An Improved Background Model for the MAJORANA DEMONSTRATOR

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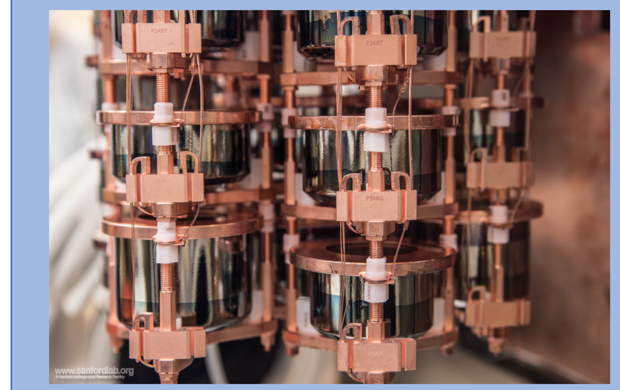
On behalf of the MAJORANA Collaboration

U.S. DEPARTMENT OF ENERGY | Office of Science

Sanford Underground Research Facility

Introduction

The MAJORANA DEMONSTRATOR is a search for neutrinoless double-beta decay of ^{76}Ge in HPGe detectors and additional physics beyond the standard model. The experiment operates underground at the 4850' level of the Sanford Underground Research Facility in Lead, SD, USA.



Some key features of the DEMONSTRATOR are:

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

Excellent Energy resolution: 2.53 keV FWHM @ 2039 keV

Low Background: 2 modules within a compact graded shield and active muon veto using ultra-clean materials

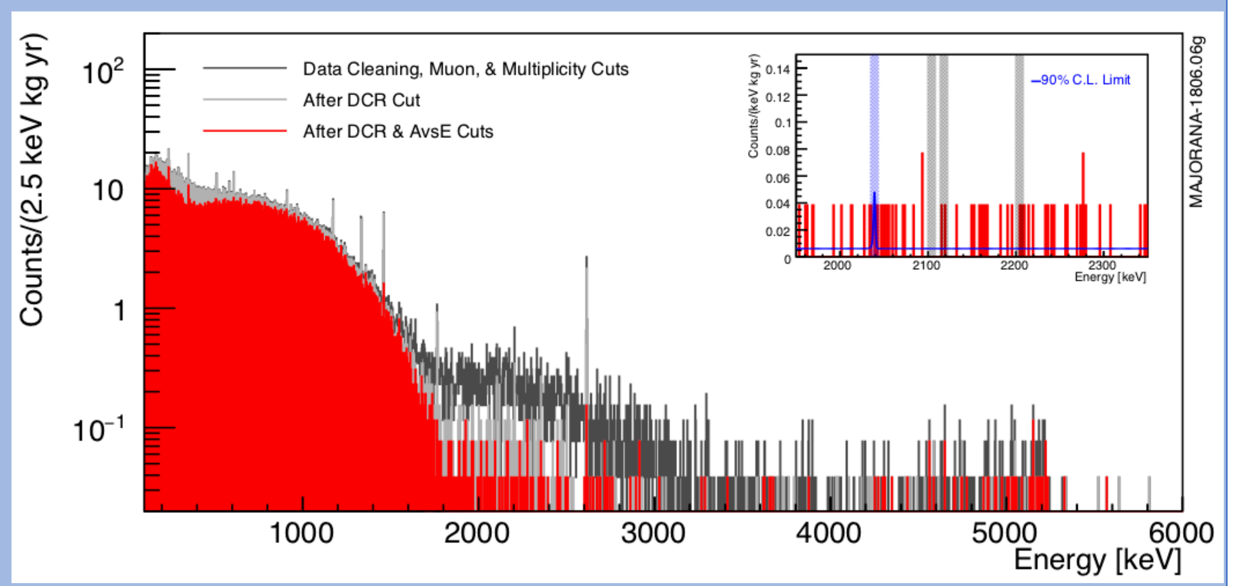
To learn more about the MAJORANA DEMONSTRATOR at Neutrino 2020, check out the following talk and posters from our collaborators:

•Wed. Jul 1: GERDA, Majorana and LEGEND - towards a background-free ton-scale Ge76 experiment (Y. Kermaidic)

•Poster 586: Status and Results from the MAJORANA DEMONSTRATOR Experiment (J. M. López-Castaño, N. Ruof, A. Hostiuc)

•Poster 254: New Results of the MAJORANA DEMONSTRATOR's for Double-Beta Decay of 76Ge to Excited States of 76Se (Ian Guinn)

Based on material assays and preliminary simulations, our projected background in the region of interest surrounding $Q_{\beta\beta}$ was 2.2 cts./FWHM-tonne-yr. Our measured background of 11.9 ± 2.0 cts./FWHM-tonne-yr in the lowest-background configuration of datasets prompted an investigation to pinpoint the origin of the deviation.[1, 2]



The discrepancy between the magnitude of the 2615 keV ^{208}Tl peak in data and the assay-based background model indicates that excess rate in the region of interest is largely due to increased ^{232}Th in some component. Understanding the source of the ^{232}Th excess will help inform design choices and background considerations for the next-generation LEGEND experiment.

