The MAJORANA DEMONSTRATOR

Progress towards showing the feasibility of a tonne-scale ^{76}Ge neutrinoless double-beta decay experiment

THE UNIVERSITY *of* NORTH CAROLINA *at* CHAPEL HILL

Padraic Finnerty

on behalf of the MAJORANA Collaboration

5 JUNE 2012

The MAJORANA Collaboration

Red text indicates students

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Open Questions in Neutrino Physics

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- What is the absolute mass scale and hierarchy?
- How have neutrinos shaped the evolution of the Universe? matter/anti-matter asymmetry?
- How do neutrinos have mass?
- What is the nature of the neutrino? Dirac or Majorana?
  - Neutrinoless double-beta decay ($0\nu\beta\beta$)

ββ-decay Overview

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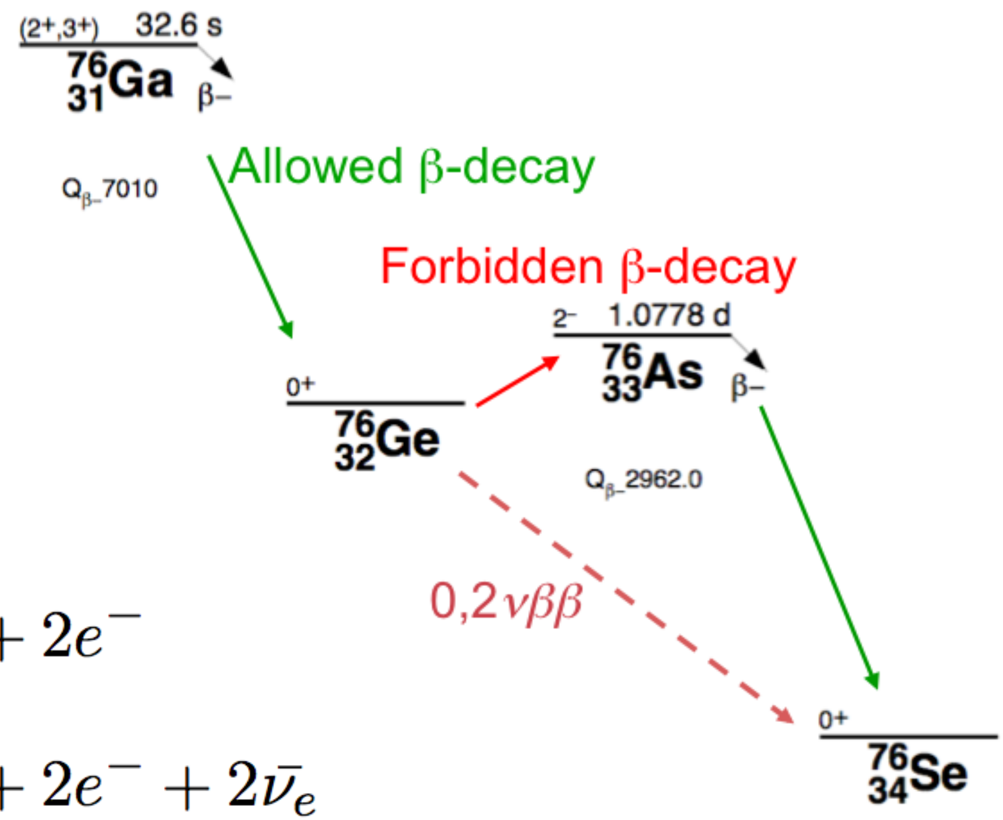
- Energetically allowed in several even-even nuclei
- Prefer nuclei stable against β^- decay



$$0\nu\beta\beta: \quad \mathrm{M(A,Z)} \rightarrow \mathrm{D(A,Z+2)} + 2e^-$$

$$2\nu\beta\beta: \quad \mathrm{M(A,Z)} \rightarrow \mathrm{D(A,Z+2)} + 2e^- + 2\bar{\nu}_e$$

ββ-decay Experimental Signature

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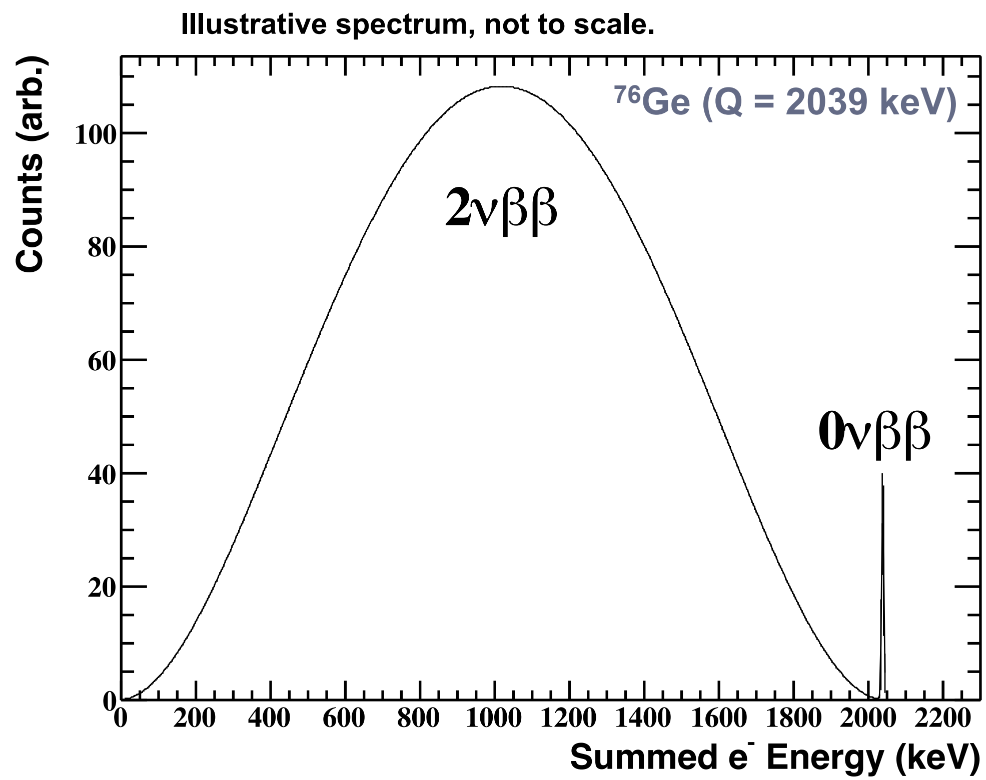
Implications

