The MAJORANA DEMONSTRATOR: Ge for $0
\nu\beta\beta$ and Dark Matter

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For the Majorana Collaboration
Germanium for $0\nu\beta\beta$

- $^{76}\text{Ge}$ is an excellent candidate $0\nu\beta\beta$ source:
  - Ge detectors are a proven technology
  - Excellent energy resolution: 0.16% at 2039keV
  - Favorable Nuclear Matrix Element
  - Demonstrated background rejection techniques:
    - Granularity
    - Pulse-shape discrimination

- P-Type Point Contact detectors (PPCs)
  - Low-noise -> sub-keV energy thresholds
  - Excellent timing discrimination
$0\nu\beta\beta$ sensitivity

![Graph showing $0\nu\beta\beta$ sensitivity](chart.png)

- Inverted Hierarchy ($m_1 \rightarrow 0$ eV)
- Zero background
- 0.1 counts/ROI/t/y
- 1 count/ROI/t/y
- 4 counts/ROI/t/y

**Mod. Phys. Lett. A 24 (2006), p. 1547 (3α):** $(1.30-3.55) \times 10^{25}$ years
MAJORANA DEMONSTRATOR R&D

Goals

• Technical goals:
  – Demonstrate backgrounds low enough to justify building a tonne-scale Ge experiment.
  – Establish feasibility to construct & field modular arrays of Ge detectors.
  – Minimize costs, optimize the schedule, and retire risks for a future 1-tonne experiment.

• Science goals:
  – Although we are driven by technical goals, we also aim to extract the maximum science from the DEMONSTRATOR prototype,
    • (Directly) Test the recent claim of an observation of $0\nu\beta\beta$ in $^{76}$Ge.
    • Exploit the low-energy sensitivity to perform searches for dark matter, axions.
  – Work cooperatively with GERDA Collaboration toward a single international tonne-scale Ge experiment that combines the best features of MAJORANA and GERDA.
The MAJORANA DEMONSTRATOR

- Background Goal in the $0 \nu \beta \beta$ peak region of interest (4 keV at 2039 keV)
  - 3 counts/ROI/t/y (after analysis cuts)
  - scales to 1 count/ROI/t/y for a tonne experiment
- 40-kg of Ge detectors
  - Baseline: 20-kg of 86% enriched $^{76}\text{Ge}$ crystals & 20-kg of $^{\text{nat}}\text{Ge}$ (up to 30-kg enriched $^{76}\text{Ge}$)
  - Detector Technology: P-type, point-contact.
- 2 independent cryostats
  - ultra-clean, electroformed Cu
  - 20 kg of detectors per cryostat
  - naturally scalable
- Compact Shield
  - low-background passive Cu and Pb shield with active muon veto
- Located underground at 4850’ Sanford Lab
The MAJORANA DEMONSTRATOR

2012 - Prototype Cryostat (3 strings, $^{nat}$Ge)
2013 - Cryostat 1 (3 strings $^{enr}$Ge & 4 strings $^{nat}$Ge)
2014 - Cryostat 2 (up to 7 strings $^{enr}$Ge)
MJD Detector Arrays

- Ge detectors mounted in custom, low-mass mounts, fabricated from EFCu, PTFE
- Mounts compatible with range of detector form factors
- Detector units stacked in strings. Strings mechanically rigid; good thermal conductivity
PPCs: Timing Capabilities

PPCs: Low-Energy Performance

- Point-contact reduces detector capacitance.
- PPCs capable of sub-keV energy thresholds.
- This presents an interesting opportunity for an array of PPC-type Ge detectors...

![Graph](Image)
Sensitivity of PPCs to WIMPs

M.G. Marino, Ph.D. Disseration, Univ. of Washington (2010)
MAJORANA DEMONSTRATOR in the Dark Matter Picture

- PPC detectors provide a unique opportunity to probe an open region of WIMP detection space!

