Pulse shape analysis studies for the MAJORANA DEMONSTRATOR

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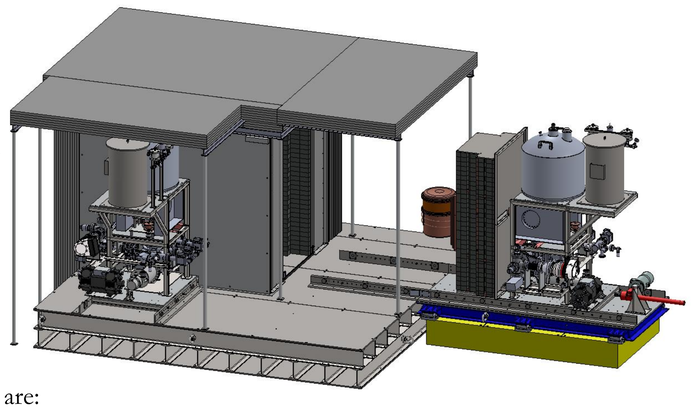
on behalf of the MAJORANA Collaboration

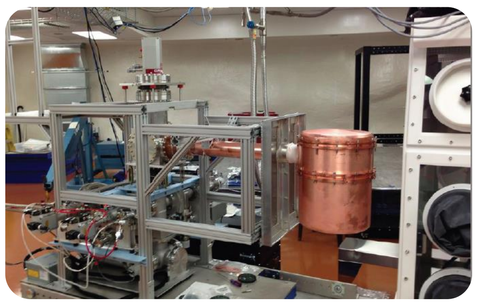
The MAJORANA DEMONSTRATOR

- 40 kg array of high purity Ge p-type point contact (PPC) detectors.
- 30 kg of detectors enriched ≥86% in ^{76}Ge.
- Background goal of 3 counts/(ROI-ton-y) in the 4 keV region of interest at 2039 keV, which scales to ~1 count/(ROI-ton-y) for a tonne scale experiment.
- Located on the 4850' level of the Sanford Underground Research Facility in Lead, SD.



The **goals** for the MAJORANA DEMONSTRATOR are:

1. Demonstrate background levels low enough to justify building a tonne scale experiment.
2. Demonstrate the feasibility of constructing & fielding modular arrays of Ge detectors.
3. Test the Klapdor-Kleingrothaus claim of a neutrinoless double-beta decay signal [H. V. Klapdor-Kleingrothaus and I. V. Krivosheina, Mod. Phys. Lett. A21, 1547 (2006)].
4. Perform searches for other physics beyond the standard model, such as dark matter and axions.



The DEMONSTRATOR will consist of two independent vacuum cryostats, each containing 20 kg of detectors. The cryostats and the majority of internal detector components will be constructed from ultra-clean, electroformed copper and installed in a compact shield of copper, lead, and an active muon veto. The modular, scalable design of the DEMONSTRATOR allows cryostats to be commissioned as they are completed.

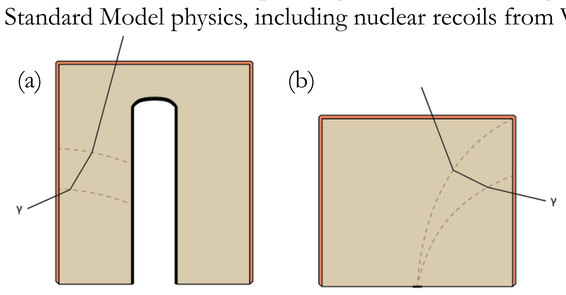
Construction of the MAJORANA DEMONSTRATOR is proceeding in three stages:

- **Prototype Module:** ^{nat}Ge detectors and components built from OFHC copper. Tested mechanical systems., fabrication processes, and assembly procedures. Provided valuable information in preparation for Module 1.
- **Module 1:** ^{enr}Ge detectors. Currently under construction.
- **Module 2:** ^{enr}Ge and ^{nat}Ge detectors.

Pulse Shape Analysis (PSA)

P-type point contact detectors

The DEMONSTRATOR will use PPC Ge detectors because they allow for efficient discrimination between multiple interactions from gamma rays and single-site neutrinoless double-beta decay events. PPC detectors have the added benefit of a relatively simple design and sub-keV energy thresholds, enabling the DEMONSTRATOR to look for non-Standard Model physics, including nuclear recoils from WIMPs.