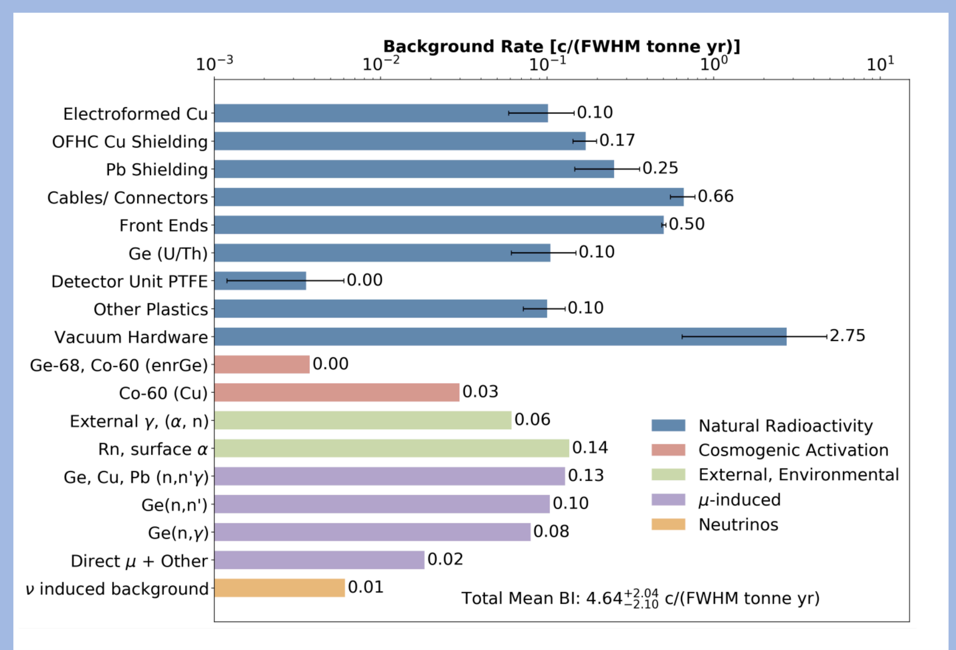
Assay-Based Background Model

An improved assay-based model was developed that incorporated newer assay values and updated simulations, which better reflect the as-built configuration of the experiment. This improved model projects a background in the region of interest of 4.64 cts./FWHM-tonne-y: a 111% increase from the previous projection and overall reduction in the discrepancy between data and assay-based model.

All simulations were performed using the GEANT4-based simulation package MaGE, developed in collaboration between the MAJORANA and GERDA experiments,

Some **significant changes** between the preliminary and improved assay-based model:

- New assay information indicating that cables have significantly higher ^{232}Th and ^{238}U activity than was initially reported.
- Increases in simulated detection efficiency for backgrounds internal to the Ge due to cut turning



Improvements were also made in the **analysis of uncertainties**:

- For each component, the U and Th activities were treated as Gaussian distributions truncated at zero, where assay-based uncertainties were used to set the standard deviation.
- If only an upper limit on the component activities is available, they too are treated as truncated Gaussian distributions centered at zero with the upper limit used as a 90% CL upper limit.
- Detection efficiencies distributions were produced in a similar manner but with statistical uncertainties in simulations being used to set the standard deviation
- A background index distribution is formed by drawing samples from the activity distribution and multiplying them by samples from the efficiency distribution.