- Assumptions:
  - 20kg of detectors
  - Spin-independent WIMPS
  - $^3\text{H}$: 15 days surface exposure
  - 0-10keV: .001 cnts/kg/keV/day
  - $n: << ^3\text{H}$, based on IGEX

Xenon 100: arxiv:1104.2549v2
Dark Matter with PPCs: MALBEK

- MAJORANA Low-Background BEGe at KURF
- PPC detector
- Low-background cryostat
- Layered shielding
  - 1” ancient lead
  - 8” low-background lead
  - 2” plastic scintillator μ veto
  - 10” polyethylene
- Testbed for MAJORANA detector electronics, DAQ, simulations.
Rise Time Cuts: Removing Degraded Pulses

![Graph showing different time cuts for 68Ga, 68Ge, and 65Zn with RT < 500 ns, RT < 1500 ns, and RT < 2500 ns.]
Producing $^{\text{enr}}$Ge Detectors

- MAJORANA received first shipment of $^{\text{enr}}$Ge Sept. 2011.
- 28.5kg GeO$_2$ enriched at ECP, Krasnoyarsk, Russia (~20kg $^{76}$Ge)
- Stored underground at Cherokee Caverns, Knoxville TN

Matthew Green - NDM12 Nara, Japan

June 11, 2012
Ge Detector Production

- Reduction & Refinement
  - ESI, Oak Ridge, TN (SBIR)
- Crystal-pulling, machining, contact deposition
  - Commercial vendor selected.
- 19 commercial \(^{nat}\)Ge detectors already on hand at SUL
MJD Lab @ SURF
Background Simulations

- MaGe: a GEANT4-based application jointly developed by MAJORANA / Gerda
  - Geometries
  - Physics lists
  - Identical output to DAQ-unified analysis code
- MaGe is well-validated
  - MALBEK full background spectrum modeled accurately
  - Extensive suite of validation tests to ensure GEANT4 accuracy in $0\nu\beta\beta$ & light WIMP regimes

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Background Simulations
Background Simulations

- Full-spectrum background model:
  - Uranium / Thorium decay chains
  - $^{40}$K / $^{60}$Co / $^{68}$Ge
  - $\alpha$ / $\beta$ emitting surface contaminants
  - Neutron backgrounds
- Engineering design support
  - Shielding / veto efficiencies
  - Materials qualifications
  - Calibration system design
- Estimation of effectiveness of analysis cuts
- $\sim$60k CPU hrs, 15Tb data on NERSC clusters
# Material Assay

<table>
<thead>
<tr>
<th>Material</th>
<th>Uses</th>
<th>Contaminant Goals</th>
<th>Equivalent Achieved Assay</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Germanium</td>
<td>Detectors</td>
<td>&lt;100 days $^{68}$Ge exp.</td>
<td>N/A</td>
<td>[Avi92],</td>
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<tr>
<td></td>
<td></td>
<td>&lt;30 days $^{60}$Co exp.</td>
<td></td>
<td>[Ell10]</td>
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<tr>
<td></td>
<td></td>
<td>&lt;14 nBq/kg U/Th</td>
<td>&lt;14 nBq/kg</td>
<td>[Det08b]</td>
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<tr>
<td></td>
<td></td>
<td>&lt;0.5 $\mu$ Bq/cm$^2$ surf. $\alpha$</td>
<td>&lt;0.5 $\mu$ Bq/cm$^2$</td>
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<tr>
<td>Electroformed Copper</td>
<td>Detector Mounts, Cryostat</td>
<td>&lt;0.1 $\mu$ Bq/kg $^{208}$Tl</td>
<td>0.2 ± 0.1 $\mu$ Bq/kg</td>
<td>[Hop09],</td>
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<tr>
<td></td>
<td>Inner Cu Shield</td>
<td>&lt;0.3 $\mu$ Bq/kg $^{214}$Bi</td>
<td>&lt;1.3 $\mu$ Bq/kg rej. fac. ≤100</td>
<td>[Hop11]</td>
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<td></td>
<td></td>
<td>&lt;20 $\mu$ Bq/kg $^{60}$Co</td>
<td></td>
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<td>Commercial Copper</td>
<td>Outer Cu Shield</td>
<td>&lt;0.3 $\mu$ Bq/kg $^{208}$Tl</td>
<td>0.3 ± 0.1 $\mu$ Bq/kg</td>
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<td></td>
<td></td>
<td>&lt;3 $\mu$ Bq/kg $^{214}$Bi</td>
<td>&lt;36 $\mu$ Bq/kg &lt;saturation</td>
<td>[Leo08]</td>
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<tr>
<td></td>
<td></td>
<td>≤saturation $^{60}$Co</td>
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<td>Lead</td>
<td>Lead Shield</td>
<td>&lt;1 $\mu$ Bq/kg $^{208}$Tl</td>
<td>&lt;1 $\mu$ Bq/kg</td>
<td>[Leo08]</td>
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<tr>
<td></td>
<td></td>
<td>&lt;10 $\mu$ Bq/kg $^{214}$Bi</td>
<td>&lt;10 $\mu$ Bq/kg</td>
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<td>Plastic</td>
<td>Detector Mounts, Insulation</td>
<td>&lt;0.4 $\mu$ Bq/kg $^{208}$Tl</td>
<td>36 ± 3 nBq/kg &lt;10 $\mu$ Bq/kg</td>
<td>[Efro10],</td>
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<tr>
<td></td>
<td></td>
<td>&lt;10 $\mu$ Bq/kg $^{214}$Bi</td>
<td></td>
<td>[Leo08]</td>
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<tr>
<td>Small Components</td>
<td>Front-End Electronics,</td>
<td>&lt;6 nBq/chan. $^{208}$Tl</td>
<td>&lt;6 nBq/chan.</td>
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<tr>
<td></td>
<td>Contacts</td>
<td>&lt;24 nBq/chan. $^{214}$Bi</td>
<td>&lt;24 nBq/chan.</td>
<td>[Loa10]</td>
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<tr>
<td>Cables</td>
<td>Signal, High-Voltage</td>
<td>&lt;40 $\mu$ Bq/kg $^{208}$Tl</td>
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<td></td>
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<td>&lt;500 $\mu$ Bq/kg $^{214}$Bi</td>
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<td>Polyethylene Shield</td>
<td>Neutron Modification</td>
<td>≥30 cm</td>
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<tr>
<td>Rock</td>
<td>Overburden</td>
<td>≥4300 mwe</td>
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<td>[Ste10]</td>
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</table>
Electroformed Cu

