Update on The MAJORANA Neutrinoless Double-beta Decay Experiment

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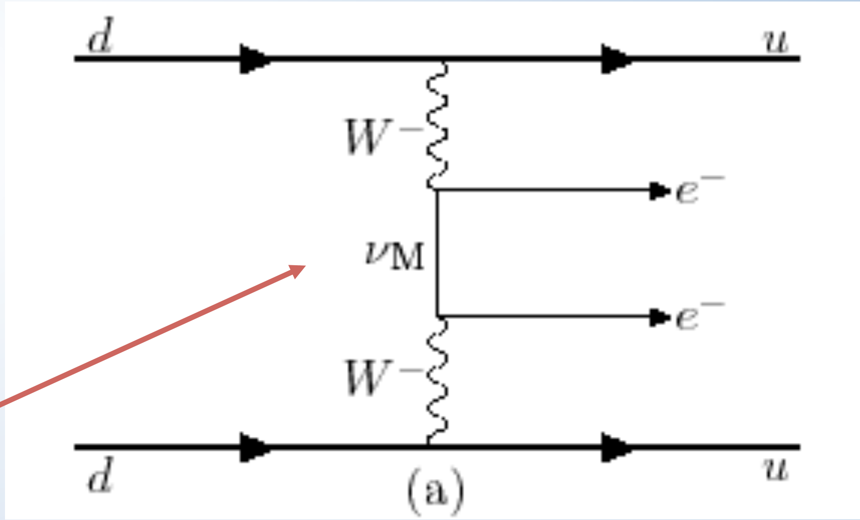
Motivation for $0\upsilon\beta\beta$ Search

Majorana

- Implications of discovery:
  - Neutrino is Majorana* (own antiparticle)
  - Total lepton number is not conserved
  - Neutrino has mass* (known)
  - Absolute neutrino mass.
- $0\upsilon\beta\beta$ nuclear decay may occur via several processes (SUSY, RH currents,…)
- Canonical example: Exchange of virtual neutrino



* Schechter et al, Phys. Rev. D**25**, 2951 (1982)

MAJORANA Collaboration Goals

Actively pursuing the development of R&D aimed at a ~1 tonne scale ^{76}Ge $0\nu\beta\beta$-decay experiment.

- –Technical goal: Demonstrate background low enough to justify building a tonne scale Ge experiment.
- –Science goal: build a prototype module to test previous claim in Ge.
- –Work cooperatively with GERDA Collaboration to prepare for a single international tonne-scale Ge experiment that combines the best technical features of MAJORANA and GERDA.
- –Pursue longer term R&D to minimize costs and optimize the schedule for a 1-tonne experiment.

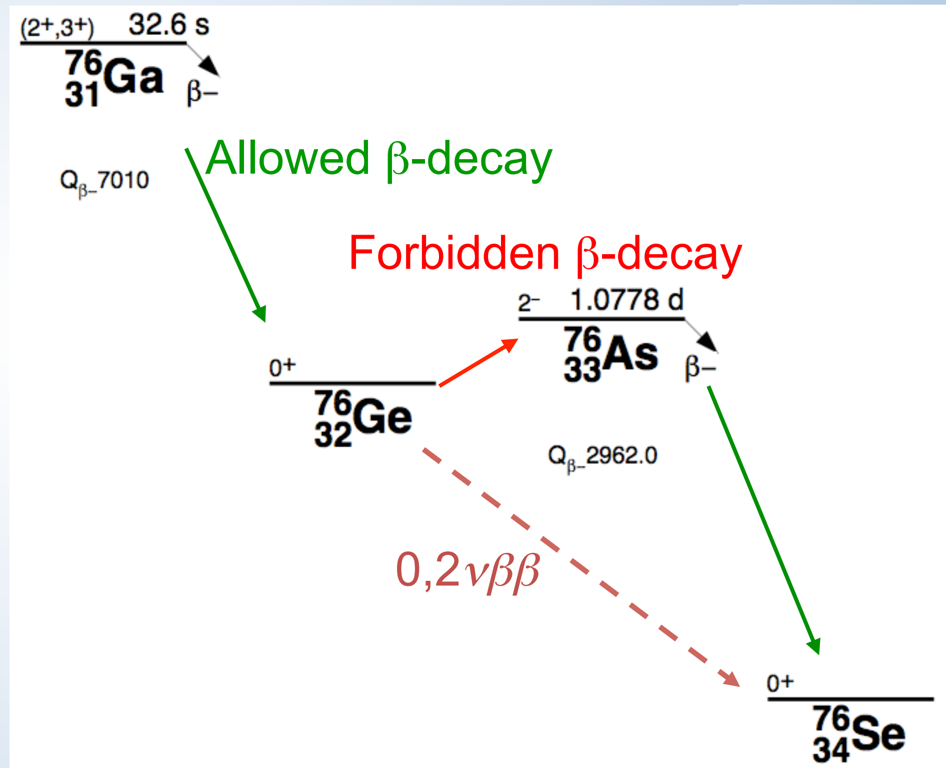
The MAJORANA DEMONSTRATOR Module

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

(Excellent energy resolution, intrinsically clean detectors, commercial technologies)

- 40-kg of Ge detectors
  - 30-kg of 86% enriched ^{76}Ge crystals
  - Point-contact detectors for MJD
- Low-background Cryostats & Shield
  - Ultra-clean, electroformed Cu
  - Naturally scalable
  - Compact low-background passive Cu and Pb
    shield with active muon veto
- Background Goal in the $0\nu\beta\beta$ peak ROI(4 keV at 2039 keV)

~ 3 count/ROI/t-y (after analysis cuts



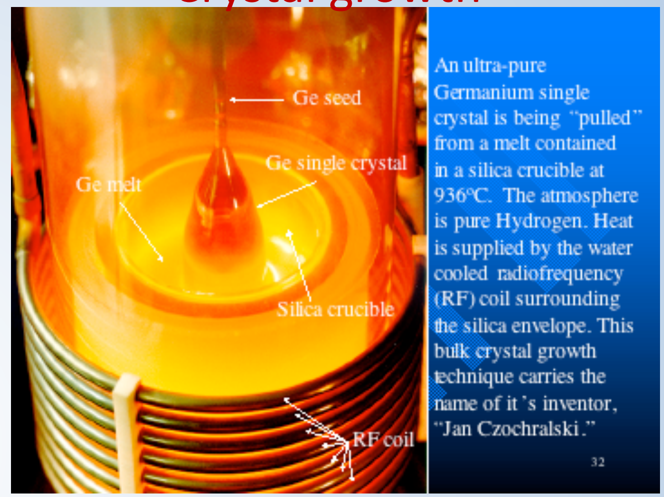
Enriched Crystal Production

Enrichment (86% ^{76}Ge)

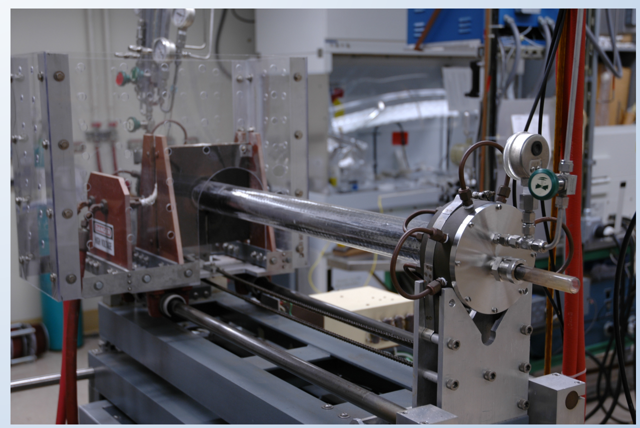
Polycrystalline bars

E.E Haller

Crystal growth



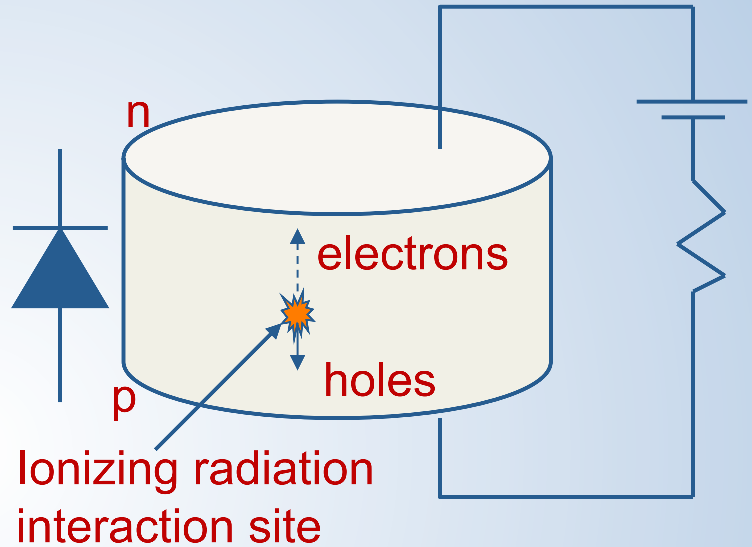
Zone refinement



Ge Detection Principle

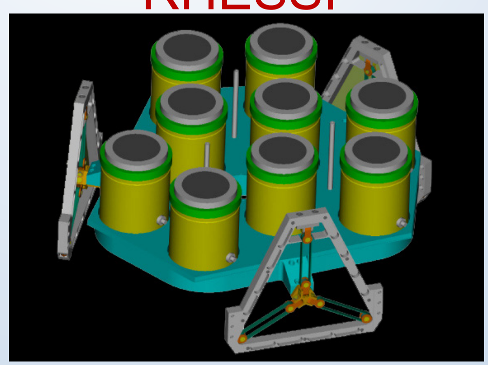
- >40 years of experience
- Ge is semiconductor -- Diode.
- Ionizing radiation creates electron-hole pairs.
- Signal generated by collecting electrons and holes.
- Gamma-ray spectroscopy