Initial Background Model Fits

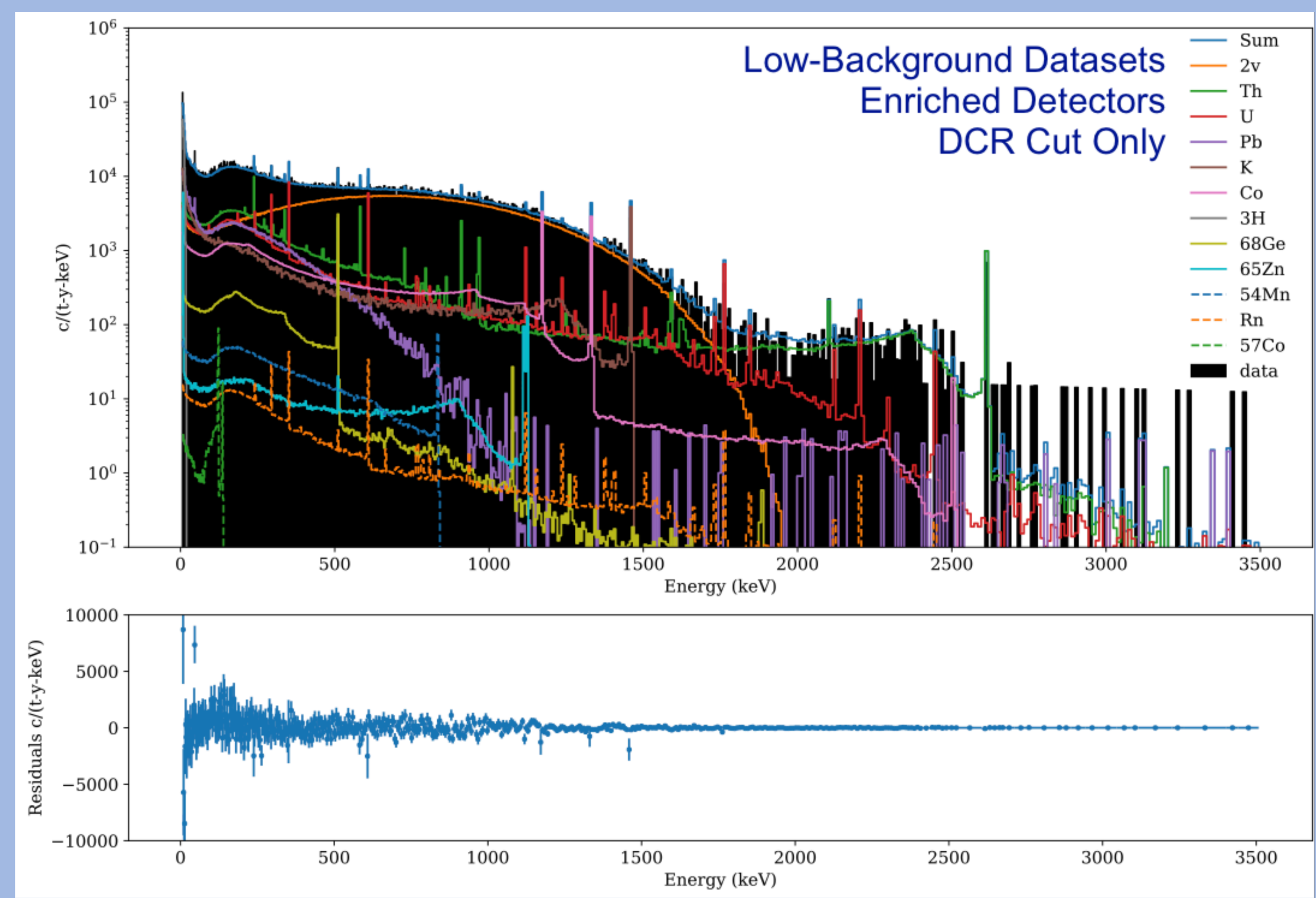
Two different statistical approaches were used for background model fits in order to provide an independent cross check. Both methods involved performing fits of >100 pdfs simultaneously to data divided by dataset, multiplicity, and detector group. Data cleaning cuts and an alpha cut were performed prior to fitting.

Bayesian fit:

- Poisson likelihood function
- Fit data between 100-2614 keV with 10 keV binning
- For each pdf, the prior is set using a truncated normal distribution centered around the assay-based activity value
- MCMC techniques were used to sample the posterior

Frequentist fit:

- Barlow-Beeston likelihood used in order to take into account finite statistics of simulations[3]
- Fit data between 7 and 3500 keV with energy-dependent binning scheme
- Used Nelder-Mead minimization algorithm

