A Status Report on The MAJORANA DEMONSTRATOR Project

Carolina International Symposium on Neutrino Physics
May 20-22, 2013 University of South Carolina

Happy Birthday
Frank and Ettore
What is $\beta\beta$?

Fig. from Deep Science

Fig. from arXiv:0708.1033

Feb. 25, 2013

Steve Elliott
\[ \Gamma_{2\nu} = G_{2\nu} |M_{2\nu}|^2 \quad \Gamma_{0\nu} = G_{0\nu} |M_{0\nu}|^2 m_{\nu}^2 \]

\( G \) are calculable phase space factors.
\[ G_{0\nu} \sim Q^5 \]
\( |M| \) are nuclear physics matrix elements.

Hard to calculate.

\( m_{\nu} \) is where the interesting physics lies.
What about mixing, $m_\nu$ & $\beta\beta(0\nu)$?

No mixing: $\langle m_{\beta\beta} \rangle = m_{\nu e} = m_1$

$$\langle m_{\beta\beta} \rangle = \sum_{i=1}^{3} |U_{ei}|^2 m_i \varepsilon_i$$

virtual $\nu$ exchange

$\varepsilon = \pm 1$, CP cons.

Compare to $\beta$ decay result:

$$\langle m_\beta \rangle = \sqrt{\sum_{i=1}^{3} |U_{ei}|^2 m_i^2}$$

real $\nu$ emission

Compare to cosmology:

$$\sum m_i = \sum m_i$$
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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,
    • Test the recent claim of an observation of 0νββ 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 Module

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

(Excellent energy resolution, intrinsically clean detectors, commercial technologies, best $0\nu\beta\beta$ sensitivity to date)

• 40-kg of Ge detectors
  – 30-kg of 86% enriched $^{76}\text{Ge}$ crystals required for science and background goals
  – 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

• Located at 4850' level at Sanford Lab

• Background Goal in the $0\nu\beta\beta$ peak ROI (4 keV at 2039 keV)
  ~ 3 count/ROI/t-y (after analysis cuts) (scales to 1 count/ROI/t-y for tonne expt.)
MJD Implementation

• Three Phases
  – Prototype cryostat (2 strings, $^{\text{nat}}\text{Ge}$) (Summer 2013)
  – Cryostat 1 (3 strings $^{\text{enr}}\text{Ge}$ & 4 strings $^{\text{nat}}\text{Ge}$) (Late 2013)
  – Cryostat 2 (up to 7 strings $^{\text{enr}}\text{Ge}$) (Fall 2014)
Underground Laboratory

May 2013

CISNP - Elliott
Underground Lab - Status

- Eforming lab operational since summer 2011
- Davis Campus lab outfitting finished
- Shield floor, LN system, assembly table, air bearing system, glove boxes, localized clean space all installed
Materials and Assay

• Significant R&D and advances made in improvement of ICP-MS sensitivity for U and Th in copper. Req. sensitivity of 0.3 ppt reached.
• Monitoring U and Th in copper baths electrolyte.
• All plastic materials selected after high sensitivity NAA analysis. Assay complete.
• Significant progress made in development of low background front-end electronics.

Plastics for NAA analysis

Front-end electronics

TIG rods in LB count system

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Electroforming

- Eforming at PNNL and at 4850’ at SURF
- Machine shop operational

Installation of mandrel in bath

Copper ready to cut

Bake/Quench

Checking Deposition

EDM installed UG

CISNP - Elliott

Lathe installed UG
### Enriched Ge

- **42.5 kg** $^{enr}$Ge received as oxide and stored UG in Oak Ridge.
- Processed to metal with 98% conversion.
- Expect additional 4-5 kg Russian contribution.