Mature Technology



Gammasphere
GRETINA/AGATA

RHESSI

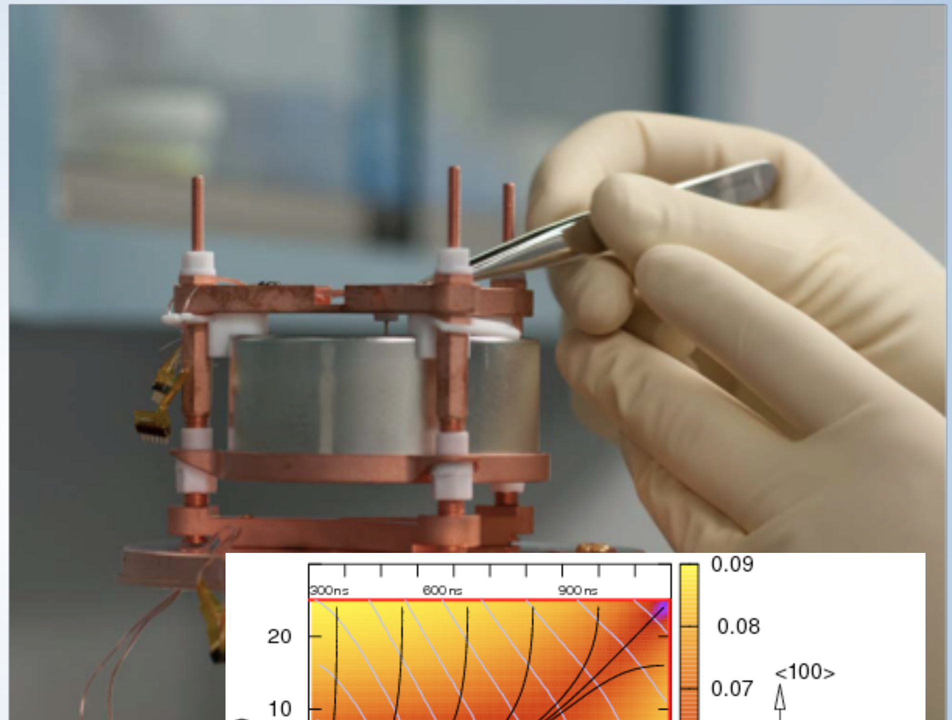


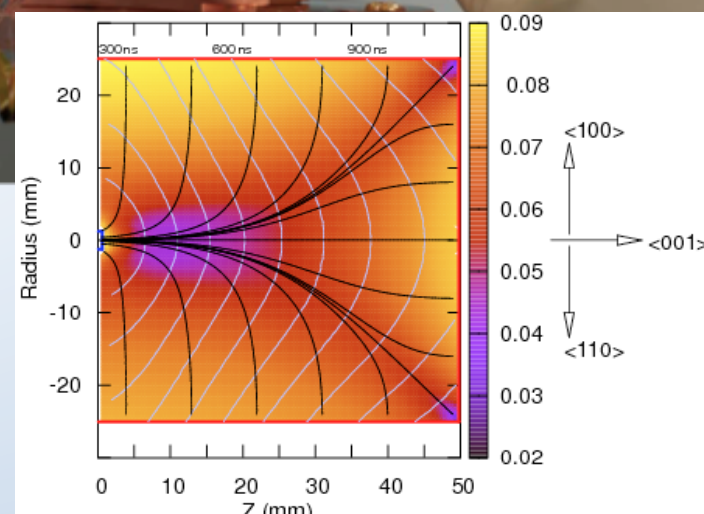
Canberra
(Commercial)

P-type Point-Contact (PPC) Detectors

Point contact:

- Small capacitance: ~1pF
- Pronounced weighting field
- Small electrical fields
- **Sub-keV Thresholds**
- Excellent Pulse-shape Analysis



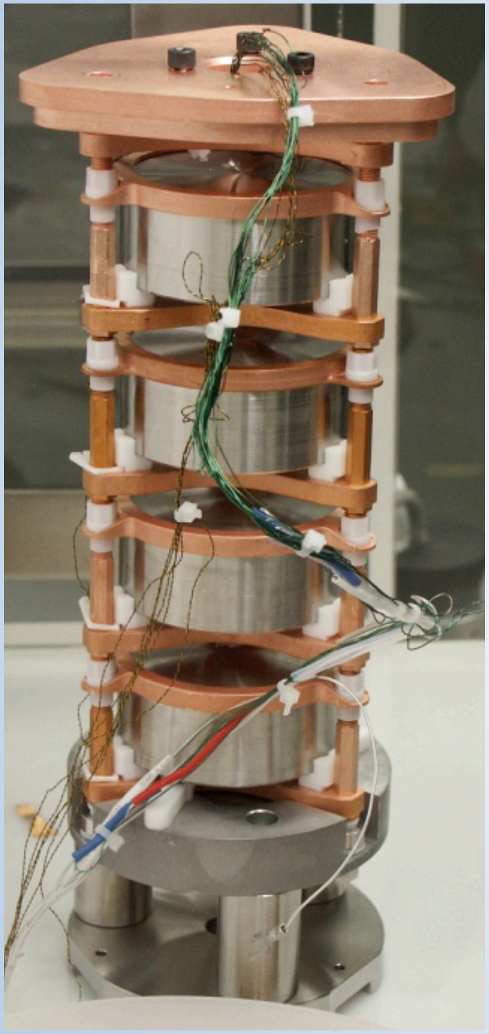


Background Identification

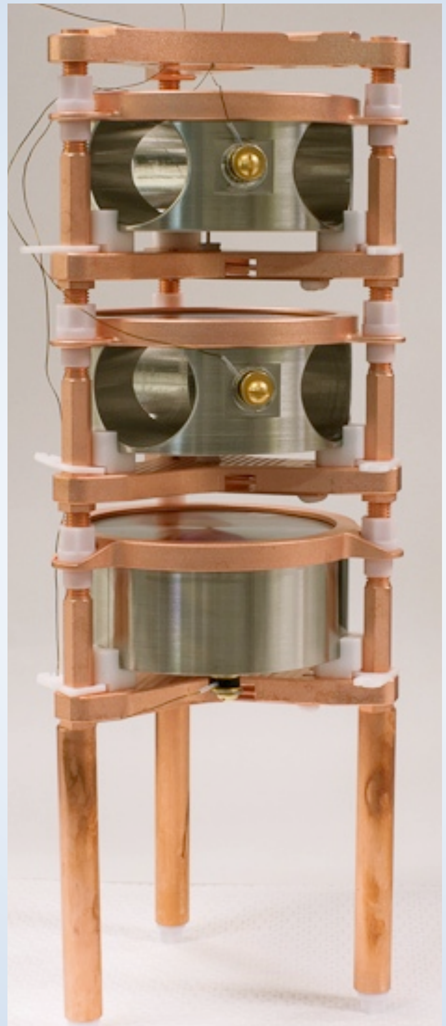
- Current Generation Experiments Reduce Backgrounds factor ~100
- Backgrounds:
  - Compton scattered gammas, surface alphas.
  - Natural isotope chains: ^{232}Th, ^{235}U, ^{238}U, Rn
  - $2\nu\beta\beta$-decays.
  - Cosmic Rays:
    - Activation at surface creates ^{68}Ge, ^{60}Co.
    - Hard neutrons from cosmic rays in rock and shield.

- Mitigation:
  - Materials Selection
  - Cleanliness and Procedures
  - Underground fabrication, assembly, and operation
- Pushing limits in ICP-MS, materials science, radio-assay. Ie. Ultra-low radioactive background, fast, low-noise electronics

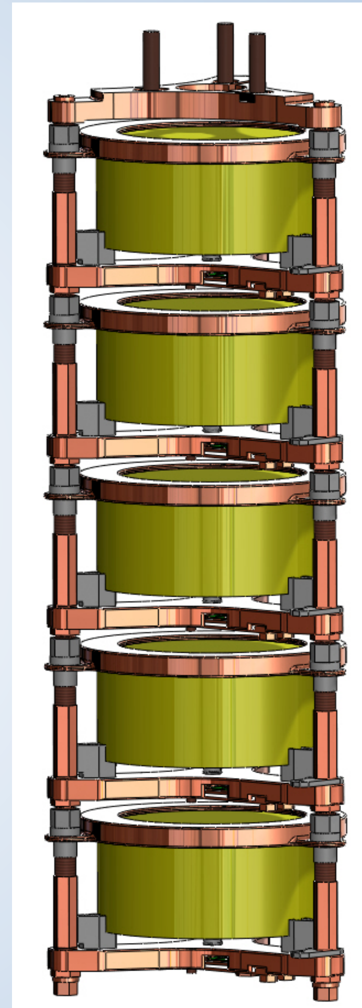
Detector Mount and String Design



LANL thermal test string
Jan 2011

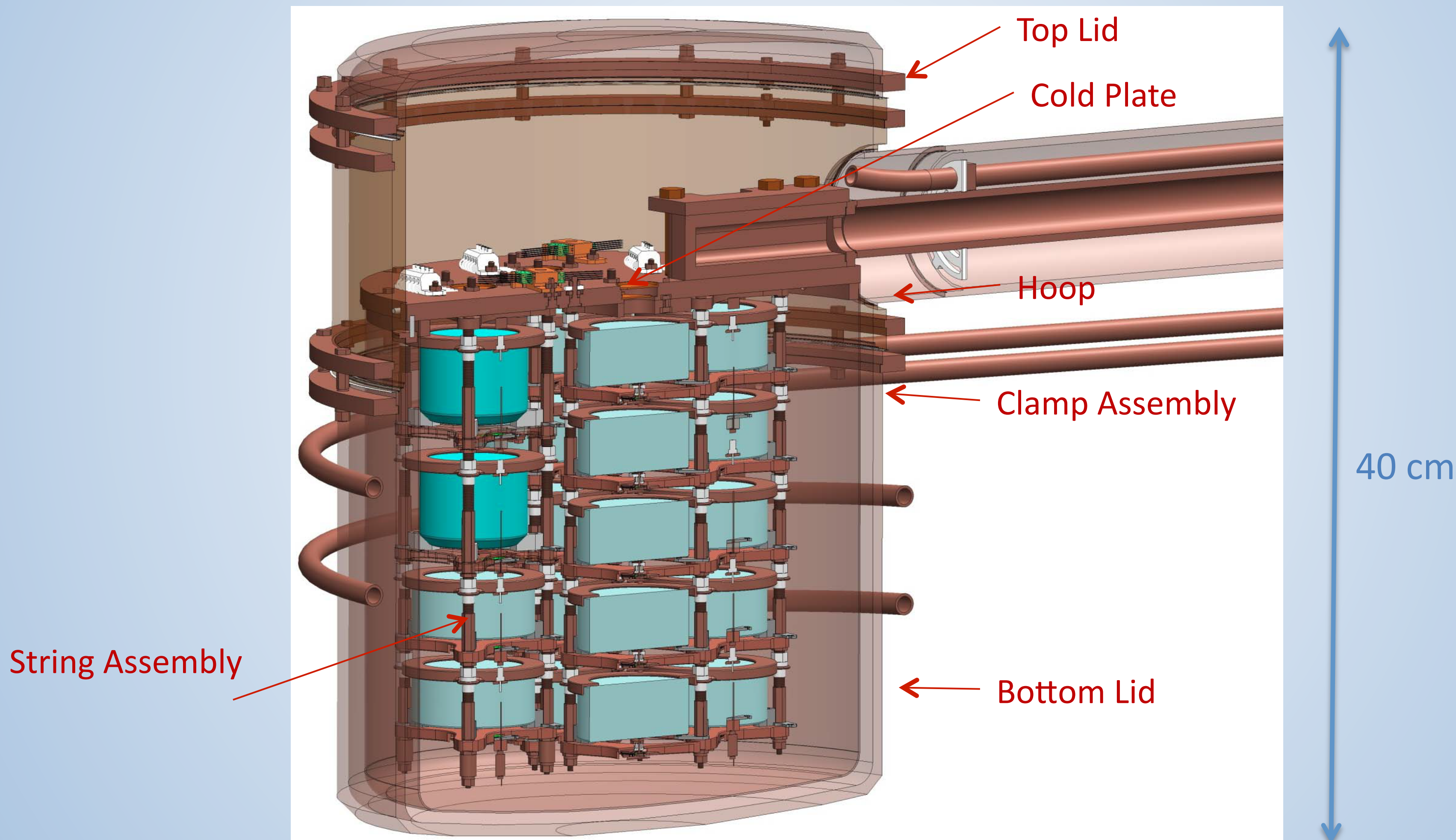


LBNL test string (w/ thermal blanks)

