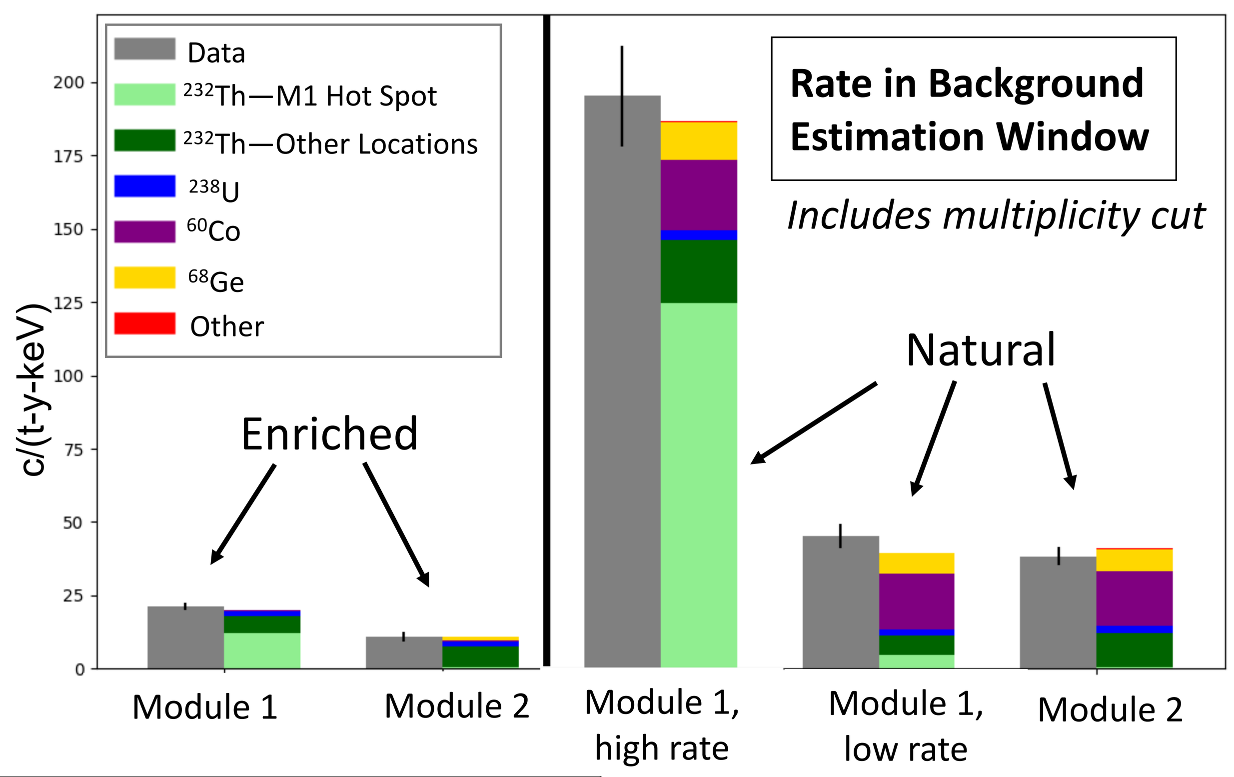
Paper currently in preparation

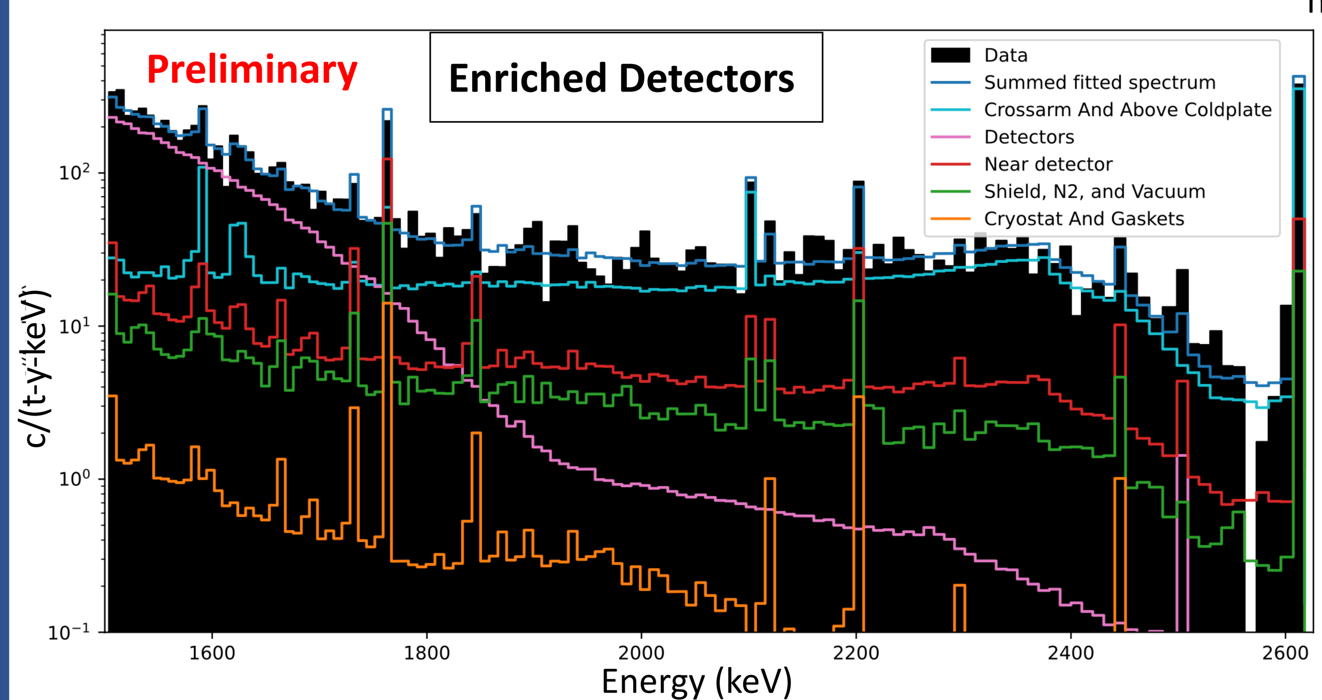


Sources of Backgrounds near $Q_{\beta\beta}$

All plots compare fitted model to data after data cleaning and main surface alpha cut but do not include a multi-site cut.

- Hot spot in Module 1 thermosyphon cavity helps account for different background rates between detector groups
- Higher cosmogenic (^{68}Ge and ^{60}Co) backgrounds in natural detectors expected from time above-ground before experiment





Rate in BEW is dominated by ^{232}Th from sources above the coldplate, including a hot spot in Module 1.

The dominant backgrounds in the DEMONSTRATOR are not from a near-detector region that would pose problems for LEGEND.

$2\nu\beta\beta$ Half-Life

$$T^{2\nu}_{1/2} = (2.05^{+0.04}_{-0.05}\ _{sys} \pm 0.010_{stat}) \times 10^{21}\ \mathrm{yr}$$

Preliminary

