Overview of the Majorana Experiment

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Double Beta Decay

The diagram illustrates the process of double beta decay, where a nucleus $^{A}Z_{N}$ decays into a nucleus $^{A}Z_{N+2}$, emitting two electrons $e^{-}$ and two antineutrinos $\bar{\nu}_{e}$.

The graph shows the distribution of summed beta energies in arbitrary units, with a peak around 1.5 MeV and a spread of energies from 0 to 2 MeV.
Double Beta Decay

\[ \Gamma^{0\nu} = G_{0\nu}^0 \left| M_{0\nu}^0 \right|^2 \left\langle m_\nu \right\rangle^2 \]
\[ 76^{\text{Ge}} \]

\[ 2^- \]

\[ 76^{\text{As}} \]

\[ \beta \beta \]

\[ Q = 2.039 \text{ MeV} \]

\[ 0^+ \]

\[ 76^{\text{Ge}} \]

\[ 0^+ \]

\[ 2^+ \]

\[ 76^{\text{Se}} \]
Germanium Semiconductors

- Source = Detector
- Excellent Resolution: ~0.2%

\[ G^{0\nu} = 0.30 \times 10^{-25} \text{ y}^{-1} \text{ eV}^{-2} \] [1]
\[ M^{0\nu} = 1.5 - 2.4 \] [2]
\[ T_{1/2}^{2\nu} = (1.3 \pm 0.1) \times 10^{21} \text{ y} \] [3]

Recent $^{76}$Ge Results

IGEX

D. Gonzales et al.,
Recent $^{76}$Ge Results

Heidelberg-Moscow

35.5 kg y: $T_{1/2}^{0v} > 1.9 \times 10^{25}$ (90% C.L.)

H.V. Klapdor-Kleingrothaus et al.,

D. Gonzales et al.,
Recent $^{76}$Ge Results

**IGEX**

116.75 mole year - 8.87 kg·year in $^{76}$Ge

Complete data set: $T_{1/2}^{0\nu} > 1.13 \times 10^{25}$ yr (90% CL)

Reduced data set: $T_{1/2}^{0\nu} > 1.57 \times 10^{25}$ yr (90% CL)

D. Gonzales et al.,

**Heidelberg-Moscow**

35.5 kg y: $T_{1/2}^{0\nu} > 1.9 \times 10^{25}$ (90% C.L.)

H.V. Klapdor-Kleingrothaus et al.,

**KKDC**

71.7 kg y

$T_{1/2}^{0\nu} = 1.2^{+3.0}_{-0.5} \times 10^{25}$ yr

$\langle m_{\nu} \rangle = 0.44^{+0.14}_{-0.20}$ eV

significance: 4.2 $\sigma$

H.V. Klapdor-Kleingrothaus et al.,
Goals for a Next-Generation $^{76}$Ge Experiment

- Sensitivity to quasi-degenerate hierarchy
- $O(200 \text{ kg})$ active material
- Backgrounds on order 1 event per ton-year
- Test KKDC
- Scalable for sensitivity to inverted hierarchy
- $O(1 \text{ ton})$ active material
- Backgrounds on order 0.1 events per ton-year
The Majorana Collaboration

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Majorana Reference Design: M180

- 180 kg detector of 86% enriched $^{76}$Ge
- 171 crystals in three 57-crystal modules
- Deep site: > 5000 mwe overburden (e.g. SNOLab)
- Background goal: 1 event per ton-year in the ROI
- Sensitivity after 3 live-years:

$$T_{1/2}^{0\nu} > 5.6 \times 10^{26}\text{ y (90% C.L.)}$$
$$\langle m_{\nu} \rangle < 100\text{ meV (using } M^{0\nu} = 2.4)$$
57-Crystal Module

- Vacuum jacket
- Cold plate
- Cold finger
- Thermal shroud
- Bottom closure

Crystal Stack

- Cap
- Tube (0.007” thick)
- 76% enriched HPGe crystal 1.1 kg (62mm x 70mm)
- Tray (plastic, Si, etc.)
Majorana Reference Design: M180

- Veto shield
- Sliding Monolith
- LN Dewar
- Inner shield
- 57-crystal modules
# Backgrounds