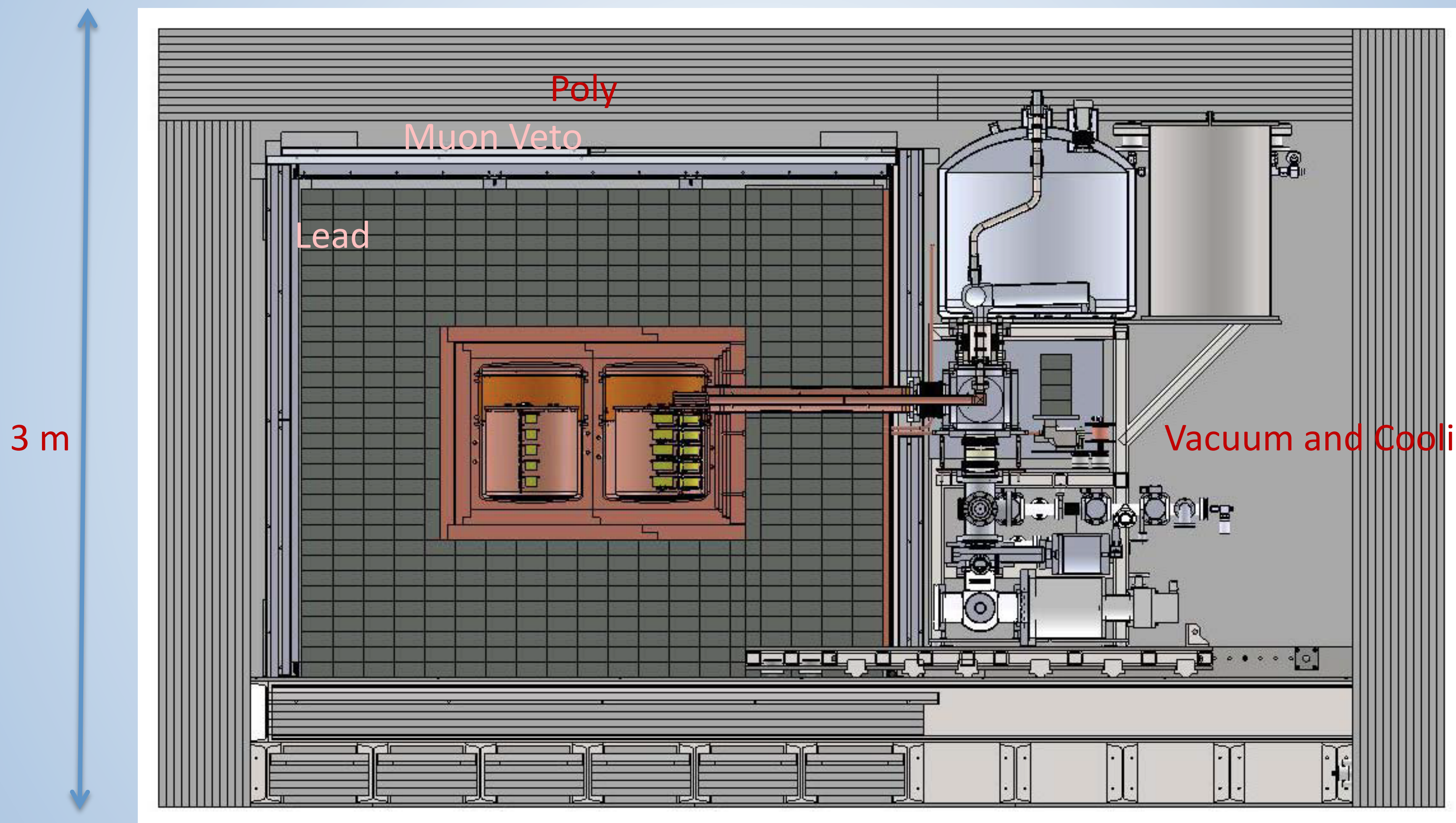


Design as released for R+D production June 2, 2011

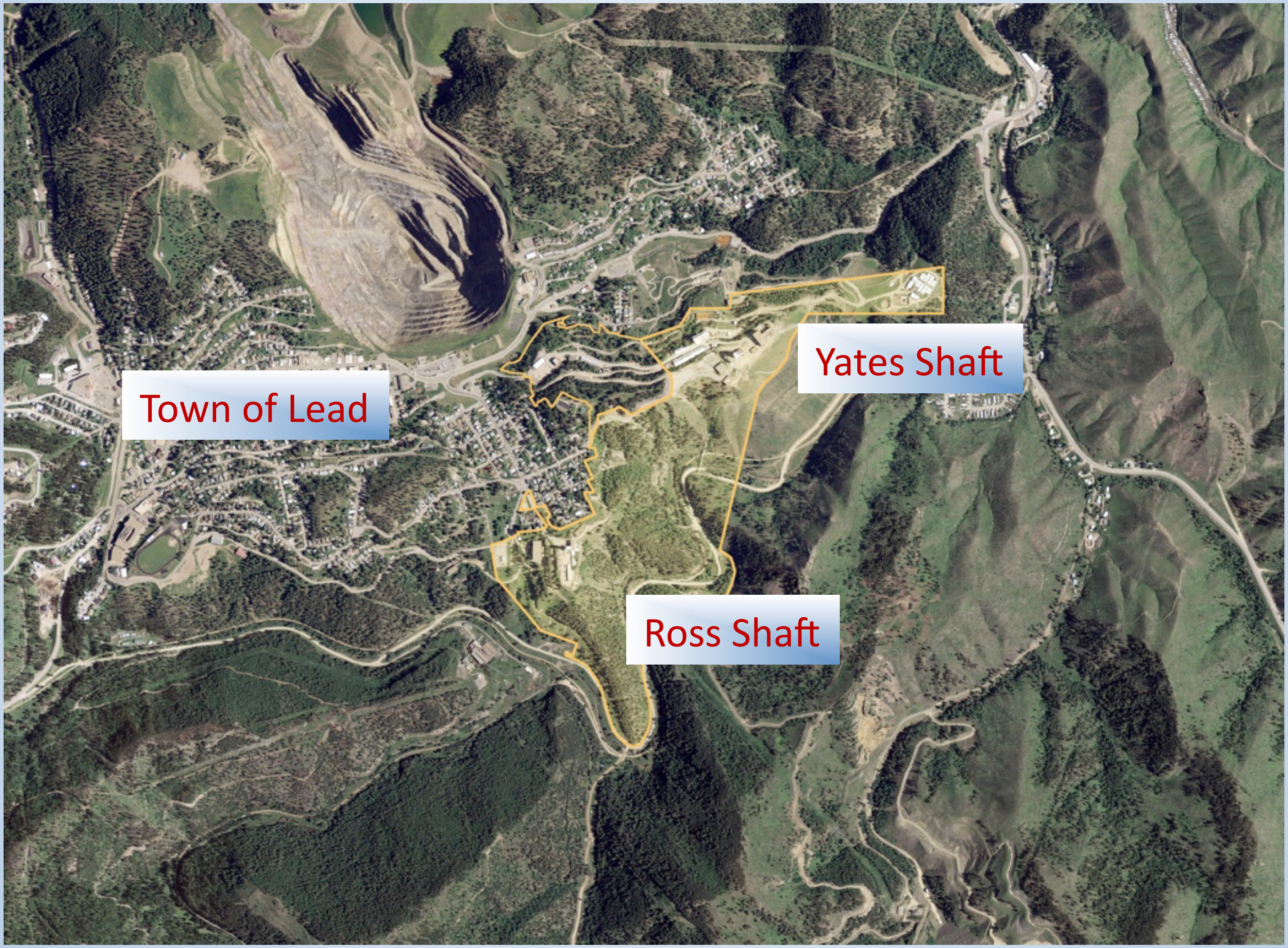
Cryostat Internals



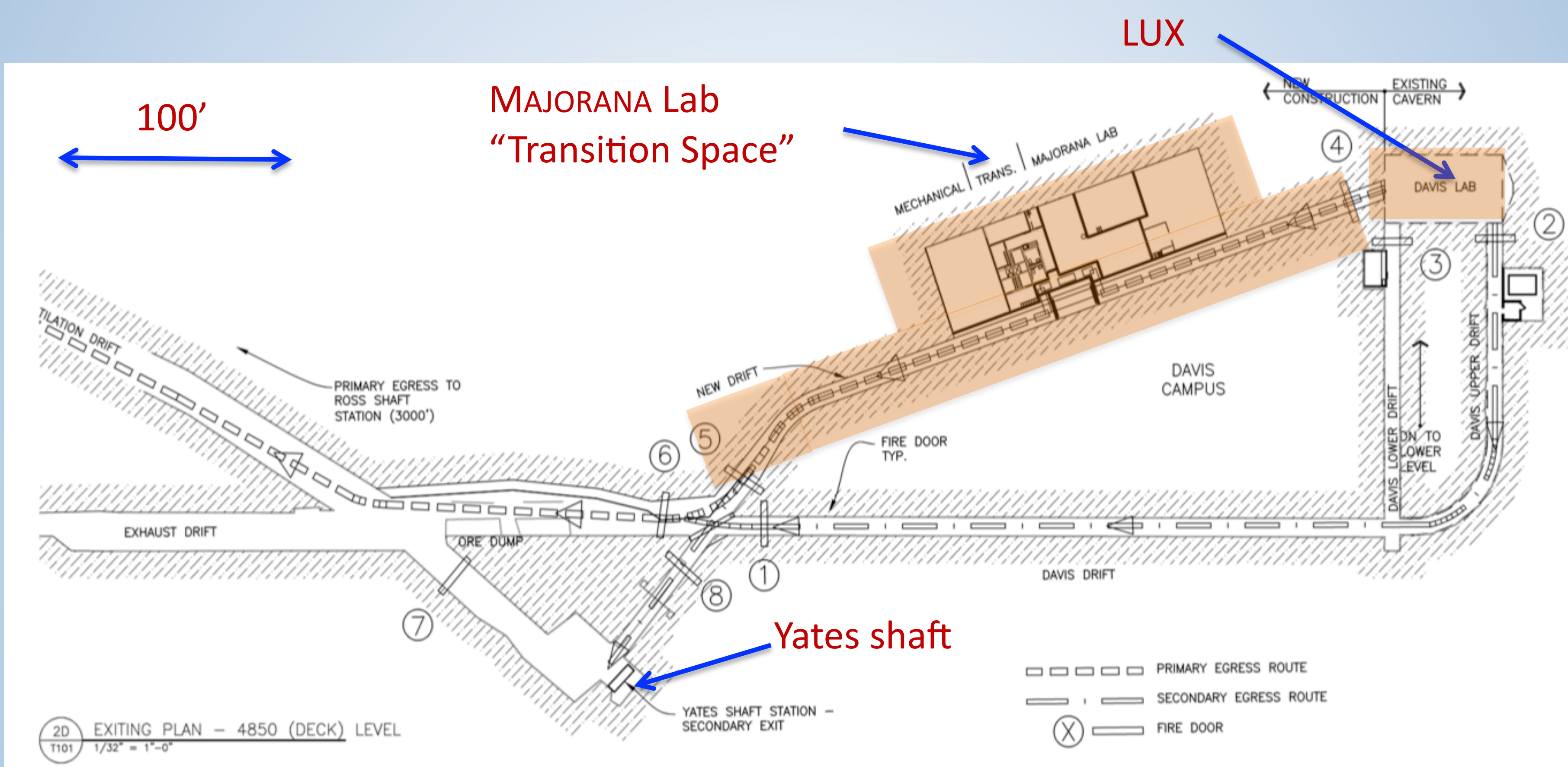
Shield structure



Sanford Underground Research Facility
Lead, South Dakota



Underground Location of MAJORANA Laboratory



Davis Campus, 4850’ level, near Yates shaft

Current Activities

Underground Electroforming facility

Main underground Lab

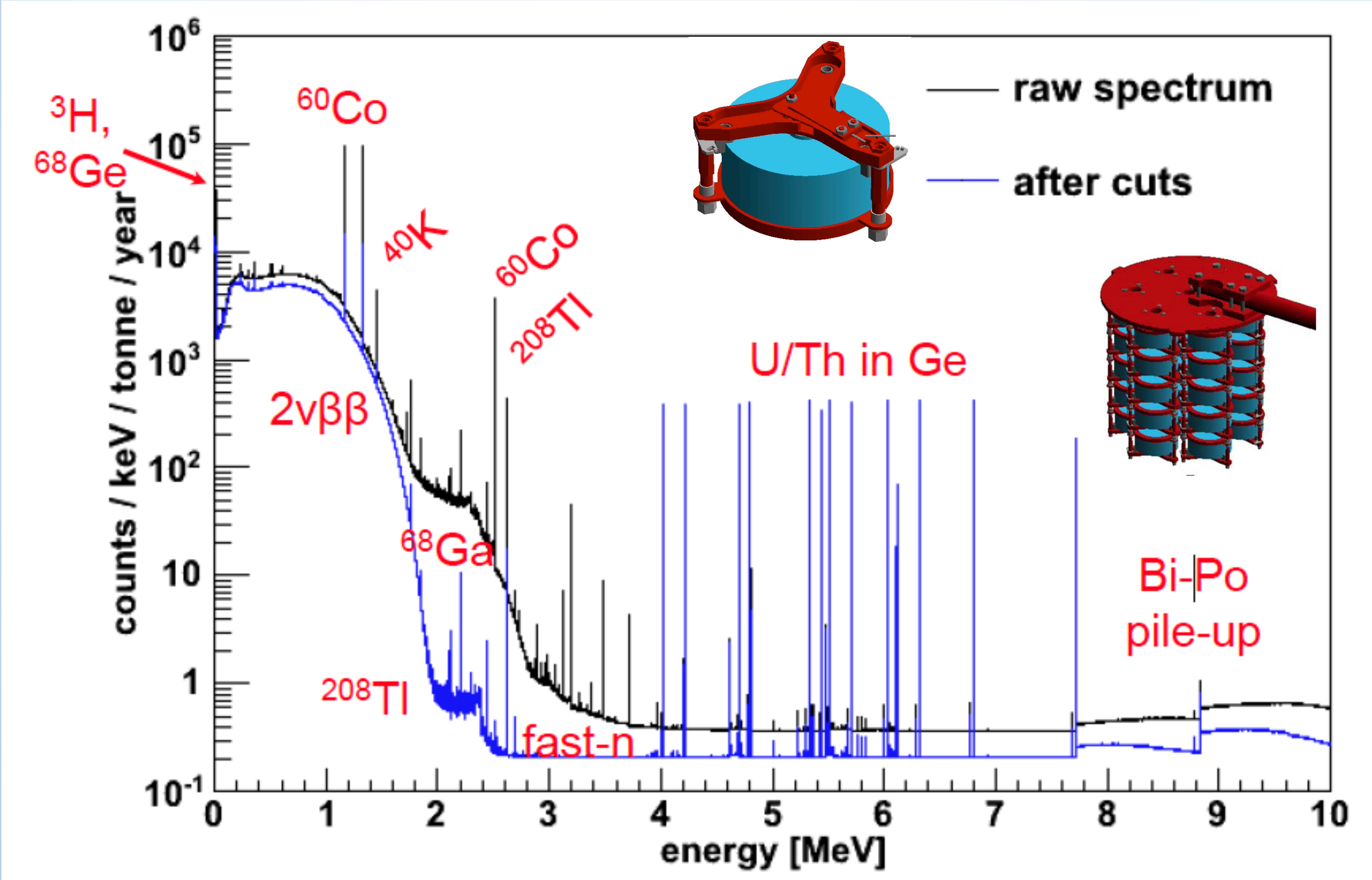
Inside Electroforming Lab

Underground machine shop

Vacuum System Assembly

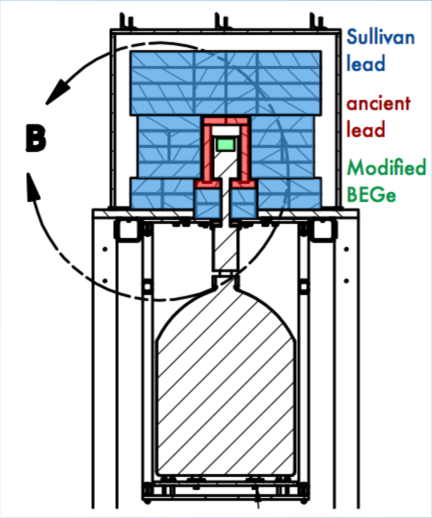