Consistent with GERDA measurement: $(2.022 \pm 0.038_{sys} \pm 0.018_{stat}) \times 10^{21}$ yr
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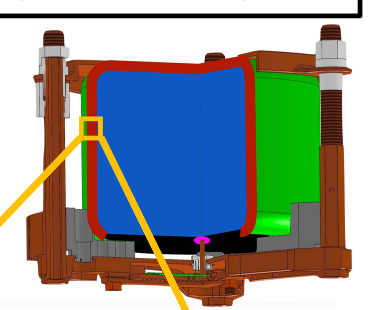
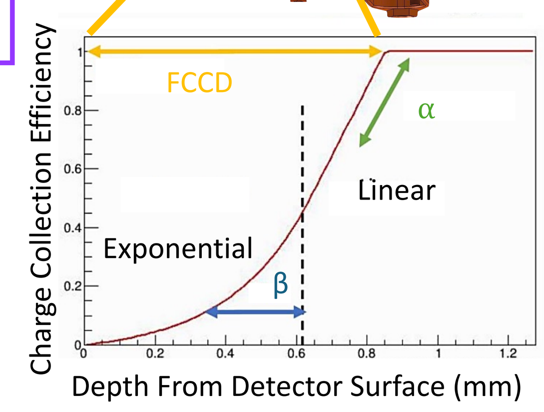
Uncertainty Contributions

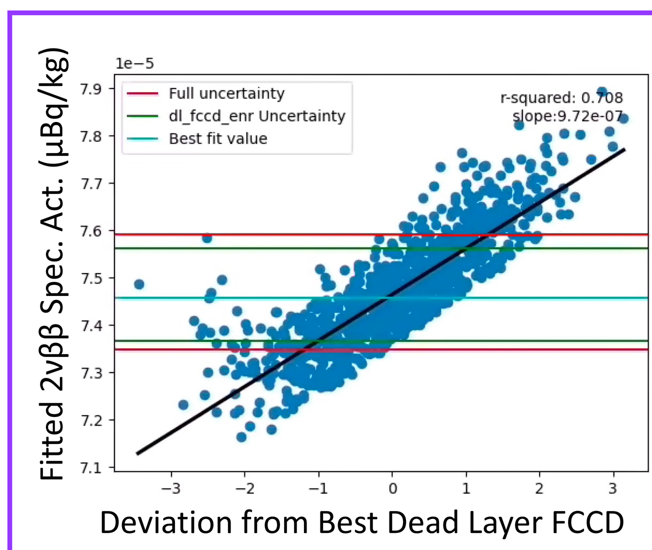
- Dead + transition layer profile and growth
- Mismodeling uncertainty
- Surface alpha efficiency
- Enrichment fraction
- Statistical uncertainty
- Simulated geometry
- Energy peakshape and nonlinearity
- Detector mass

- Statistical uncertainty evaluated by profile likelihood
- Most sources of systematic uncertainty (listed in purple) quantified by varying systematics parameters applied to simulations and repeating fits.

Example: Dead Layer







Dead layer full charge collection depth (FCCD) is the dominant uncertainty source

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