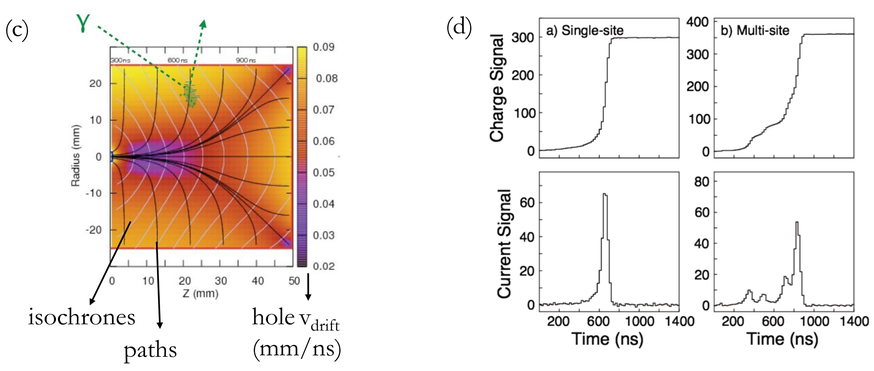


Favorable characteristics of PPC Ge detectors:

- Small point-like central contact; no deep hole.
- Short length possible.
- Simple, cost-effective, low intrinsic radioactivity.

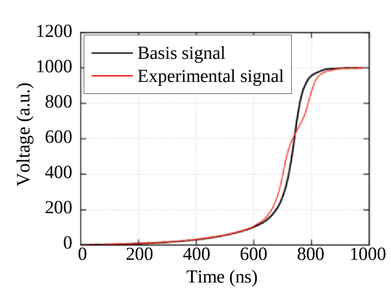
Multiple interactions from a gamma ray in a coaxial detector (a) and a point contact detector (b). The sharply peaked weighting potential of the point contact detector (c) results in distinct signals from each energy deposition (d).

The multiple interaction sites events (**MSE**) exhibit multiple steps in the charge signal waveform and, correspondingly, multiple peaks in the current signal waveform. Single-site events (**SSE**) give a single peak.



χ^2 calculation

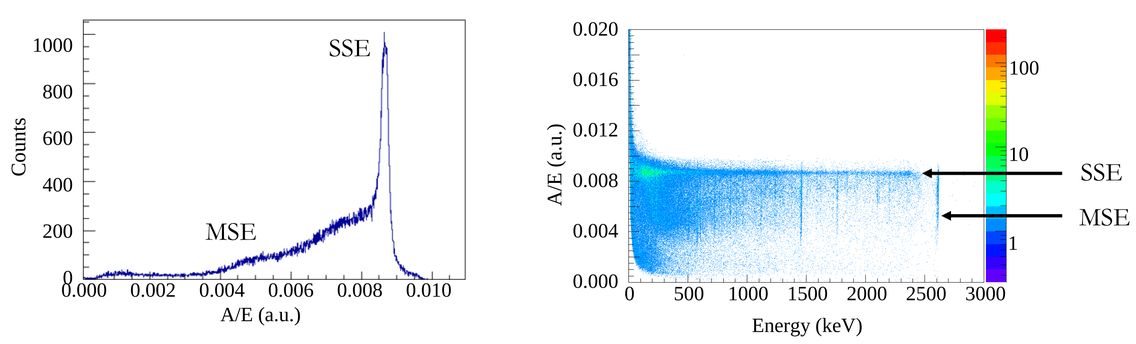
- Developed an algorithm based on a library of unique, measured single site pulse shapes.
- **Event-by-event χ^2 fitting of experimental pulse shapes**.
- Depending on χ^2, MSE and SSE are distinguished.
- Performs well in preliminary tests and in good agreement with benchmark simulations.
- More work needed on user interface, optimization, evaluating systematic uncertainties.



Experimental MSE compared to a reference SSE.

A/E optimization

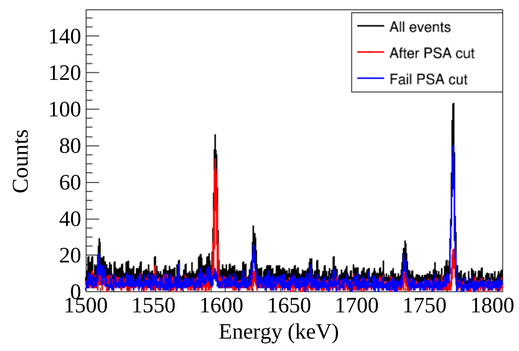
- Peak amplitude to total energy or A/E: Ratio of the maximum current, calculated from the time differentiation of the recorded charge waveforms, to the event total energy.
- With total energy deposited at multiple stages, MSE generally have smaller maximum current for the same energy, i.e. smaller A/E.
- Optimum estimation under study:
  - **Energy** estimation: Calculated with a trapezoidal filter, but on-board energy or cusp filter are also being considered.
  - **Amplitude** determination: Calculated off-line through a trapezoidal or RC filter. Comparison of different time constants.
- **A/E** calculation: Fitting A/E(E) to remove the energy dependence of the cut.