- Lepton number conservation violated
- Neutrinos are Majorana particles
- Provide insight into the neutrino mass

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

$$T_{1/2}^{0\nu} > 10^{25}\text{ years}$$

$$T_{1/2}^{2\nu} \sim 10^{21}\text{ years}$$



Daunting task ahead

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- Searching for $0\nu\beta\beta$ in ^{76}Ge, Q = 2039 keV difficult due to intrinsic backgrounds
  - materials contaminated with U/Th, ^{60}Co, ^{40}K, …
  - ^{68}Ge in Ge detector (cosmogenics)
  - Muons from cosmic rays

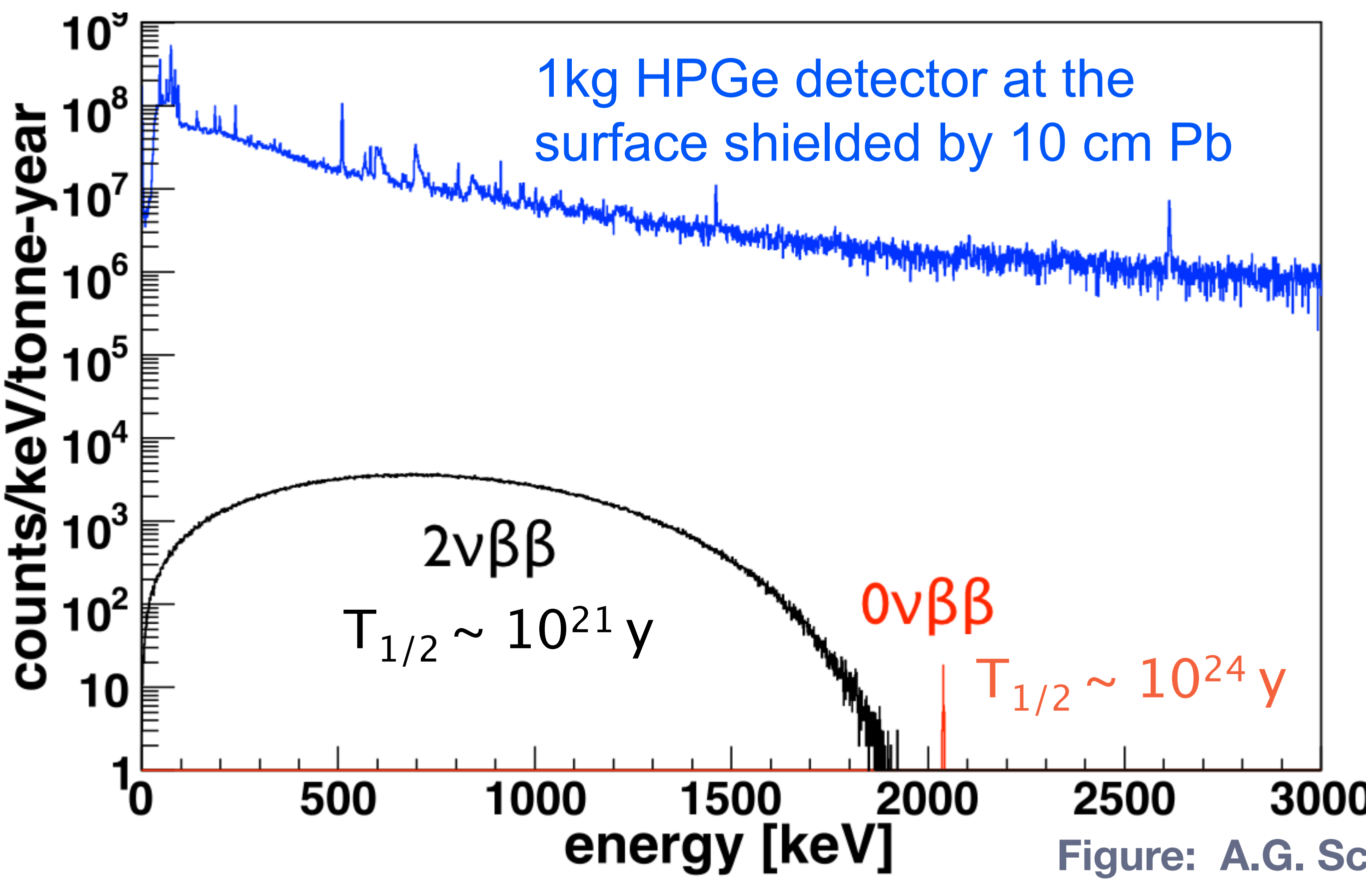

Figure: A.G. Schubert