Simulation of Backgrounds

60,000 combinations of parts and isotopes.



MALBEK

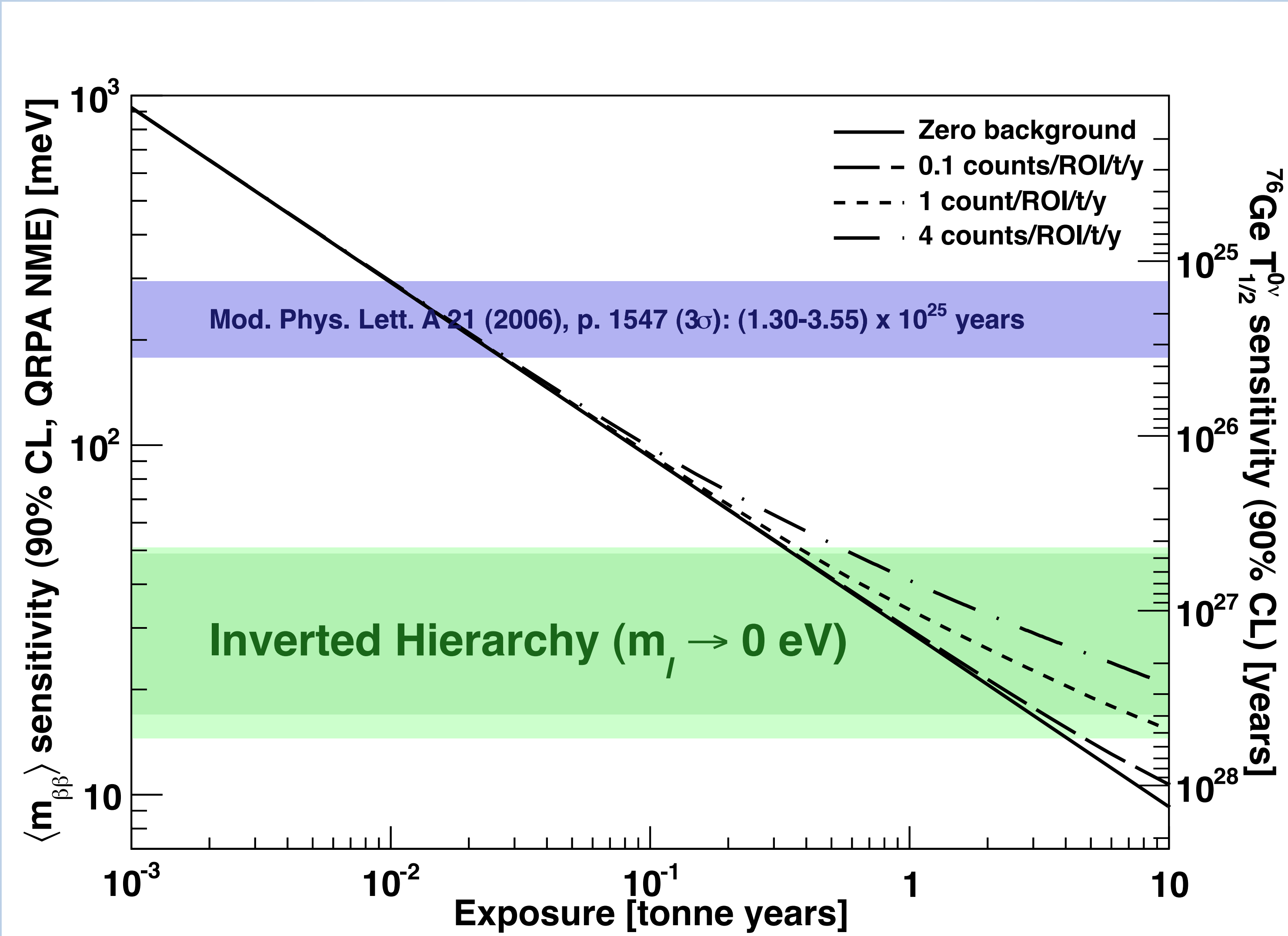
- MALBEK is a 450-g R&D mod.- BEGe detector, mounted in a low-background cryostat. It has a smaller contact size and a larger ditch diameter.
- MALBEK is operating at KURF (1450 m.w.e.), located in Ripplemead, VA
- Goals:
  - Systematically characterize spectrum.
  - R&D low-energy triggering and DAQ (low-energy pulses difficult to distinguish from noise).
  - R&D PSA in low-energy region
  - Background model verification
  - Dark Matter search



