The MAJORANA DEMONSTRATOR Neutrinoless Double-Beta Decay Experiment

Vincente Guiseppe on behalf of the MAJORANA Collaboration

The MAJORANA DEMONSTRATOR

The MAJORANA DEMONSTRATOR is a neutrinoless double-beta decay experiment using germanium as source and detector. The goals for the DEMONSTRATOR are:

1. Demonstrate background levels low enough to justify building a tonne-scale experiment
2. Establish the feasibility of constructing & fielding modular arrays of Ge detectors
3. Search for additional physics beyond the Standard Model, such as solar neutrinos and dark matter

- Background Goal in the 0.9ββ peak region of interest (4 keV at 2 MHz)
- 3 σ events/ROI/h (after analysis cuts)
- Seeks to 1 count/ROI/h for a tonne experiment
- 40 kg of Ge detectors
- 30 kg of 86% enriched 76Ge crystals
- 20 kg of pure Ge
- Detector Technology: P-type, point-contact.
- Two independent cryostats
- Ultra-clean, electroformed Cu
- 25 kg of detectors per cryostat
- Naturally scalable
- Compact Shield
- Low-background passive Cu and Pb shield with active muon veto
- Located underground at the 4800-foot level of the Sanford Underground Research Facility in Lead, SD

Status:
- Commissioning prototype module with 3 strings of natural Ge
- Producing 12 kg of enriched geranium crystals for the DEMONSTRATOR
- Module 1 in operation by end of 2014 with 7 strings containing 76Ge
- Module 2 in operation by end of 2015 with 7 strings of 76Ge and 86Ge

76Ge and Double-Beta Decay

Discovery of the neutrinoless double-beta decay provides:

1. Neutrino is its own antiparticle
2. Lepton number violating process
3. Effective Majorana mass

\[ \Gamma_{\beta\beta} = G_{\text{eff}} |M_{\beta\beta}|^2 (m_{\beta\beta})^2 \]

- Ge is the source & detector
- Maximize source to total mass ratio
- Well-understood technologies
- Excellent energy resolution 0.016% at 2 MeV, 4-kV ROI
- Advantages for improving signal to background
- Existing, well-characterized large Ge arrays
- Demonstrated ability to reject 7.4% to 80%
- Favorable nuclear matrix element
- Slow 2ββ rate \( T_{1/2} = 1.4 \times 10^{21} \) yr
- Powerful background rejection technologies
- Granularity, timing, pulse shape discrimination
- Proof Ge 0ββ searches have highly competitive lifetime limits

Approach

Ge crystal

String

Array inside cryostat

Detector mounts

Shield

Detectors

- Ultra-low background rate requires a pulse shape analysis (PSA) rejection of multi-site gamma events
- P-type Point-Contact (PPC) detector
  - No deep hole; small point-like central contact
  - Simple, cost-effective, low intrinsic radiactivity
  - Locally weighting potential gives excellent rejection of events with multiple interaction sites
  - Low capacitance (~1 pF) gives superb resolution at low energies

Material Purity and Backgrounds

Background predicted on material assay:
- The detector
- Ge crystal zone refined and pulled into a crystal
- Provides purification
- Limit surface exposure to prevent cosmic activation
- Deep underground operation
- Detector mounts
- Ultra-pure plastic and electroformed Cu
- Low mass design
- Custom cable connectors and front-end boards
- Cryostat and inner shielding
- Underground electroformed Cu

Simulated background spectra before and after analysis cuts

Underground Facilities

Cu Electroforming

Underground Cu electroforming laboratory produces all of the ultra-pure inner Cu.

Cu Machining

Underground clean room machine shop already adjacent to a chemical cleaning lab and detector hall.

Detector and Module Construction

Detector units and strings built inside a glovebox with a radon-reduced, dry N₂ environment

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 PERFORMANCE LOCATION

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Performance Location

- Sanford Underground Research Facility, Lead, SD
- University of Wisconsin, Madison, WI
- University of Tennessee, Knoxville, TN
- Texas A&M University, College Station, TX
- University of Alabama, Tuscaloosa, AL
- Texas Tech University, Lubbock, TX
- University of Texas at Austin, TX
- Illinois Institute of Technology, Chicago, IL
- Oak Ridge National Laboratory, Oak Ridge, TN
- Brookhaven National Laboratory, Upton, NY
- Los Alamos National Laboratory, Los Alamos, NM
- University of Washington, Seattle, WA
- University of Alberta, Edmonton, AB
- The University of Hong Kong, Hong Kong, China
- Shanghai Jiaotong University, Shanghai, China

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