The MAJORANA DEMONSTRATOR

A search for neutrinoless double-beta decay of germanium-76

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on behalf of the MAJORANA Collaboration
The MAJORANA Collaboration (June 2011)

Note: Red text indicates students

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Neutrinoless double-beta decay ($0\nu\beta\beta$)

- Observation indicates:
  - Neutrino is a Majorana particle
  - Lepton number is not conserved
  - Measurement of rate could provide information about neutrino mass

![Diagram of Neutrinoless double-beta decay](image)

- $e^-$
- $\bar{\nu}_e = \nu_e$
- $e^-$
- $Z$ to $Z+2$

Summed electron energy

Counts vs. Q-value

$2\nu\beta\beta$

$0\nu\beta\beta$
Neutrino mass and $0\nu\beta\beta$

$0\nu\beta\beta$ rate

$$(T_{1/2})^{-1} = G_{0\nu} |M_{0\nu}|^2 m_{\beta\beta}^2$$

Neutrino mass hierarchy

- Normal Hierarchy: $\nu_e, \nu_\mu, \nu_\tau$
- Inverted Hierarchy: $m_3 > m_1 > m_2$

Sensitivity of a tonne-scale $^{76}$Ge experiment

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

- Zero background
- 0.1 counts/ROI/yr
- 1 count/ROI/yr

NME: Simkovic et al, Phys Ref C 79, 055501 (2009)
The GERDA and MAJORANA Experiments

Detector array: enriched Ge crystals submerged in liquid argon
Shield: high-purity liquid argon, $\text{H}_2\text{O}$

Detector array: enriched Ge crystals in vacuum cryostats
Shield: lead, copper

Goal: select best techniques developed in GERDA and MAJORANA for a joint tonne-scale Ge experiment

http://www.mpi-hd.mpg.de/gerda
http://majorana.npl.washington.edu
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The MAJORANA Experiment

- Search for neutrinoless double-beta decay using an array of germanium detectors enriched in $^{76}$Ge
- First phase of MAJORANA under construction: the DEMONSTRATOR, 40-kg R&D detector
- Attempt to achieve a background rate 100x lower than previous Ge experiments
The MAJORANA Experiment

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Background goal for tonne-scale:
1 count per tonne-year in 4-keV region surrounding Q-value
The MAJORANA DEMONSTRATOR

- First phase of the MAJORANA experiment
- 40-kg ultra-clean Ge detector array deployed in two cryostats at 4850’ level of Sanford Lab
- 20 to 30 kg of crystals enriched to 86% $^{76}$Ge
- **Technical goal:** demonstrate background levels that justify construction of tonne-scale experiment
- **Science goal:** test recent claim of $0\nu\beta\beta$ observation - Phys. Lett. B 586 198 (2004)
The **Majorana Demonstrator**

- Ge detector
- Detector string
- Cryostat

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The MAJORANA DEMONSTRATOR

Ge detector

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**The DEMONSTRATOR**
The MAJORANA DEMONSTRATOR

Passive and active shielding:
- polyethylene scintillator veto
- radon exclusion box
- lead
- commercial copper
- electro-formed copper
Germanium detectors

- **MAJORANA** will use p-type point contact Ge detectors
- Excellent energy resolution: 0.16% FWHM at 2039 keV Q-value
- Can be enriched to 86% in $^{76}$Ge: *source is detector*
- Pulse-shape analysis can distinguish multi-site backgrounds from single-site signal events
- Low energy threshold allows opportunistic physics: *dark matter search*

**Model of electric field in PPC detectors**

**Energy spectrum with pulse-shape analysis**

- $^{208}$Tl
- DEP
- all events
- single-site events
Backgrounds
Backgrounds

Expected backgrounds

**Intrinsic radiation:** U and Th decay chains, $2\nu\beta\beta$

**Cosmic rays:**
- Activation at surface creates unstable isotopes in Ge, copper
- Muons, muon-induced neutrons can interact in detectors and apparatus
# Backgrounds

## Expected backgrounds

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## Background reduction techniques

**Passive and active shielding:** copper, lead, polyethylene, scintillator

**Ultra-clean materials:** Ge, copper, parylene

**Depth:** experiment will be conducted deep underground
Backgrounds

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**Background mitigation techniques**

- **Analysis cuts:** $0\nu\beta\beta$ should deposit energy in a small region of a single detector; other events can be flagged:
  - events that deposit energy in multiple detectors
  - events that deposit energy in multiple locations in one detector
  - events that are time correlated with other events

*The Majorana Demonstrator*
Recent progress

- DOE and NSF funding started in FY 2010
- **November 2010:** 19 of 36 natural Ge detectors delivered to Sanford Lab
- **April 2011:** All 36 natural Ge detectors characterized and accepted by Los Alamos National Lab
- **June 2011:** Isoflex completed enrichment of 20 kg Ge; delivery by Sept. 2011
- **August 2010:** Production of electro-formed copper started in shallow site at Pacific Northwest National Lab
- **July 2011:** Ten electro-forming baths operational at Sanford 4850’ level
- Preparation of lab in Davis Campus at Sanford 4850’ level is underway
Recent progress: germanium detectors

Facility established for reduction of GeO$_2$ to metal, zone refinement of Ge metal

19 natural Ge detectors delivered to Sanford in November 2010

Underground storage facility in Cherokee Caverns

Ongoing MC background simulation campaign

Isotope Fractional Composition

- $^{70}$Ge: 0.00006(1)
- $^{72}$Ge: 0.00011(1)
- $^{73}$Ge: 0.00033(3)
- $^{74}$Ge: 0.086(5)
- $^{76}$Ge: 0.914(5)

Facility established for reduction of GeO$_2$ to metal, zone refinement of Ge metal

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Progress and Highlights

- Isotope Fractional Composition
- Underground storage facility in Cherokee Caverns
- Facility established for reduction of GeO$_2$ to metal, zone refinement of Ge metal
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Recent progress: production of ultra-clean copper

 electro-forming laboratory at Sanford

machining of electro-formed copper from PNNL

electro-forming baths in the underground clean room at 4850’ level of Sanford Lab
Recent progress: electronics and cabling

- Requires materials very low in radioactive impurities
- Trace proximity of traces provides ~1 pF
- Silica or sapphire substrate provides thermal control
- Amorphous Ge resistor: deposit in H gives proper resistance at low temperature

Front End Preamp

- Amorphous Ge resistor
- Silica substrate
- Au/Cr traces
- Custom Parylene coated wires

Prototype front-end electronics

Clean parylene cable production

Parylene ribbon cable ~ 3 mm

Multiple-detector electronics test string
Summary and Outlook

• Observation of neutrinoless double-beta decay would determine Majorana nature of the neutrino and could provide information about neutrino mass

• **MAJORANA** will search for 0νββ of $^{76}$Ge with an array of Ge detectors

• Construction of the first phase of **MAJORANA**, the **DEMONSTRATOR**, is underway:
  
  • Beneficial occupancy of MJD lab by May 2012
  
  • Prototype cryostat of natural Ge by late summer 2012
  
  • Enriched material ready for detector fabrication by February 2012
  
  • First module with enriched Ge in 2013
Thank you!

The MAJORANA Collaboration
Neutrino mass

Estimated KATRIN Sensitivity

Disfavored by $0\nu\beta\beta$

Klapdor-Kleingrothaus et al. claimed signal

Inverted

Normal
Isotopic concentrations of enriched material

<table>
<thead>
<tr>
<th>Isotope</th>
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PNNL measurement of material from ECP