GERDA and MAJORANA

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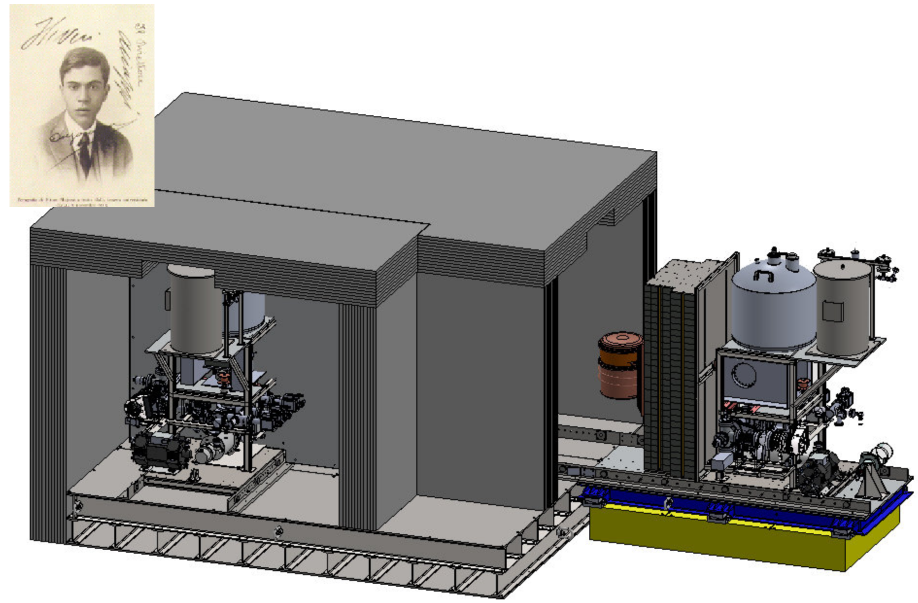
Detector array: enriched Ge crystals submerged in LAr
Shield: high-purity LAr, H_2O
http://www.mpi-hd.mpg.de/gerda/



Detector array: enriched Ge crystals in vacuum cryostats
Shield: lead, copper
http://www.npl.washington.edu/majorana/

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

The Majorana Demonstrator

Support from DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from collaborating institutions.

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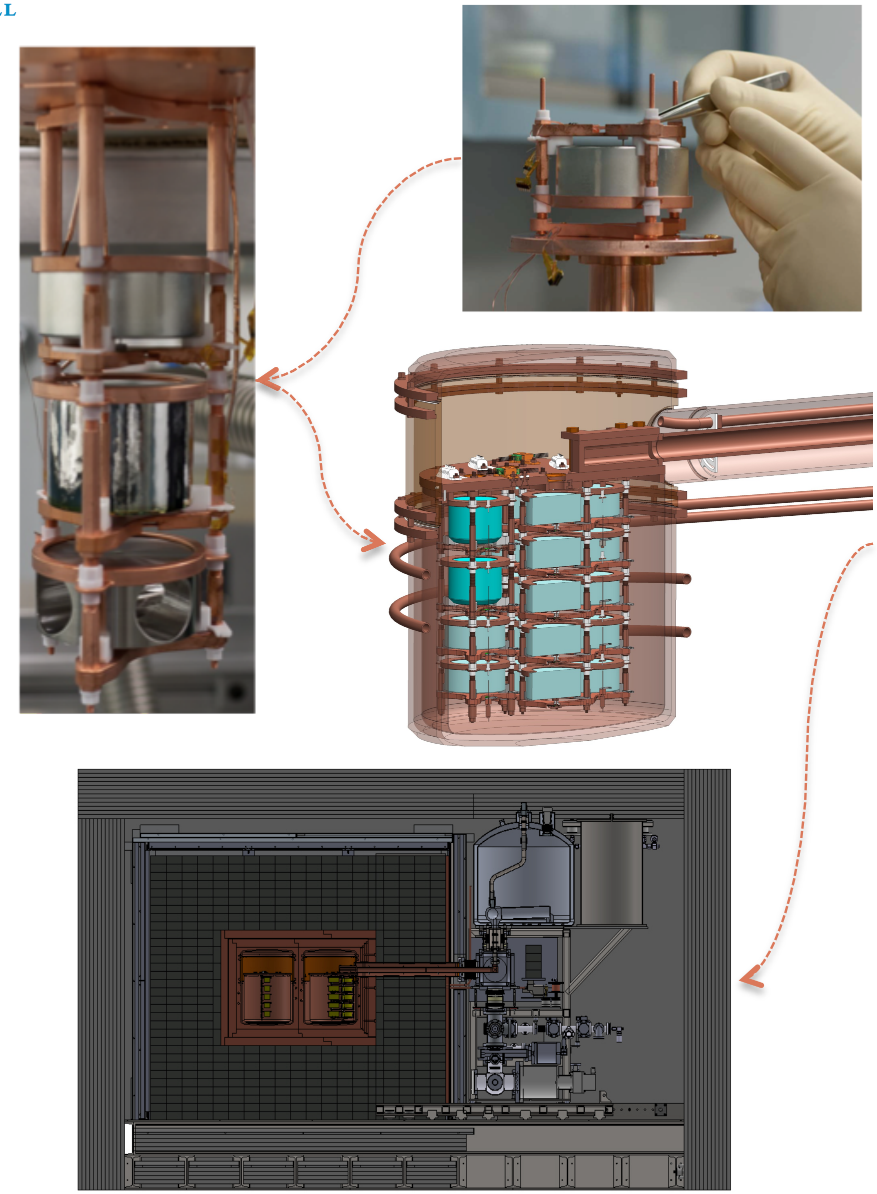
Technique

