The MAJORANA DEMONSTRATOR
double-beta decay experiment

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on behalf of the MAJORANA Collaboration
The MAJORANA Collaboration

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0νββ experimental signature

observation implies

• neutrino is a Majorana fermion
• lepton number is violated
• plausible scenario for generation of baryon asymmetry
• model dependent mass measurement

Germanium-76: 32 protons 44 neutrons

Q = 2039 keV

Selenium-76: 34 protons 42 neutrons

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\[ \text{Selenium-76: 34 protons 42 neutrons} \]

\[ Q = 2039 \text{ keV} \]
0νββ rate and m_{ββ}

\[ [T_{1/2}^{0νββ}]^{-1} = G^{0νββ} |M^{0νββ}|^2 < m_{0νββ} >^2 \]

Effective 0νββ mass, m_{ββ} [eV]

Lightest neutrino mass [eV]

Inverted

Normal

KATRIN sensitivity

mixing parameters from PDG 2012
$0\nu\beta\beta$ rate and $m_{\beta\beta}$

\[
[T_{1/2}^{0\nu\beta\beta}]^{-1} = G^{0\nu\beta\beta} |M^{0\nu\beta\beta}|^2 < m_{0\nu\beta\beta} >^2
\]
$0\nu\beta\beta$ rate and $m_{\beta\beta}$

$$[T_{1/2}^{0\nu\beta\beta}]^{-1} = G^{0\nu\beta\beta} |M^{0\nu\beta\beta}|^2 < m_{0\nu\beta\beta} >^2$$

![Graph showing $0\nu\beta\beta$ rate and $m_{\beta\beta}$](image)

- Normal mixing parameters from PDG 2012
- Inverted
- Next generation
- KATRIN sensitivity

Current experiments
backgrounds and sensitivity

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

- Zero background
- 0.1 counts/ROI/t/y
- 1 count/ROI/t/y
- 4 counts/ROI/t/y

Mod. Phys. Lett. A 21 (2006), p. 1547 (3\(\sigma\)): (1.30-3.55) \(\times 10^{25}\) years

Inverted Hierarchy \( (m_\nu \rightarrow 0 \text{ eV}) \)
backgrounds and sensitivity

arXiv:1307.4720v1, Gerda phase 1: $> 3 \times 10^{25}$ years
The MAJORANA DEMONSTRATOR

Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics, with additional contributions from international collaborators.

Goals
- Demonstrate backgrounds low enough to justify building a tonne scale experiment
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Test Klapdor-Kleingrothaus claim
- Search for additional physics beyond the standard model

- Located underground at 4850' Sanford Underground Research Facility
- Background Goal in the 0νββ 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
  - 30 kg of 86% enriched $^{76}$Ge crystals
  - 10 kg of $^{nat}$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
The **MAJORANA DEMONSTRATOR**

- **Poly Shield**
- **Plastic Scintillator**
- **Muon Veto**
- **Lead Shield**
- **Outer Commercial Copper Shield**
- **Inner Electroformed Copper Shield**
Construction of the DEMONSTRATOR is proceeding in three stages.

Protoype Cryostat*  
summer 2013

Cryostat 1  
early 2014

Cryostat 2  
late 2014

*The Prototype Cryostat components are built from OFHC copper.
electroformed copper

- copper is electrodeposited onto stainless steel forms
- a 1.4-cm thick electroform takes approximately 8-12 months to complete.
- required purity levels are < 0.3 $\mu$Bq $^{238}$U/kg Cu and < 0.3 $\mu$Bq $^{232}$Th/kg Cu (substantially cleaner than commercially available)
- done underground
MJD background budget

MJD $\beta\beta(0\nu)$ background goals [cnts/ROI-t-\(\gamma\)]

- Electroformed Cu: 0.888
- OFHC Cu shielding: 0.480
- Lead shielding: 0.195
- Cables: 0.222
- Front ends: 0.270
- Ge (U/Th): 0.067
- Plastics + other: 0.030
- 68Ge, 60Co (enrGe): 0.088
- 60Co (Cu): 0.055
- External $\gamma$, (\(\alpha,n\)): 0.100
- Rn, surface $\alpha$: 0.054
- Ge, Cu, Pb (n, n'\(\gamma\)): 0.210
- Ge(n,n): 0.170
- Ge(n,\(\gamma\)): 0.130
- direct $\mu$ + other: 0.030
- $\nu$ backgrounds: 0.011

Legend:
- Natural Radioactivity
- Cosmogenic Activation
- External, Environmental
- $\mu$-induced
- Neutrinos
p-type point contact detectors


- allow multiple-site scattering event discrimination
- simple, relatively cheap, and easy to handle
- added benefits from sub-keV thresholds:
  - allow rejection of events from cosmogenically produced $^{68}$Ge, a background to $0\nu\beta\beta$.
  - extends physics reach of the DEMONSTRATOR

![Graphs showing charge and current signals for single-site and multi-site events](image)
MJD at Sanford Underground Research Laboratory

- Main MJD lab at 4850L Davis Campus, beneficial occupancy in May 2012.
- Operating Temporary Cleanroom Facility (TCR) at 4850L Ross Campus since Spring 2011.
10 baths at Sanford producing copper since July 2011 about 75% of EFCu complete, including major parts for cryostat 1
parts are manufactured in the MJD clean machine shop at the Davis Campus
8 enriched PPC detectors at SURF (as of 8/13)
2 strings of natural Ge detectors undergoing testing
both strings were constructed in the MJD Davis Campus lab
string 1 is installed in a string test cryostat
tools for automated string characterization are
being built
string 2 is installed in the prototype cryostat
physics beyond the standard model

with sub-keV thresholds, MJD can search for light WIMPS, solar axions, etc...

MALBEK

- 30 inches
- modern lead
- ancient lead
- cryostat
- Ge crystal
- LN dewar
- support frame
physics beyond the standard model

with sub-keV thresholds, MJD can search for light WIMPS, solar axions, etc...

MALBEK

modern lead
ancient lead
cryostat
Ge crystal
LN dewar
support frame
0νββ-decay observation would demonstrate lepton number violation and indicate that neutrinos are Majorana particles constituting a major discovery. Such a discovery would need to be confirmed from independent experiments using different isotopes and measurement techniques.

Construction of MJD well underway and proceeding on schedule.
- Prototype Cryostat: summer 2013
- Cryostat 1: early 2014
- Cryostat 2: end of 2014

During 2014 both MJD Cryo 1 and GERDA Phase II should be collecting data.

Working cooperatively with GERDA towards the establishment of a single international tonne-scale ⁷⁶Ge 0νββ collaboration.
simulated 60 kg-year spectrum
simulated 60 kg-year spectrum

all cuts applied
Tonne-scale background budget

Tonne-scale 76Ge 0νββ background goals [cnts/ROI-t-γ]

- Electroformed Cu
- OFHC Cu shielding
- Lead shielding
- Cables
- Front ends
- Ge (U/Th)
- Plastics + other
- 68Ge, 60Co (enrGe)
- 60Co (Cu)
- External γ, (α,n)
- Rn, surface α
- Ge, Cu, Pb (n, n'γ)
- Ge(n,n)
- Ge(n,γ)
- direct μ + other
- ν backgrounds

Natural Radioactivity
Cosmogenic Activation
External, Environmental
μ-induced
ν-induced
neutrinos
backgrounds and sensitivity

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