DEMONSTRATOR Schedule

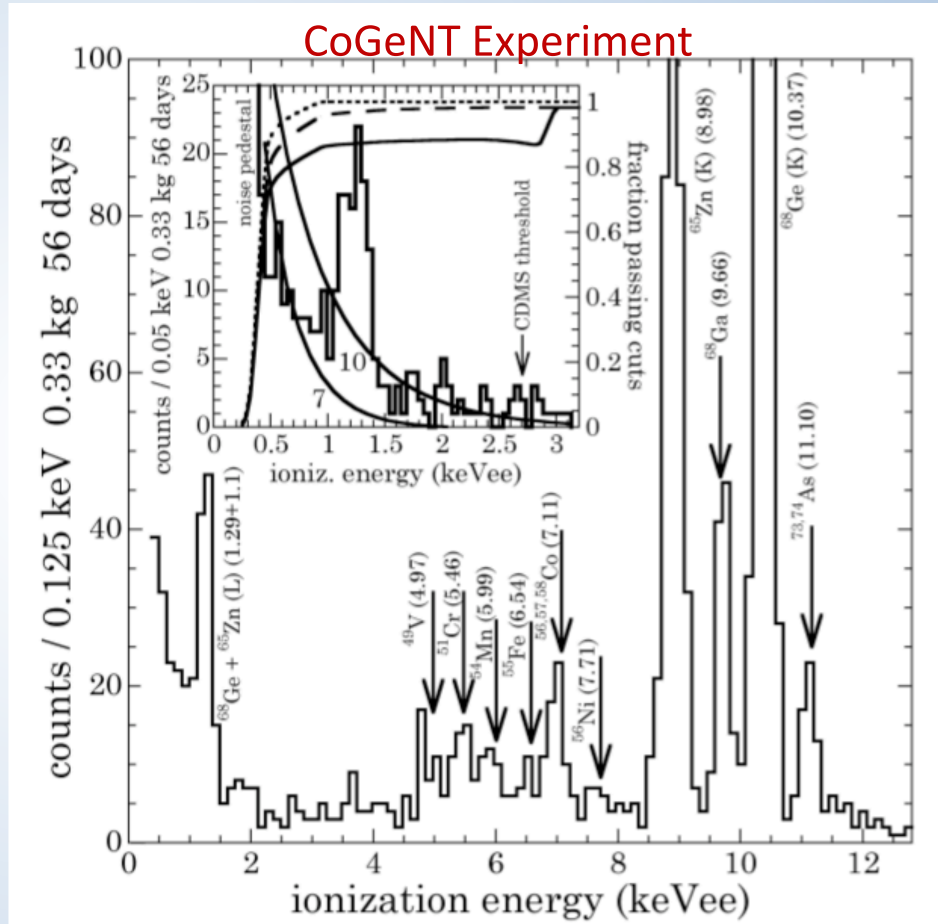
- First 20 kg of enriched material in hand and refined to electronic grade.
- Prototype Module (all natural Ge) on-line: Fall 2012
- First module (~12 kg enriched) on-line: 2013.
- Second Module (additional ~18 kg enriched) on-line: 2014.

Ge Sensitivity



Other Physics with PPC Detectors

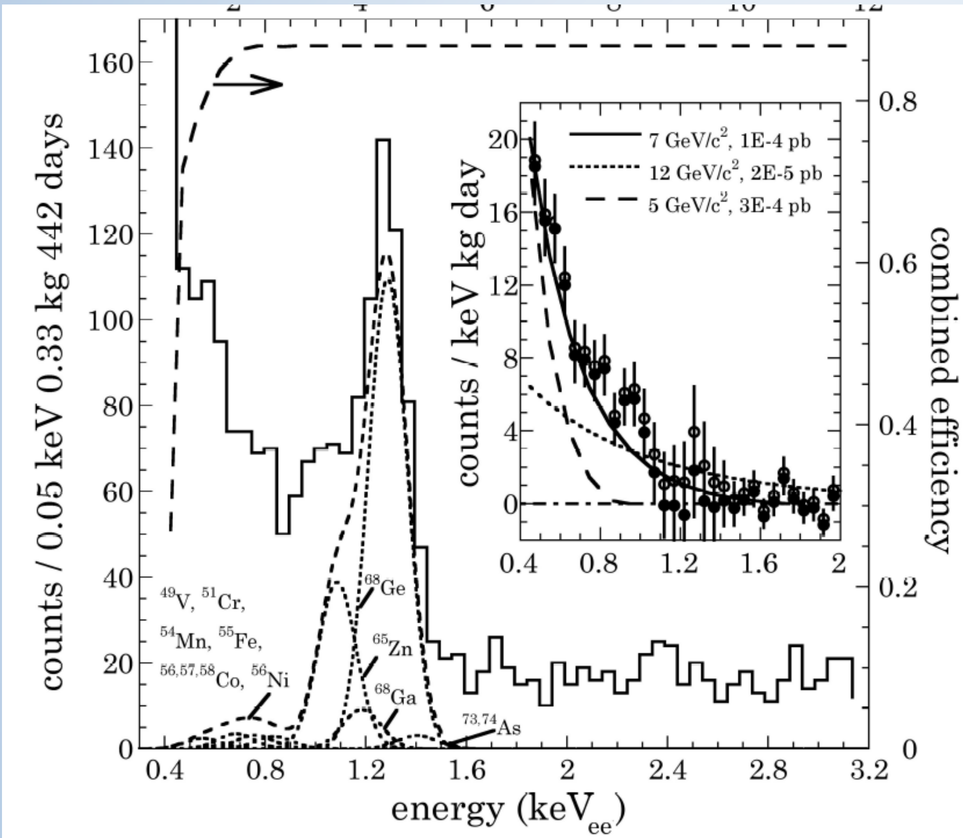
- Low-E thresholds of PPC design opens new possibilities for dark matter and neutrino scattering experiments
- Coherent neutrino nuclear scattering an initial goal
- ν+e scattering, solar axions, etc.
- Enrichment reduces low-E backgrounds