- Located at 4850L of the Sanford Underground Research Facility (**SURF**) in Lead, South Dakota, USA
- 40 kg of Ge detectors
  - Baseline: 30 kg of 86% enriched ^{76}Ge crystals and 10 kg of ^{nat}Ge
  - p-type point contact HPGe detectors
- *Two independent cryostats*
  - *ultra-clean, electroformed Copper*
  - *20 kg of detectors per cryostat*
  - *naturally scalable*
- *Compact shield*
  - *low-background passive Copper and Lead shield with active muon veto*



Implementation

- Prototype cryostat – December 2012
  - 2 strings, ^{nat}Ge
  - Same design as Cryostat 1 & 2, but constructed out of OFHC Copper, not electroformed
- Cryostat 1 – October 2013
  - 3 strings, ^{enr}Ge, 4 strings ^{nat}Ge
- Cryostat 2 – August 2014
  - 7 strings ^{enr}Ge

The MAJORANA DEMONSTRATOR

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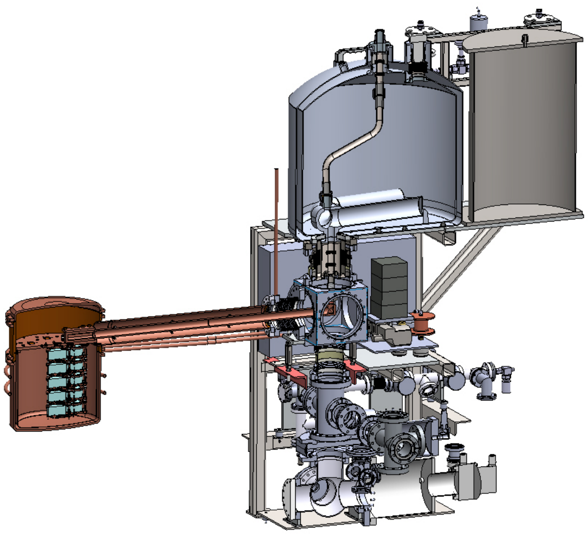

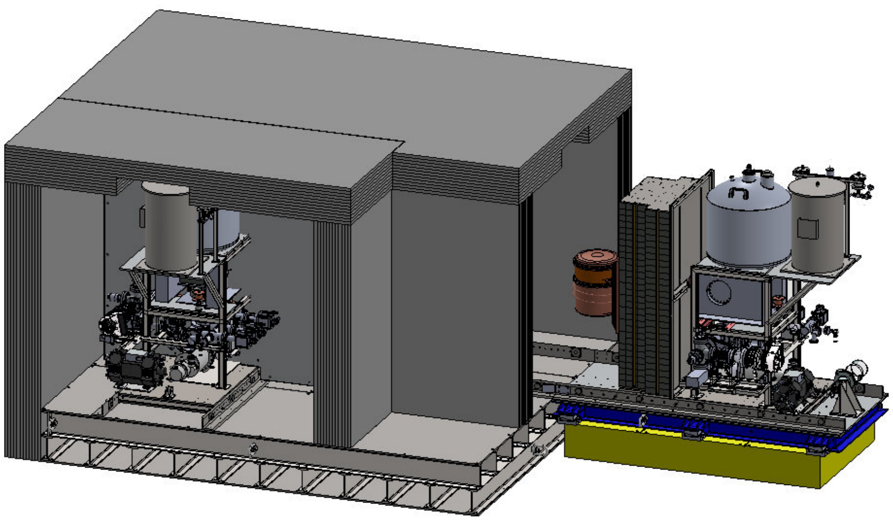

Goals

- Demonstrate **backgrounds low enough** to justify building a tonne scale experiment with GERDA.
- Background goal in $0\nu\beta\beta$ peak ROI (4 keV at 2039 keV):
  - 3 counts/ROI/t/y (after analysis cuts)
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Test Klapdor-Kleingrothaus claim*.
- Light WIMP search (< 10 GeV)

** H. V. Klapdor-Kleingrothaus and I. V. Krivosheina, Mod. Phys. Lett. A21, 1547 (2006).*

Recent Progress

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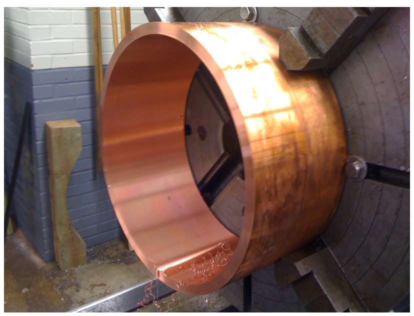
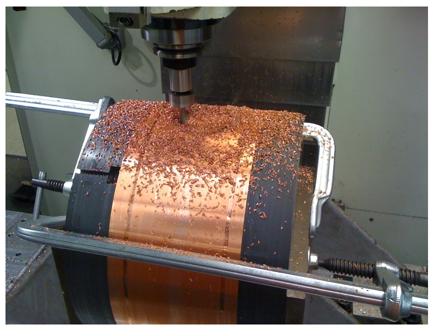
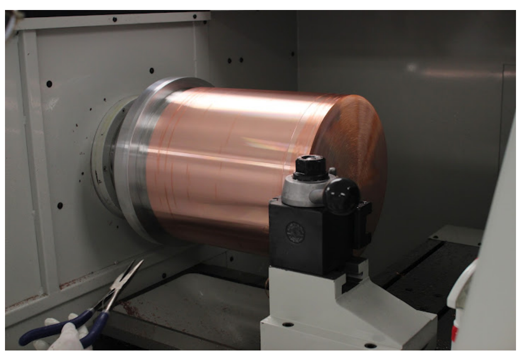
Prototype Cryostat

