The MAJORANA Demonstrator Project

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(For the MAJORANA COLLABORATION)

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Modes of Double-Beta Decay

\[(A,\nu) \rightarrow (A,Z+2) + 2e^- + 2\nu_e\]

\[(A,Z) \rightarrow (A,Z+2) + 2e^-\]

\[\text{2}\nu \text{ Double Beta Decay} \]

allowed by the Standard Model
observed: \(T_{1/2} = 10^{19} - 10^{21}\) y

\[\text{Neutrinoless Double Beta Decay (0}\nu\text{-DBD)}\]
never observed (except KKDK claim)
\(T_{1/2} > 10^{25}\) y

Lepton-Number Violation? Dirac or Majorana Character? Neutrino Mass Scale?
Towards a Ton-scale Experiment: the MAJORANA Demonstrator
The MAJORANA Demonstrator Module

$^{76}$Ge offers an excellent combination of capabilities & sensitivities.

(Excellent energy resolution, intrinsically clean detectors, commercial technologies)

- **40-kg of Ge detectors**
  
  Up to 30-kg of 86% enriched $^{76}$Ge crystals required for science and background goals focus on point-contact detectors for DEMONSTRATOR

- **Low-background Cryostats & Shield**
  
  – ultra-clean, electroformed Cu
  
  – naturally scalable
  
  – Compact low-background passive Cu and Pb shield with active muon veto

- **Background Goal in the $0
\nu\beta\beta$ peak ROI (4 keV at 2039 keV)**

  ~ 4 count/ROI/t-y (after analysis cuts) (scales to 1 count/ROI/t-y for tonne expt.)
Electroformed Copper Cryostat

- Top Lid
- Thermosyphon mounting plate
- Coldplate
- Cross Arm
- Bottom Lid
- Thermal Shield Can
- Thermosyphon Tube
The Dual Module Shield

• **Three Phases**
  – *Prototype cryostat (3 strings, \( \text{nat} \text{Ge} \)) (Sept. 2012)*
  – *Cryostat 1 (3 strings \( \text{enr} \text{Ge} \) & 4 strings \( \text{nat} \text{Ge} \)) (Mar. 2013)*
  – *Cryostat 2 (up to 7 strings \( \text{enr} \text{Ge} \)) (Sept. 2014)*
Point contact Ge detectors allow multi-site events to be identified - invented by Paul Luke (LBNL), Developed by Juan Collar for MAJORANA
Effectiveness of Pulse-Shape Discrimination With MAJORANA POINT Contact Detectors

Single-site versus multi-site event discrimination

Example of DUPPC $^{232}$Th spectrum:
MAJORANA Demonstrator Sensitivity

\[
\langle m_{\beta\beta} \rangle \text{ sensitivity (90\% CL) [eV]}
\]

- MAJORANA Prototype Module (30 kg, 1 count/ROI/t/y)
- MAJORANA Prototype Module (30 kg, 10 counts/ROI/t/y)

KKDC (3\sigma): (0.69-4.18) \times 10^{25} \text{ years}
Acquisition of Enriched $^{76}$Ge

• The first 29 kg of GeO$_2$ of Ge enriched to >86% in $^{76}$Ge has been processed and is already on its way to Oak Ridge (20 kg of Ge metal)

• It is proceeding by truck from the Electrochemical Plant in Zelenogorsk, Russia to the Port of St. Petersburg, then by ship to a U.S. port, then by truck to Oak Ridge.

• It is being shipped in a steel shipping shield to reduce exposure to cosmic ray neutrons that generate $^{56,57,60}$Co, $^{68}$Ge, $^{65}$Zn, etc., by spallation reactions.
The Shipping Shield (GERDA design, built in Russia)
Shield Dimensions
A Photo of the MAJORANA SHIPPING SHIELD
Reduction of the GeO$_2$ and Zone Refining the Ge

• Unfortunately, no experienced commercial company in the U.S. would agree to reduce the oxide and zone-refine the enriched Ge.

• This required the setting up of a complete facility to do this.

• A building was rented, experts, some from the Ge industry, were hired, and all necessary equipment was purchased and installed.

• The process is being tuned using 29 kg of $^{\text{nat}}$GeO$_2$. 
Reduction of the $^{\text{nat}}\text{GeO}_2$ to $^{\text{nat}}\text{Ge}$ Metal

Reduction Furnace at 650 °C, Then Melt at 1030 °C.

The First 12 of 29 Bars from Reduction. Each is ~0.75 kg
Zone Refining the $^{\text{nat}}\text{Ge}$

50 KW LEPEL RF Generator and Zone Refiner coils (left)
Above is shown the graphite boat with about 2.5 kg of Ge moving through the RF coils.
## Cutting Zone-Bar I, Reduction Bars 27-29 (2155.6 g)

<table>
<thead>
<tr>
<th>Zone Bar</th>
<th>Reduction Bars</th>
<th>Total Mass (g)</th>
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<tbody>
<tr>
<td>A</td>
<td>2-6</td>
<td>2634.0</td>
</tr>
<tr>
<td>B</td>
<td>7-9</td>
<td>1658.0</td>
</tr>
<tr>
<td>C</td>
<td>10-12</td>
<td>1694.4</td>
</tr>
<tr>
<td>D</td>
<td>13-15</td>
<td>1952.5</td>
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<tr>
<td>E</td>
<td>16-18</td>
<td>2223.2</td>
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<tr>
<td>F</td>
<td>19-21</td>
<td>2257.2</td>
</tr>
<tr>
<td>G</td>
<td>22-24</td>
<td>2251.3</td>
</tr>
<tr>
<td>H</td>
<td>25-26</td>
<td>2155.6</td>
</tr>
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**MAJORANA and GERDA for the Ton Scale Effort**

**MAJORANA**
- Modules of $^{76}$Ge housed in high-purity electroformed copper cryostat
- Shield: electroformed copper / lead
- Initial phase: R&D demonstrator module: Total $\sim$40 kg (up to 30 kg enr.)

**GERDA**
- ‘Bare’ $^{76}$Ge array in liquid argon
- Shield: high-purity liquid Argon / H$_2$O
- Phase I (2011): $\sim$18 kg (HdM/IGEX diodes)
- Phase II (2012): add $\sim$20 kg new detectors - Total $\sim$40 kg

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**Joint Cooperative Agreement:**
- Open exchange of knowledge & technologies (e.g. MaGe, R&D)
- Intention is to merge for 1 ton exp. Select best techniques developed and tested in GERDA and MAJORANA
Predictions for the Ton-Scale Experiment
Estimated Schedules

3σ inclusion region: (1.30-3.55) x 10^{25} years

Shift time by ~ One Year
The MAJORANA Collaboration (Feb. 2011)

Note: Red text indicates students

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