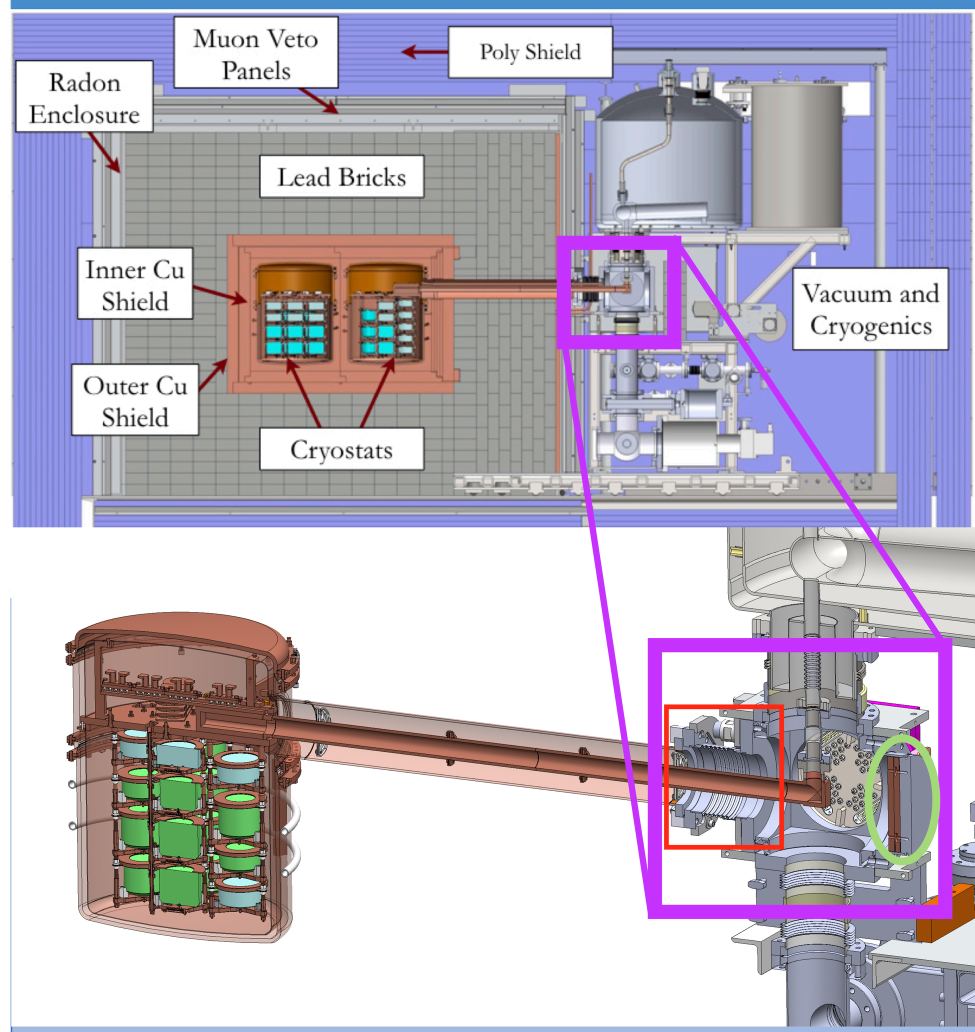


M. Buuck, UW, PhD Dissertation 2019

Conclusions from initial fits:

- Both fits support initial assessments that the excess in observed backgrounds over assay predictions in the ROI is predominately due to the ^{232}Th chain.
- Both fits also agree that this excess is produced by a source distant from the detector array.
  - This is confirmed by additional studies, including studies of peak ratios and coincident gammas
  - LEGEND will make use of modified MAJORANA designs for some near-detector components, such as front end electronics, and neither fit indicated that the Th excess originated in these components.
- However, there is not yet sufficient evidence to point to a single component as the definitive source of the excess. Due to the low efficiency of counts from distant sources, a higher fidelity modeling of distant components is required to complete the model.