- Clean machining and etching of prototype cryostat underway.







Infrastructure

- Preparations ongoing in main MJD lab.
- Electroforming facility at 4850L Ross campus since Oct 2010

Recent Progress

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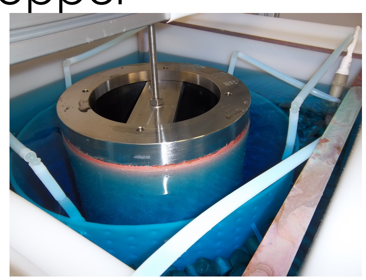
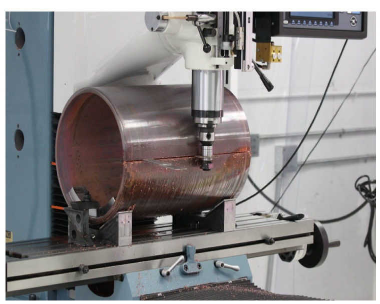
Electroformed Cu

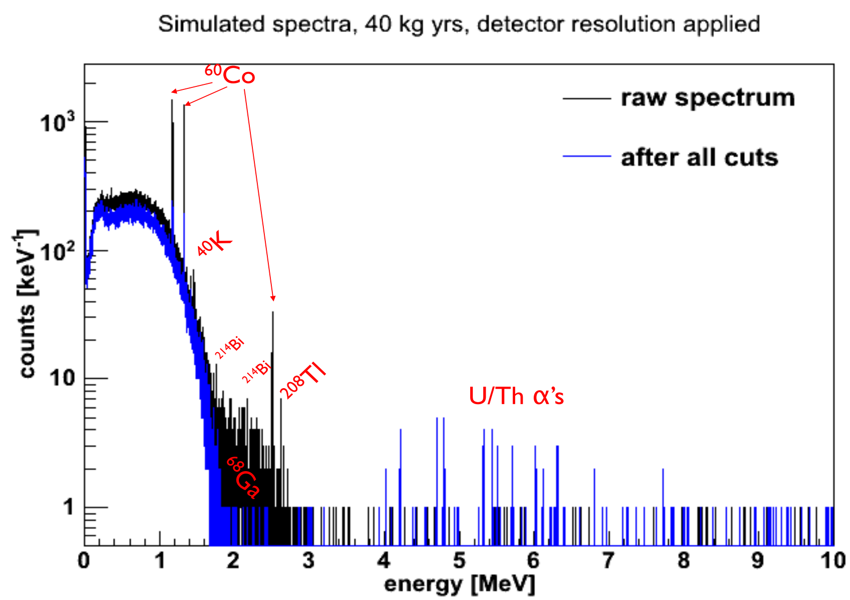
- Pure Cu → $CuSO_4$ bath + current → Plate out on Cu cathode → Removes ^{60}Co, U, Th
- Operating 16 baths at SURF 4850L, 6 at PNNL with **ultra-pure** chemicals and in an **underground cleanroom** environment
- Currently fabricating parts from electroformed Copper





Simulations

- Full simulation, incorporating radioactivity of our components, shows we should meet our background requirement.



2 year expected spectrum

Recent Progress

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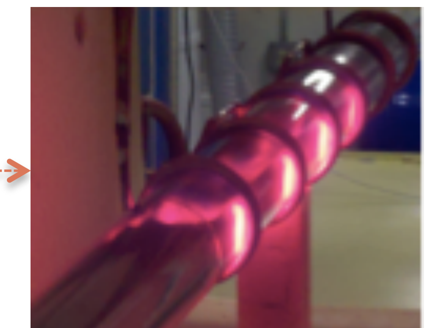
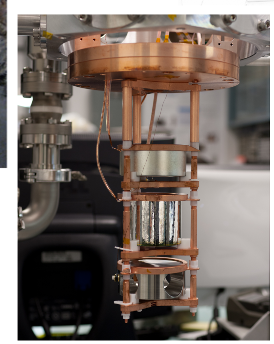
Enrichment

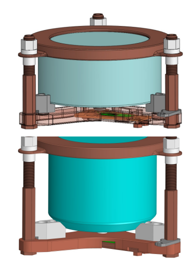
- Successful reduction and refinement of first 20 kg of ^{enr}Ge with 97.3% yield



Detectors

- 33 ^{nat}Ge detectors underground at SURF
- ORTEC vendor for ^{enr}Ge detectors
- Detectors operated in string configuration with custom electronics