<table>
<thead>
<tr>
<th>Background Source</th>
<th>Gross and Net Rates for Important Isotopes</th>
<th>Total Est. Background (per t-y)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Counts in ROI per t-y</td>
<td>Counts in ROI</td>
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<tr>
<td></td>
<td>$^{68}\text{Ge}$</td>
<td>$^{60}\text{Co}$</td>
</tr>
<tr>
<td>Germanium (100 day exp)</td>
<td>Gross</td>
<td>2.54</td>
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<tr>
<td></td>
<td>Net</td>
<td>0.01</td>
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<td>Net</td>
<td>0.22</td>
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<tr>
<td>Copper Shield</td>
<td>Gross</td>
<td>2.28</td>
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<tr>
<td></td>
<td>Net</td>
<td>0.64</td>
</tr>
<tr>
<td>Small Parts</td>
<td>Gross</td>
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<td></td>
<td>Net</td>
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<tr>
<td>External Sources (6000 mwe)</td>
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<tr>
<td></td>
<td>Net</td>
<td>0.003</td>
</tr>
<tr>
<td>$2\nu\beta\beta$ decay</td>
<td>&lt; 0.01</td>
<td>TOTAL SUM</td>
</tr>
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Jason Detwiler

INT Seminar, 13 July 2005
Germanium Purity

Surface Activation of 86% Enriched Ge (in atoms/day/kg) [1]

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<th>Lal et al. [2]</th>
<th>Hess et al. [3]</th>
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<tr>
<td>$^3$H</td>
<td>~113</td>
<td>~140</td>
</tr>
<tr>
<td>$^{54}$Mn</td>
<td>0.37</td>
<td>1.4</td>
</tr>
<tr>
<td>$^{57}$Co</td>
<td>0.28</td>
<td>1.0</td>
</tr>
<tr>
<td>$^{58}$Co</td>
<td>0.59</td>
<td>1.8</td>
</tr>
<tr>
<td>$^{65}$Zn</td>
<td>3.12</td>
<td>6.4</td>
</tr>
<tr>
<td>$^{68}$Ge</td>
<td>0.54</td>
<td>0.94</td>
</tr>
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</table>

Shipping container: 2m x 2m x 2m cube

Ge storage: 4m x 4m x 4m cube

Support Materials

Electroformed Copper

- Low-mass design
- Choice plastics (Teflon®, Delrin®, CuFlon®, etc)

Low-background front-end electronics

- High-purity OFHC anode stock
- Ion exchange at C removes Ra, Th
- Factor of >8000 Th removal has been demonstrated
- Expect to achieve 1 μBq/kg $^{232}$Th specification
Advanced Event Tagging

Segmentation

Effective against multisite events (especially internal $\gamma$'s) distributed in $z/\Phi$
(2x-5x red.)

Pulse Shape Discrimination

Effective against multisite events (especially internal $\gamma$'s) distributed in $\rho$ (1.5x-4x reduction)
Advanced Event Tagging

Granularity

Single Site Time Correlation

\[ ^{68}_{31} \text{Ga} \quad ^{68}_{32} \text{Ge} \]

\[ Q_{\text{EC}} = 2921.1 \text{ keV} \quad Q_{\text{EC}} = 10.367 \text{ keV} \]

Look back in time from 2.9 MeV positron to veto \(^{68}\text{Ga}\) (~10x reduction)

Advanced Veto/Cooling Schemes

Liquid Ar?

Effective against
- \(^{208}\text{Tl}\) and \(^{214}\text{Bi}\) (2x-5x red.)
- some neutrons
- Muons (~10x red.)

40 cm
Cosmogenic Backgrounds

Graph showing the relationship between depth (km.w.e.) and \( \mu \)-induced backgrounds (events/keV/kg/year). The graph includes a data point for KKDC (Gran Sasso) multiplied by 7.4 due to granularity, PSD, and segmentation. There is a horizontal line representing the Majorana total background target. The Sudbury depth is indicated at 6 km.w.e.
## Background Budget

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*Gross/Net = before/after applying cut efficiencies

Dominated by $^{232}$Th in Cu

**TOTAL SUM** 1.21
Majorana Sensitivity

Background model: 0.00025/kg/keV/year

Half Life (Years)

Measurement Time (Months)

60 kg start time
120 kg start time
180 kg start time

KKDC sensitivity

$(0.69 - 4.18) \times 10^{25}$ yrs
Sensitivity to KKDC Signal

KKDC: 71.7 kg y

\[ T_{1/2}^{0\nu} = 1.2^{+3.0}_{-0.5} \times 10^{25} \text{ y} \]

\[ \langle m_\nu \rangle = 0.44^{+0.14}_{-0.20} \text{ eV} \]

significance: 4.2 \sigma
Sensitivity to KKDC Signal
Summary

- The M180 reference design is massive, clean, hi-tech, and scalable.

- We are confident we can push the background rate in the ROI to ~1 event per ton-year.

- Sensitivity (90% C.L.) for 460 kg y exposure:

  \[ T^{0\nu}_{1/2} > 5.6 \times 10^{26} \text{ y or } \langle m_{\nu} \rangle < 100 \text{ meV} \]

- The collaboration is highly experienced in all aspects of the experiment; no reliance on unproven technologies.

- We are ready to proceed!