(a) A/E distribution of a detector in the Prototype module with a ^{228}Tl source and no shielding. A is calculated with a trapezoidal filter and a 200 ns time constant. (b) Energy dependence of A/E of the same data.

^{228}Th calibration as reference population

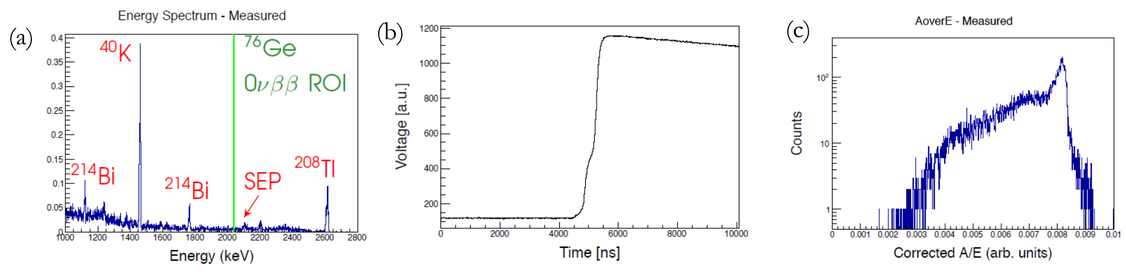
- **SSE**: Double escape peak (DEP) of 2614.5 keV photons of ^{208}Tl is at 1592.5 keV.
- **MSE**: Full energy photon peaks with similar energy, e.g. 1620.5 keV photons from ^{212}Bi and single escape peak (SEP) of 2614.5 keV photons of ^{208}Tl at 2103.5 keV.
- Preliminary results:
  - MSE rejection: 90% (A/E) - 99% (χ^2)
  - SSE survival: 90% (A/E) - 98% (χ^2)



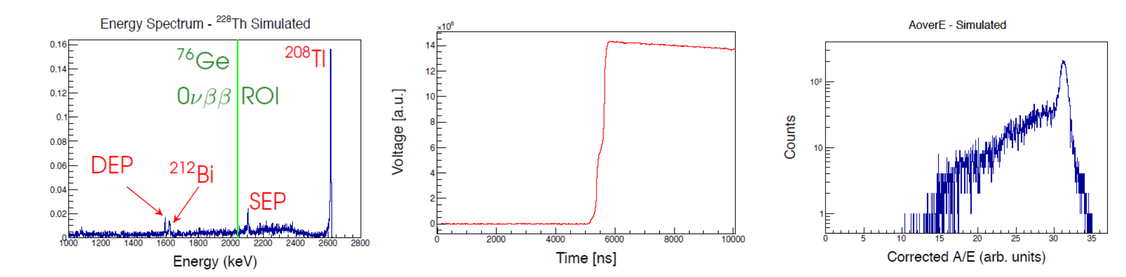
PSA performance of a detector in the Prototype Module (A/E cut applied) with a ^{228}Tl source and no shielding.

Pulse shape simulations

- Monte Carlo simulations are carried out with MaGe, a simulation software framework based on Geant4 developed by the MAJORANA and GERDA collaborations. In addition to the simulations to accomplish a background model of the MAJORANA DEMONSTRATOR, pulse shape simulations are in progress to validate the PSA techniques and estimate the systematics.
- The result is unique to detector, depends on geometry and impurities. Electronics is also considered in the data analysis: noise, preamp shaping.
- Preliminary results:
  ^{228}Th source in the Prototype Module **experimental measurements** (no shielding):



^{228}Th source in the Prototype Module **simulations**:



(a) Energy Spectra. Note that the Prototype Module was not shielded in the measurement, but rock is not included in simulation (no ^{238}U chain or ^{40}K). (b) Charge waveforms of a multisite event. (c) A/E corrected value calculated in the 1000-2800 keV energy range.

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