P-type Point-Contact (PPC) Ge Detectors

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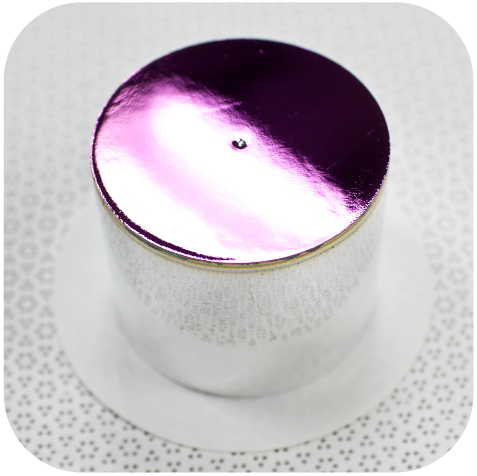
- Source = Detector
- Distinguish between single/multi-site interactions
- Excellent energy resolution: 0.16% @ 2039 keV (Q value)
- Simple, easy to handle, commercially available
  - investigated all major vendors ORTEC, Canberra, PHDs, PGT
- Low Capacitance → Low Noise → Low thresholds (< 1 keV):
  - allows for novel background rejection techniques
  - extends physics reach of MJD



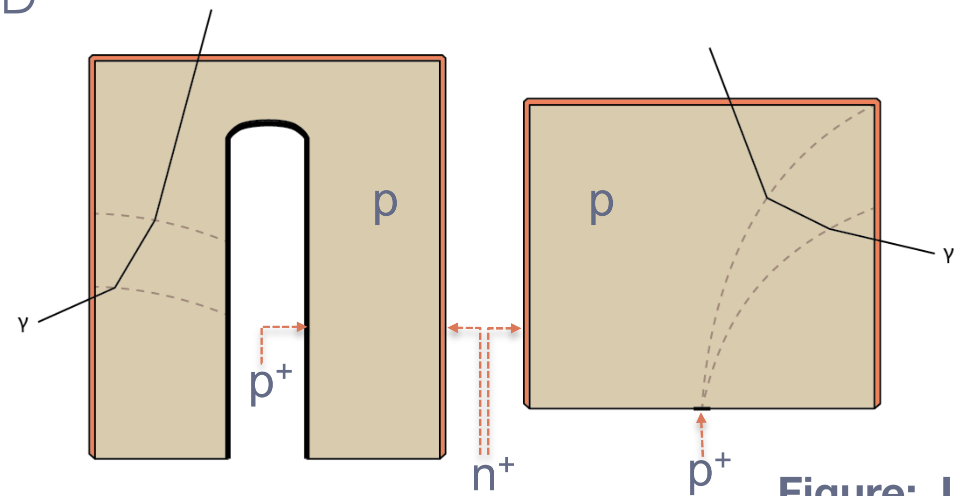


Figure: J. Loach

R.J. Cooper et al., Nucl. Instr. and Meth. A 629, (2010) 11.
P. S. Barbeau, J. I. Collar, and O. Tench, J. Cosm. Astro. Phys. 0709 (2007).
Luke et al., IEEE trans. Nucl. Sci. 36 , 926(1989).

The MAJORANA Low-Background BEGe @ KURF (MALBEK)

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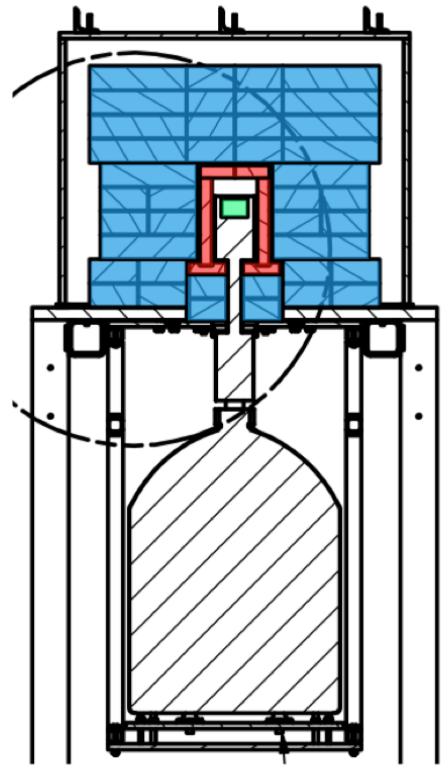
- Canberra 455 g ^{nat}Ge modified BEGe PPC
- Located at 1450 m.w.e. in Ripplemead, Virginia, USA at the Kimballton Underground Research Facility (**KURF**)
- Low-background, low-noise
  - geometry designed for optimal charge collection
    - small point contact
    - larger passivation ditch
- Goals:
  - validate simulations
  - study geometry optimization
  - characterization of low-energy spectrum
  - light WIMP search (<10 GeV)



P. Finnerty et al., Nucl. Instr. and Meth. A 652, (2011) 692-695.
P. Finnerty et al. IEEE NSS-MIC, (2010) 671-673.

The MAJORANA Low-Background BEGe @ KURF (MALBEK)