#### Batch 1 (20 kg) Assay results

<table>
<thead>
<tr>
<th></th>
<th>Specs</th>
<th>ECP</th>
<th>ORNL Physics (Sample 1)</th>
<th>ORNL CSD (sample 2)</th>
<th>PNNL (Sample 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{76}$Ge</td>
<td>$\geq 86.0$</td>
<td>87.67</td>
<td>86.9 (2)</td>
<td>87.9 (9)</td>
<td>88.2 (3)</td>
</tr>
<tr>
<td>$^{74}$Ge</td>
<td>12.16</td>
<td>12.5 (1)</td>
<td>12.0 (1)</td>
<td>11.8 (3)</td>
<td></td>
</tr>
<tr>
<td>$^{73}$Ge</td>
<td>0.07</td>
<td>$&lt; 0.2$</td>
<td>0.052 (1)</td>
<td>0.04 (2)</td>
<td></td>
</tr>
<tr>
<td>$^{72}$Ge</td>
<td>0.05</td>
<td>$&lt; 0.2$</td>
<td>0.0058 (3)</td>
<td>0.02 (1)</td>
<td></td>
</tr>
<tr>
<td>$^{70}$Ge</td>
<td>$\leq 0.07$</td>
<td>0.05</td>
<td>$&lt; 0.2$</td>
<td>0.0157 (3)</td>
<td>0.005 (4)</td>
</tr>
</tbody>
</table>
• 20 kg of modified natural-Ge BEGe (Canberra) detectors in hand (33 dets. UG).
• ORTEC selected to produce enriched detectors. Excellent projected yield.
• First enriched detectors (9.5 kg in 10 det.) delivered UG.
Point Contact Detectors

Sharp weighting potential permits good discrimination between multiple and single site events

[Graph showing charge and current signals with time axis (t [ns]) and amplitude (Arb. units)]

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Multi-Site Rejection

Removes 89% of multi-site events (gamma rays)
Retains 90% of single-site events ($0\nu\beta\beta$)
• Prototype cryostat assembled and being tested. E-beam welds completed.
• Thermosyphon design validated. Fabricated and tested.
• Prototype vacuum system designed, reviewed, assembled, and being operated.
• String test cryostats built.
• Parts and material tracking in place.
• Clean machining implemented underground.
Mechanical Systems

- Glove box (Mbraun) underground.
- Hovair delivered and tested.
- Overfloor installed UG.
- Majority of shielding material in hand, some is underground.
- Prototype calibration system demonstrated.
Data Acquisition

- Slow controls fielded and in operation in TCR and Davis campus Prototype cryostat vacuum system in operation.
- Low sub-keV threshold digital system operating for MALBEK.
- The DAQ software and hardware is up and running and in continuous use in test stands at UNC, PNNL, LBNL, LANL, and UW.
- Detector acceptance and characterization systems operating at SURF.
- Tablet and smart phone support.
Simulation: MJD 0-10 MeV
DEMONSTRATOR Background Model

Total BG expected 3 cnts/(ROI-t-y)
Towards 1TGe

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

**GERDA**
- ‘Bare’ $^{\text{enr}}$Ge array in liquid argon
- Shield: high-purity liquid Argon / H$_2$O
- Phase I (2012): ~18 kg (HdM/IGEX diodes)
- Phase II (2013): add ~20 kg new detectors - Total ~40 kg

**Joint Cooperative Agreement:**
- Open exchange of knowledge & technologies (e.g. MaGe, R&D)
- Intention is to merge for tonne-scale experiment. Select best techniques developed and tested in GERDA and MAJORANA
MJD Overview

- Assembly and construction proceeding at Sanford Davis Campus laboratory.
- Based on assays, material backgrounds projected to meet cleanliness goals.
- EF copper being produced underground at SURF and PNNL
- Successful reduction and refinement of $^{\text{enr}}\text{Ge}$ with 98% yield.
- Detector vendor AMTEK (ORTEC) has produced 9.5 kg in 10 detectors from the reduced/refined $^{\text{enr}}\text{Ge}$. 9 detectors underground at SURF.

Schedule
- Prototype Cryostat – Summer 2013
- Cryostat 1 – Late 2013
- Cryostat 2 - Fall 2014