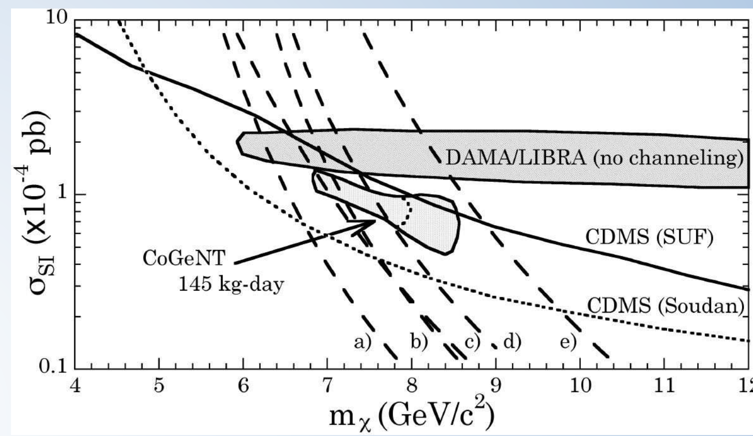


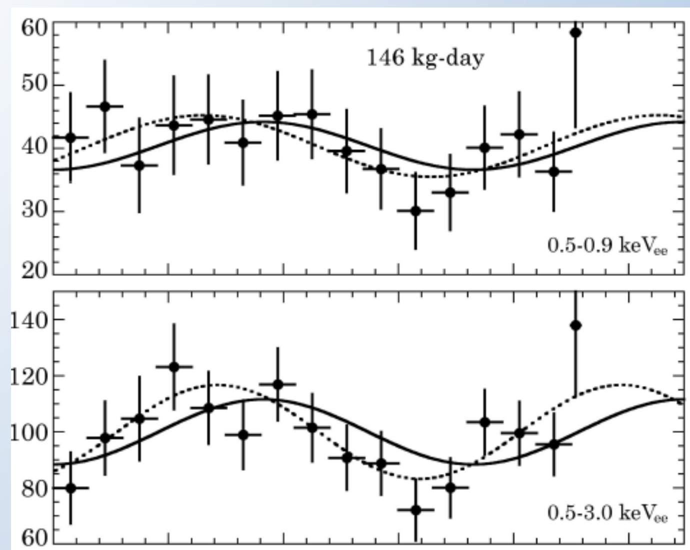
PRL 106:131301, 2011

CoGeNT Annual Modulation

PRL 107:141301 (2011)*

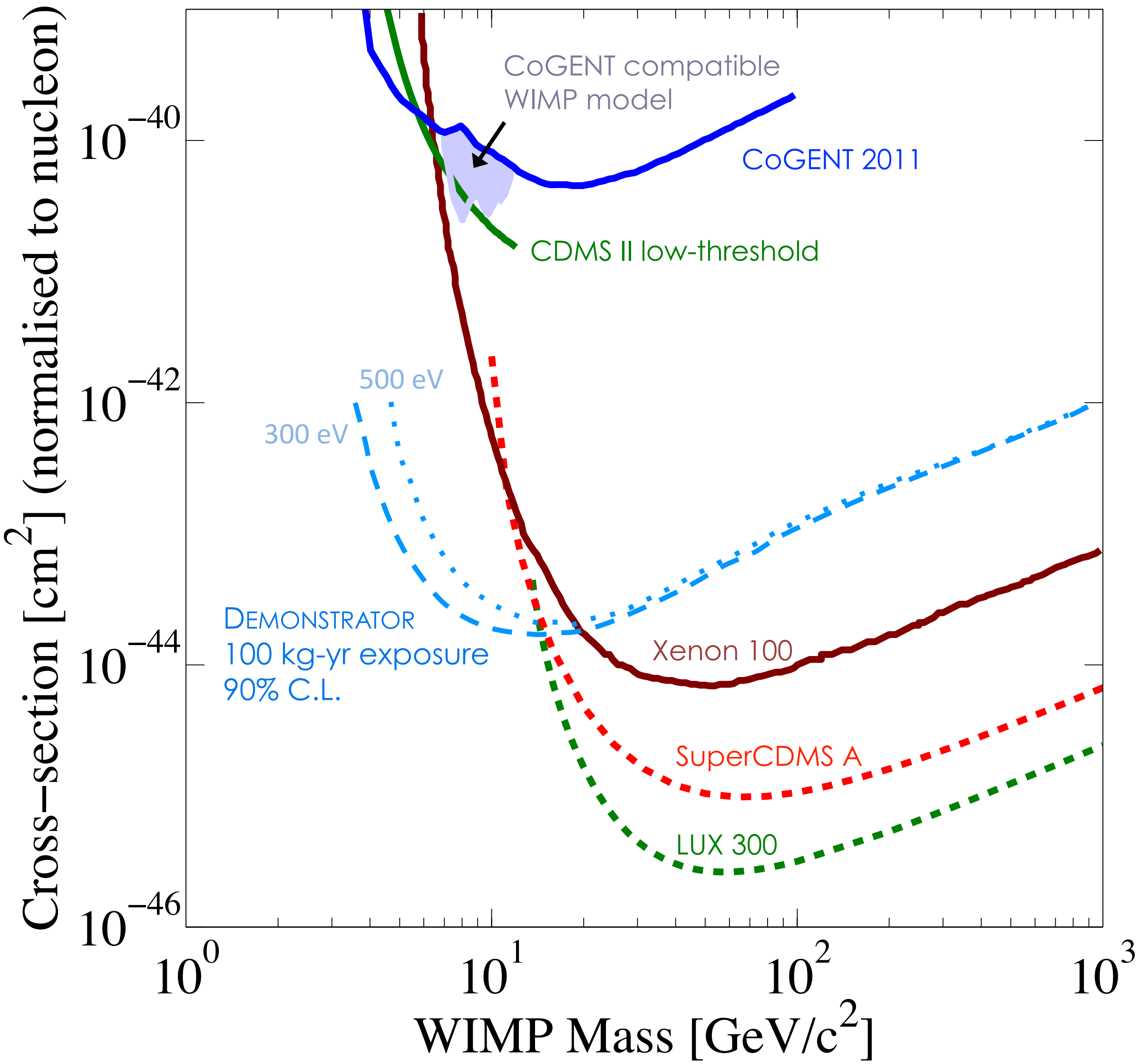






* CoGeNT subsequently claimed significant background contamination at TAUP 2011

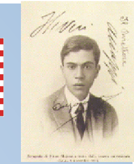
MAJORANA Dark Matter Sensitivity



Conclusions

- MAJORANA currently under construction. Will deploy first enriched detectors in 2013.
- MAJORANA pursuing R&D with GERDA for 1-tonne-scale Ge experiment
- Other physics possible as well.
- Will test KKDC results in Ge with DEMONSTRATOR Module.

The MAJORANA Collaboration (May 2012)



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Backups

What is neutrinoless double-beta decay ($0\nu\beta\beta$)?

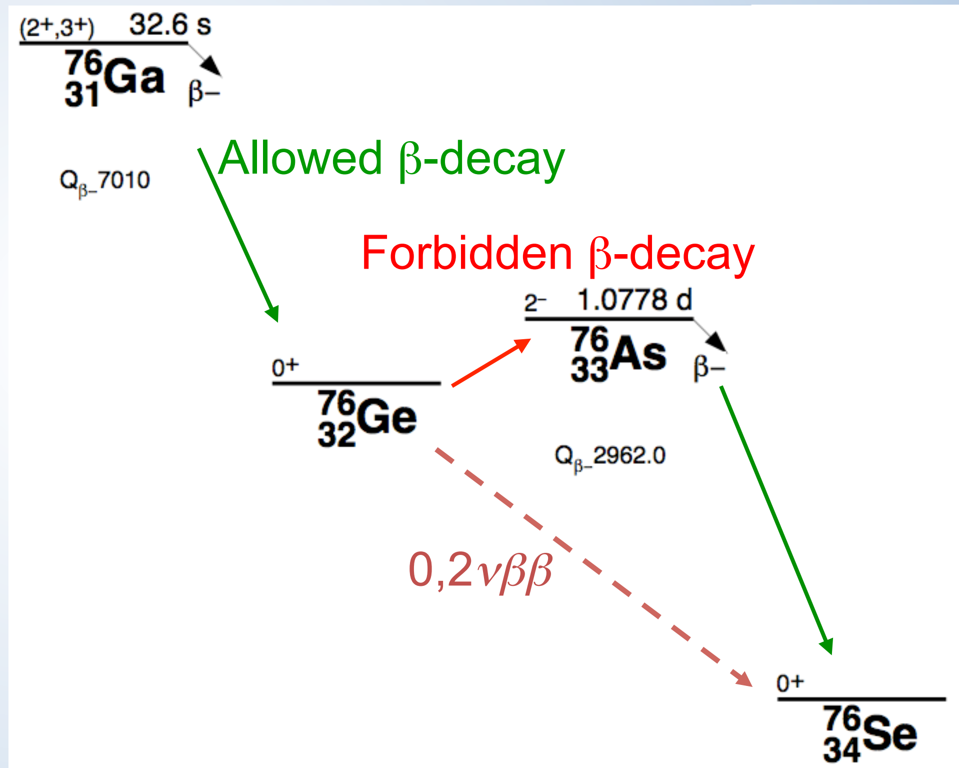
$$^{Z}A \Rightarrow {}^{Z+2}A + 2e^{-}$$

Energetically allowed in many nuclei.

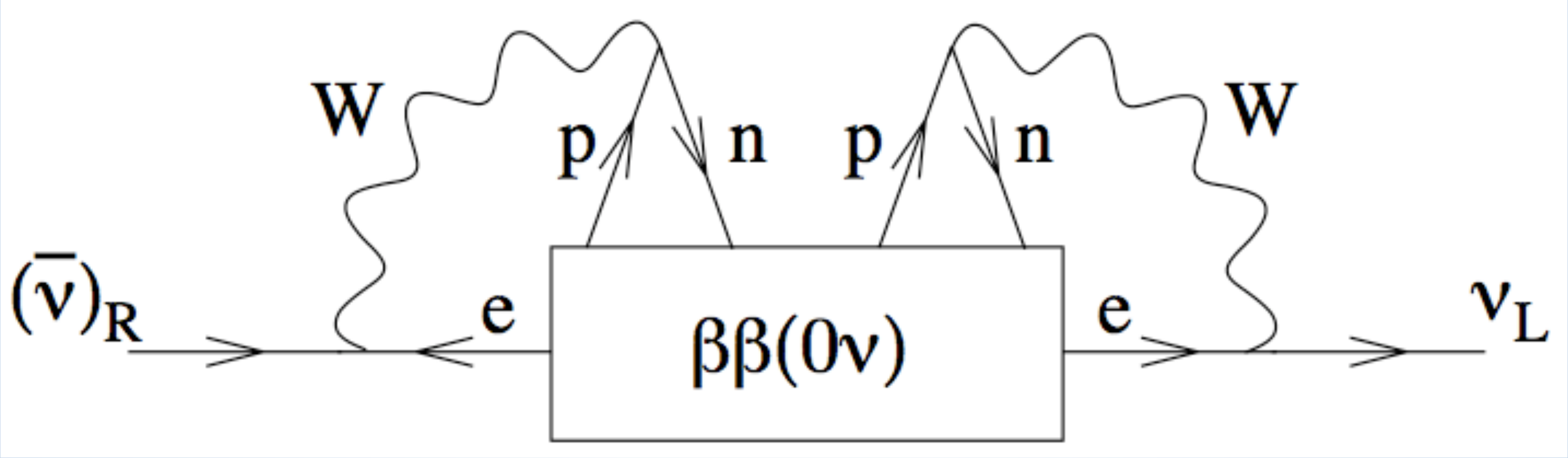
Prefer nuclei stable against β-decay (about 30)

$2\nu\beta\beta$: Observed 2nd order weak process.

$$^{Z}A \Rightarrow {}^{Z+2}A + 2e^{-} + 2\bar{\nu}_{e}$$



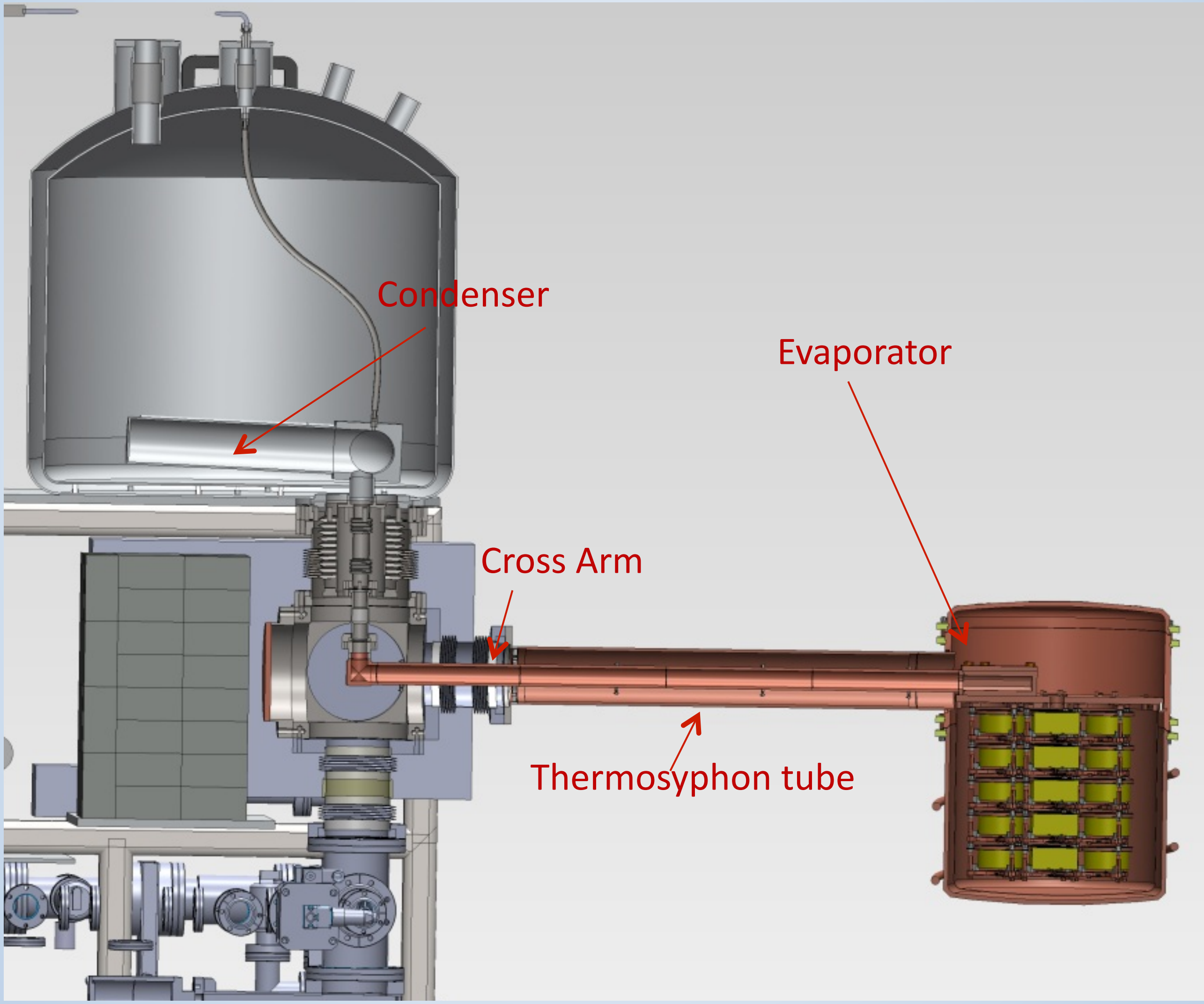
$0\nu\beta\beta$–decay and Majorana Neutrinos



Schechter et al, Phys. Rev. D**25**, 2951 (1982)

Majorana nature verification ***independent*** of process that mediates $0\nu\beta\beta$ decay!