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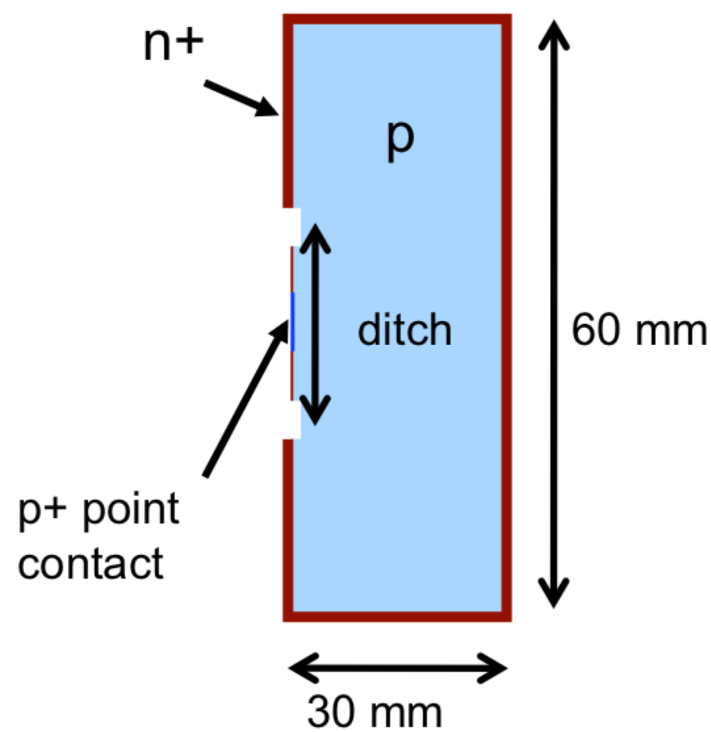
- 455 g ^{nat}Ge modified BEGe PPC (CANBERRA)
- Located at 1450 m.w.e. in Ripplemead, Virginia, USA.
- Low-background, low-noise
  - geometry designed for optimal charge collection
    - small point contact
    - larger passivation ditch
- Goals:
  - validate simulations
  - study geometry optimization
  - characterization of low-energy spectrum
  - direct dark matter search



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MALBEK and Slow Signals

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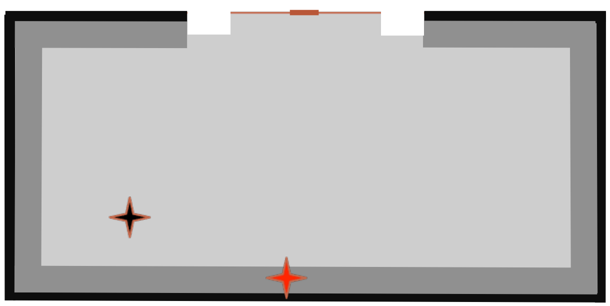
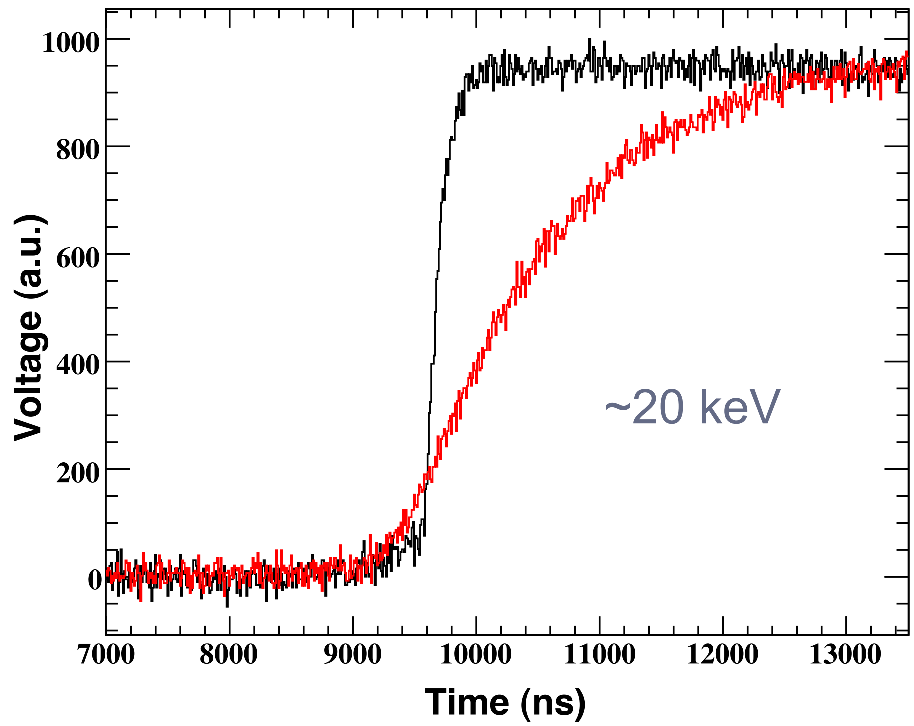
- Slow, energy-degraded events



- active volume
- n+ dead layer
- transition region – partial charge collection



- Currently investigating contribution to low-energy spectrum – possible contamination in DM search ROI