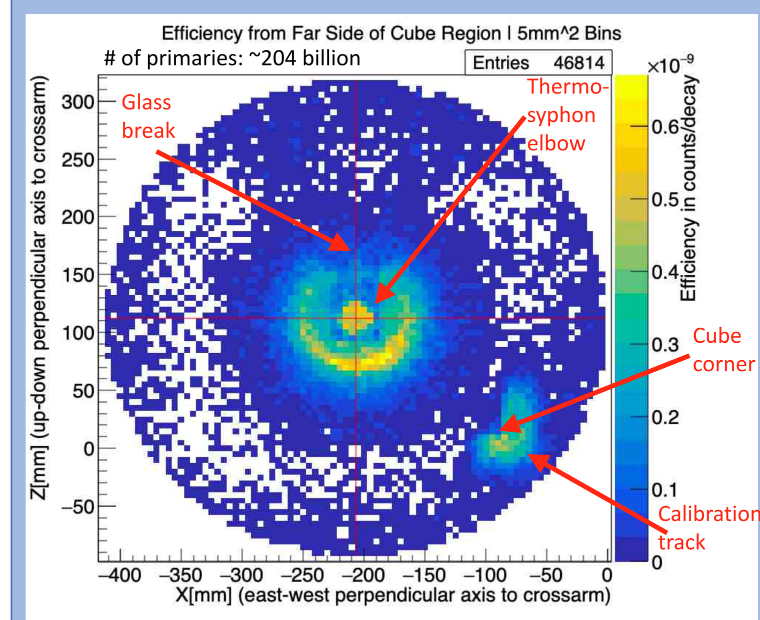
Cube Backgrounds

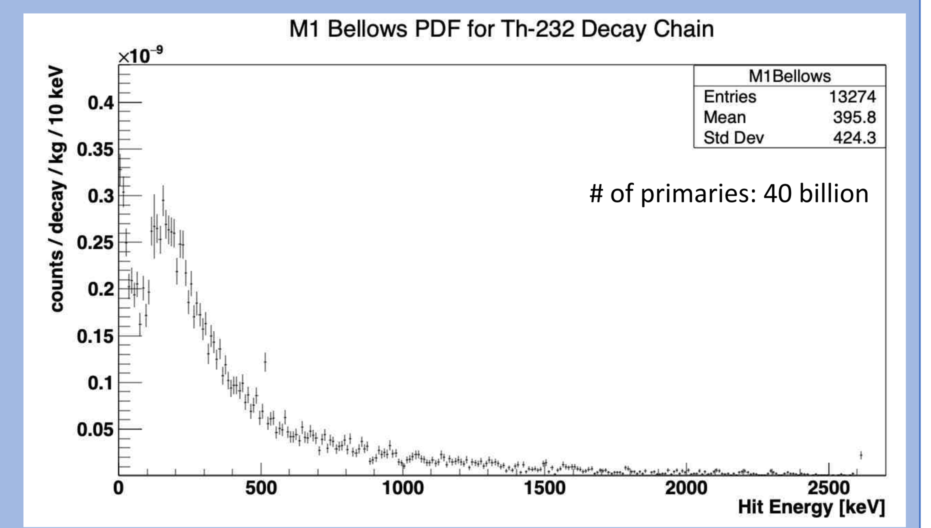


- **Left**: Full shielding configuration of the DEMONSTRATOR
- **Below Left:** The stainless steel cube structure (pink box) that houses components with line of sight to detectors via the copper "crossarm".

A candidate for the distant source that could explain the ^{232}Th chain excess is **the cube region.** Modeling the effect of decays from this region is difficult due to the low detector efficiency for such counts. This efficiency also varies based on position within the cube region, due to shine-path restrictions. As a result, higher statistic simulations for components in the cube region are required to produce pdfs from this region for improved fits.

To illustrate the variance in efficiency based on position in the cube region, a simulation of 2615 keV gammas (a high-intensity gamma line of the ^{232}Th chain) was carried out. Below-left is a histogram that shows the efficiency based on source position along the far side of the cube region (green circle above). The red crosshairs show the center position of the crossarm. Bottom-right is a pdf of the bellows component (red box above) of Module 1 produced through a high statistics simulation - an example of why the poor detector efficiency for these sources makes pdf generation so difficult.





Plans for Improved Fits

- **Eliminate degeneracy in pdfs**: Combine component groups from similar locations
- **Split pdfs by source module:** Module 1 has higher ^{232}Th backgrounds
- **Test improved fitting algorithms:** Fit speed and convergence may be improved by use of analytic gradient or other methods
- **Add all blinded data**

Systematic studies will be performed to test the sensitivity of the fit to factors such as the dead layer model, the effect of missing pdfs, and the impact of energy non-linearities.

In addition to yielding an improved background model, the improved fits will allow for an updated measurement of the $2\nu\beta\beta$ rate as well as measurements for ongoing BSM studies.

Citations

[1] N. Abgrall, I.J. Arnquist, and F.T. Avignone III *et. al.* "The MAJORANA DEMONSTRATOR radioassay program". In: *Nucl. Instrum. Methods Phys. Res. A* 828 (2016). pp. 22-36. DOI: https://doi.org/10.1016/j.nima.2016.04.070.

[2] S. I. Alvis *et al.* "Search for neutrinoless double-β decay in ^{76}Ge with 26 kg yr of exposure from the MAJORANA DEMONSTRATOR". In: *Phys. Rev. C* 100, 025501. DOI: https://doi.org/10.1103/PhysRevC.100.025501

[3] R. J. Barlow and C. Beeston, Fitting using Finite Monte Carlo samples," Comput. Phys.Commun., vol. 77, pp. 219-228, 1993.

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This material is supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, the Particle Astrophysics and Nuclear Physics Programs of the National Science Foundation, and the Sanford Underground Research Facility.