- Cryostats 1&2, their detector components, shielding to be fabricated from underground e-formed Cu
- Baths operational at SUL, PNNL shallow underground facility
- Electroforming process inherently high-purity
- Assays of produced Cu show < 1ppt U$^{238}$
- 75 μm/day growth rate
Cryostat and Component Fabrication

- Underground cleanroom machine shop being installed in MJD lab
- Most copper components will have no surface exposure
- Only clean, water-soluble lubricant
- All components acid-etched, surface-passivated
- Parts-tracking DB in use
Glovebox Assembly

Detectors handled in Rn-mitigated glovebox.
The Prototype Cryostat

- Commercial Cu Cryostat
- Test of fabrication and assembly techniques / procedures
- Test of mechanical design
Vacuum & Cryogenic Systems

- Remotely-operated UHV vacuum system
- Prototype Cryostat vacuum system commissioning underway
- Thermosyphon system for detector array cooling
- Prototype Cryostat Thermosyphon fabricated and ready for integration with vacuum system
Passive Shielding: Copper

- 5cm ultra-pure EFCu inner shield
- 5cm low-background commercial copper outer shield
- Design complete, fabrication begun.
- Inner shield EFCu in production
Passive Shielding: Lead

- 45cm Pb shielding
- 3500 5cm x 10cm x 20cm bricks purchased from Sullivan Lead, virgin Doe Run Source
- ~3000 bricks donated from University of Washington
- Cleaning facilities constructed
- Stacking pattern designed
Active Muon Veto

• Near-complete $4\pi$ coverage
• Monte Carlo studies: >99% efficiency
• Scintillator parts being procured

June 11, 2012
Potential DEMONSTRATOR Physics Reach

• The Demonstrator is an ultra-low background, low-threshold, high-resolution detector.
• Possible searches for new physics include:
  – $0\nu\beta\beta$
  – Dark Matter WIMPs
  – Axions
  – Sterile neutrinos
  – Pauli Exclusion Principle violation, other exotic things
Toward Tonne-Scale

- Utilizes and builds on major R&D activities of GERDA and MAJORANA Collaborations.
- Pursuing a range of shield designs between the compact and the GERDA-like. Ultimate design will be based on results from GERDA Phases I & II and the MAJORANA DEMONSTRATOR.
- Should have preliminary information from both GERDA Phase II and MJD Cryo 1, aim to reach agreement on the down-select process during 2014.
- Various site options:
  - SNOLAB 6800L
  - China Jinping Underground Laboratory 8240’
  - Homestake 4850L - compact shield looks very risky based on current knowledge of background requirements. LAr also faces risks.
Summary

- The MAJORANA DEMONSTRATOR will probe $0\nu\beta\beta$ and dark matter with an ultra-low background detector.

- Phased deployment over the next 3 years, with data from enriched detectors as soon as 2013.

- The MAJORANA & Gerda Collaborations will combine efforts on a tonne-scale $0\nu\beta\beta$ experiment that will have the sensitivity to probe $0\nu\beta\beta$ lifetimes in $^{76}\text{Ge} \sim 10^{27}$-$10^{28}$ years.
The MAJORANA Collaboration

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June 11, 2012

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