P. Finnerty et al., Nucl. Instr. and Meth. A 652, (2011) 692-695.
P. Finnerty et al. IEEE NSS-MIC, (2010) 671-673.

Thank you

Open Questions in Neutrino Physics

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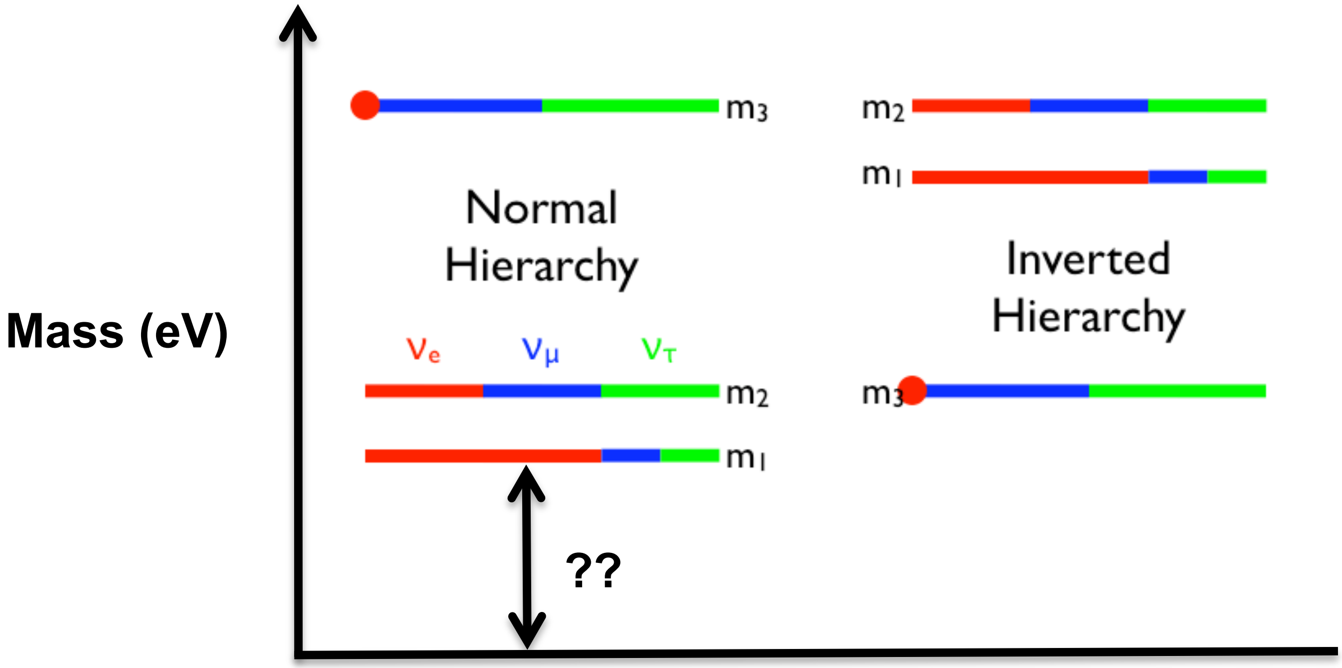
- What is the absolute mass scale and hierarchy?



$0\nu\beta\beta$ Experimental Signature

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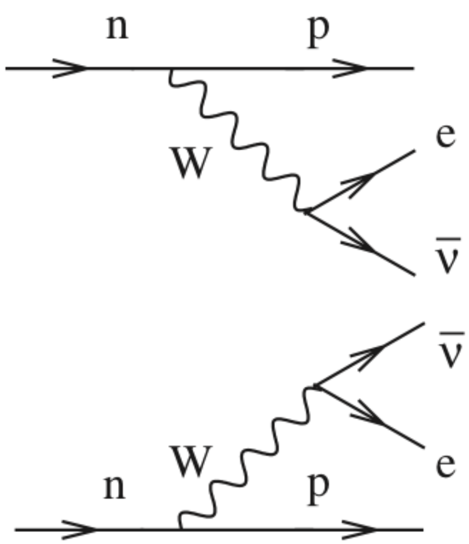
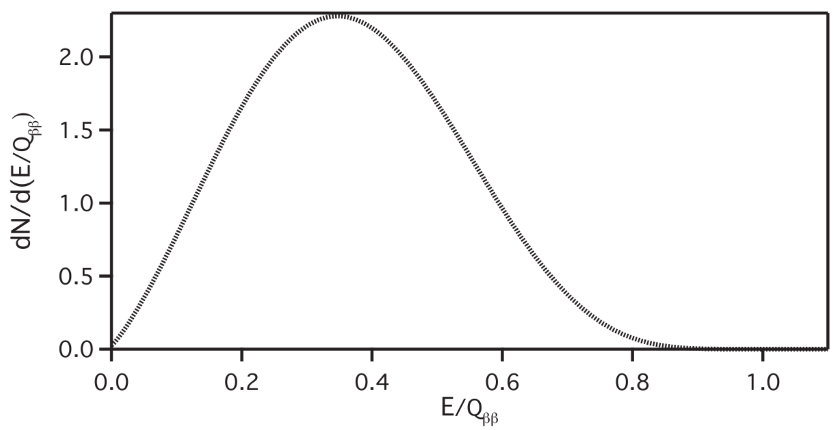
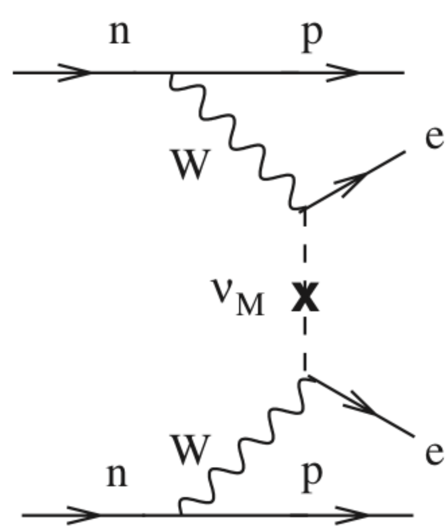


$T_{1/2} \sim 10^{21}$ years



F. T. Avignone, S. R. Elliott, and J. Engel, Rev. Mod. Phys. 80, 481 (2008).



$T_{1/2} > 10^{25}$ years