Thermosyphon

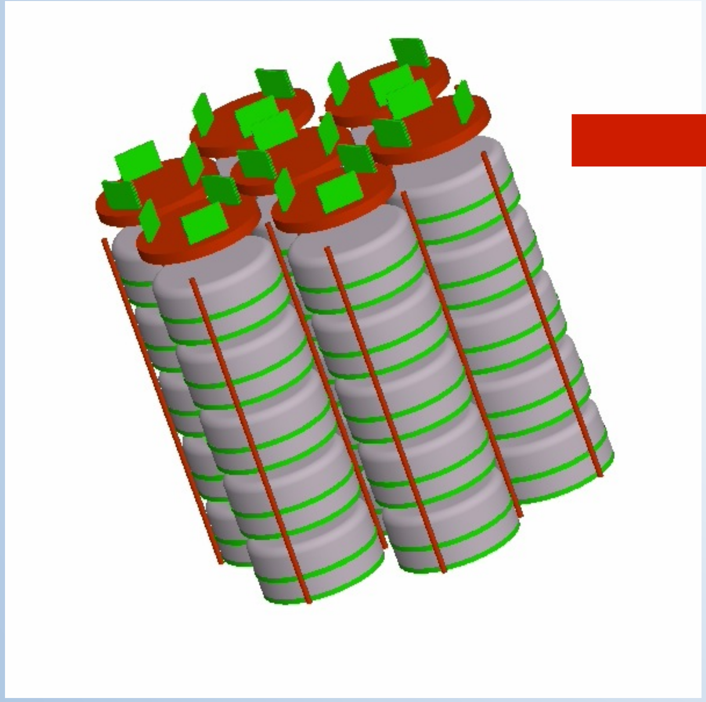


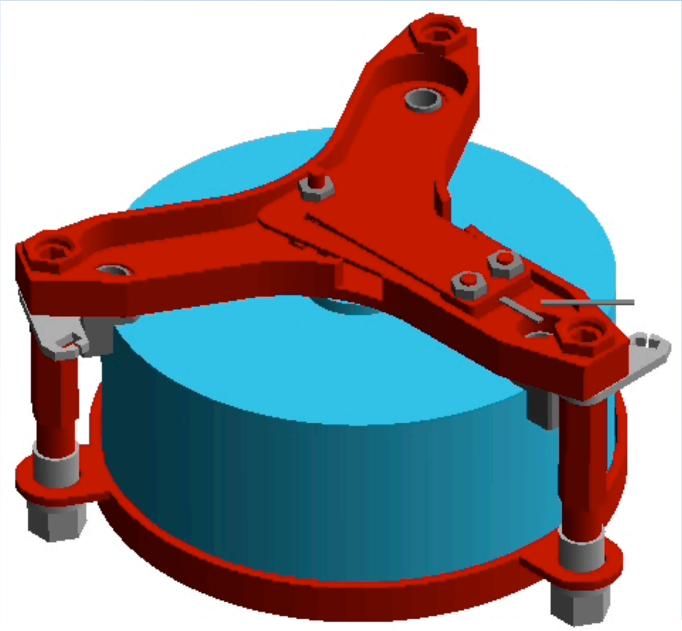
Majorana Underground Electroforming at Sanford Lab

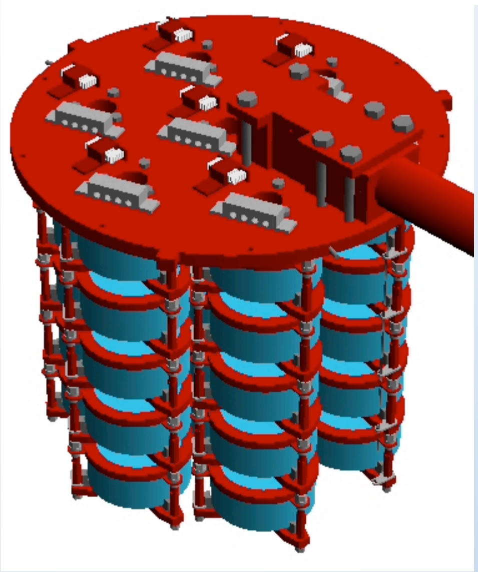
View of Sanford 4850' area where the future TCR would be located

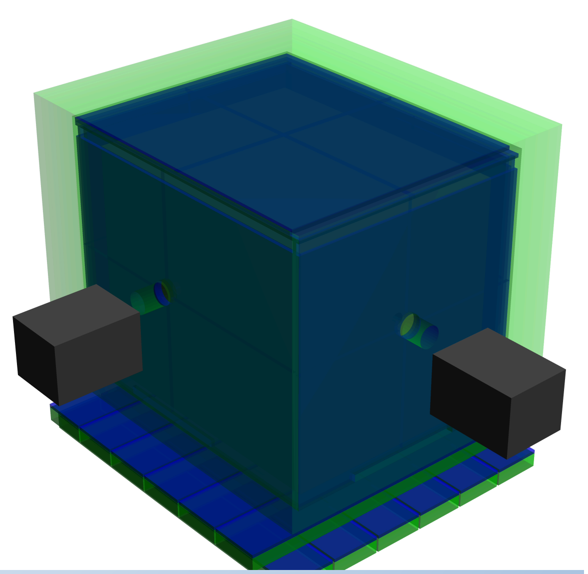
Simulation of Preliminary Design

- High-definition MJD geometry implemented





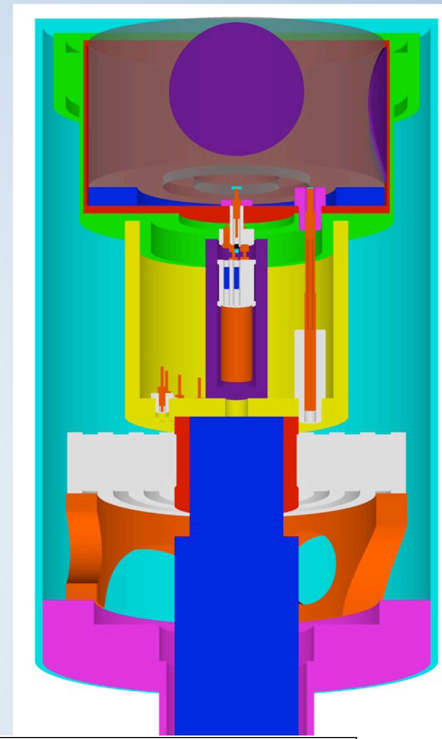


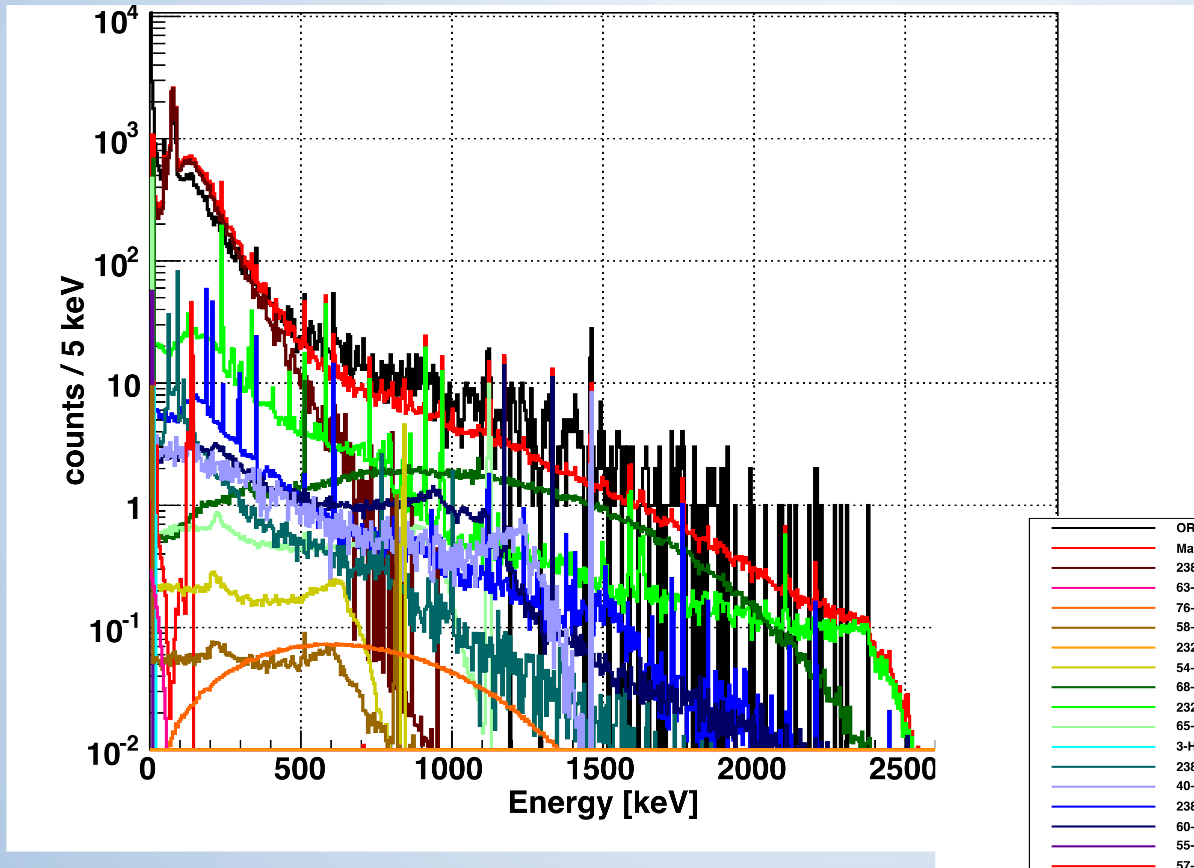


Full-Spectrum Comparison with Data

- MALBEK detector:

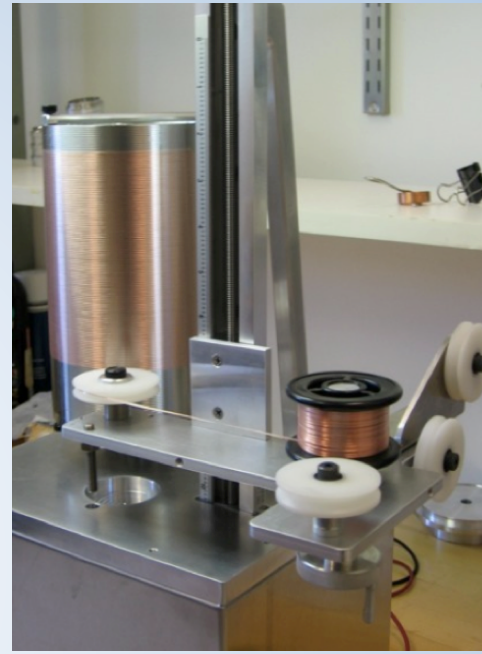
  MC vs. **DATA**



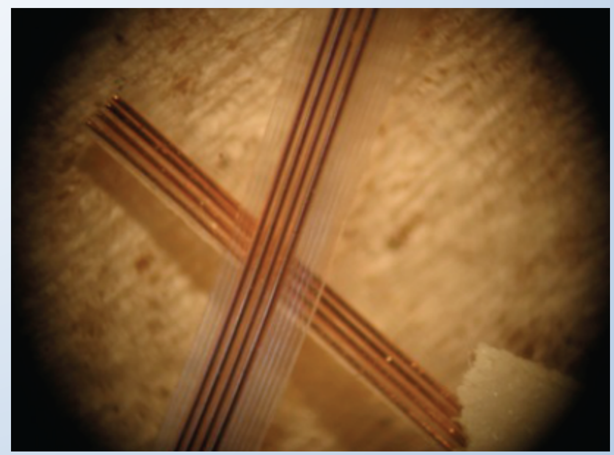


Signal Cable

- Parylene-N and -C are promising polymers
- Low radioactivity (assay limits from NAA)
- Dry vacuum deposition
- Excellent insulator, pinhole free for t>0.1 micron coatings
- “Standard” technology in healthcare and circuits
- Unshielded prototype made at UW:
  - 0.003” dia. Cu conductor at 0.006” pitch
  - 0.0005” thick parylene
  - $Z_o \sim 10\ \Omega$

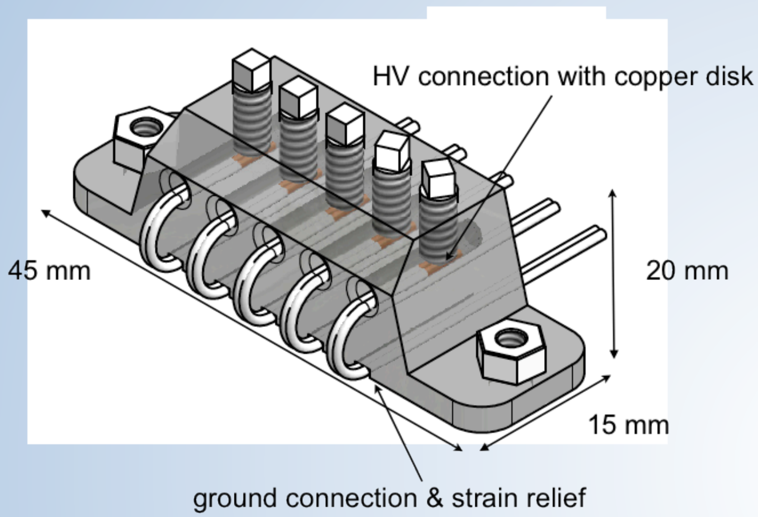


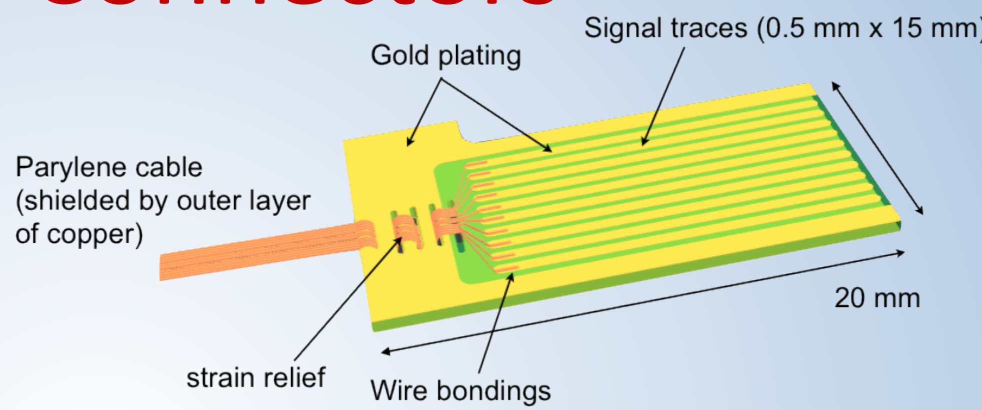
Cable winder

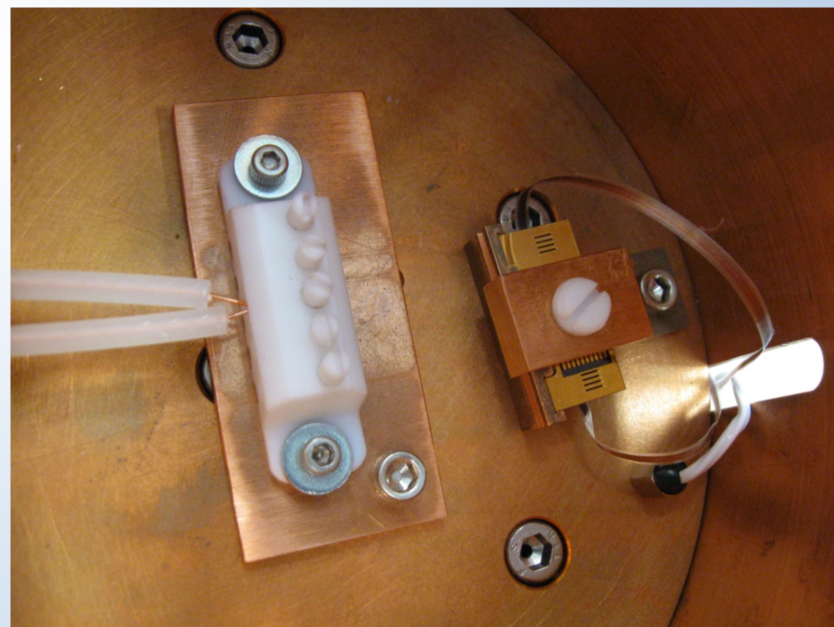


4-conductor cable prototype

Internal Connectors

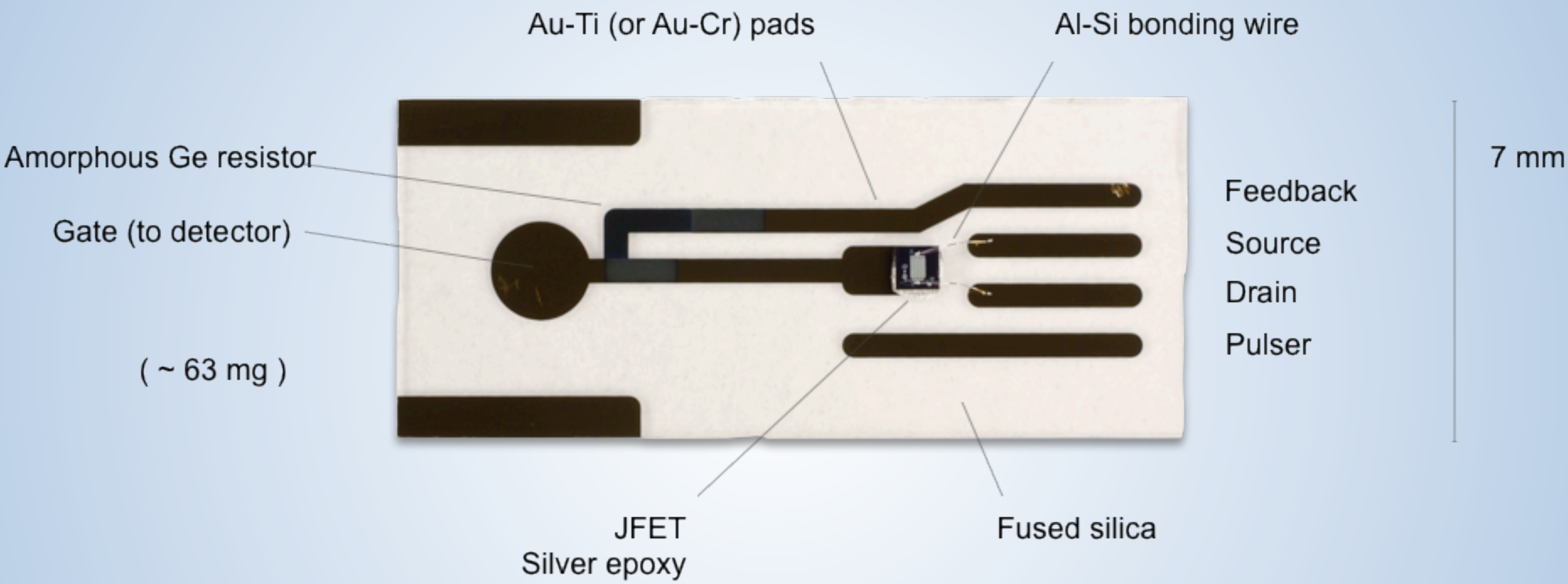






- Both designs are viable, need some minor adjustments

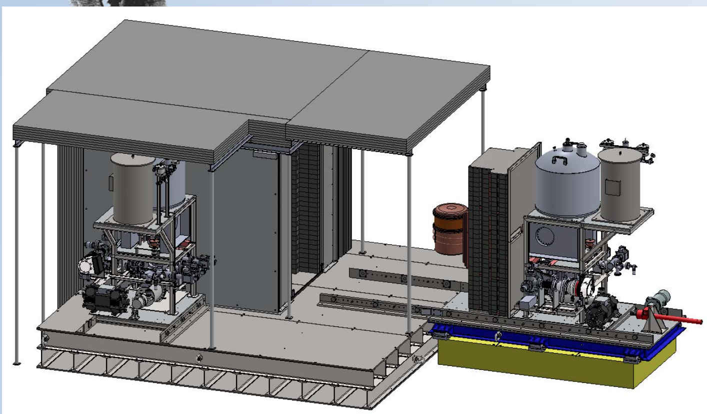
Low Mass Front End (LMFE)



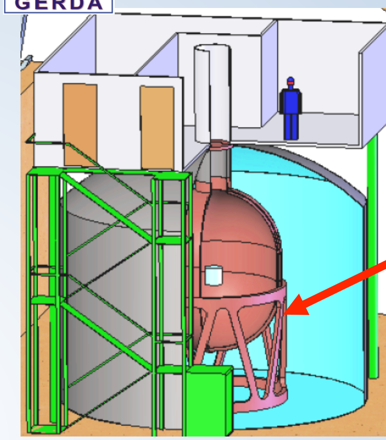
Fused silica (*high purity, low dielectric losses, low thermal conductivity)*	MX-11 JFET
Amorphous Ge film for R_f (*high purity, low noise)*	$R_f \sim$ 10-100 GΩ at 77K
Stray capacitance for C_f	$C_f \sim$ 0.2 pF

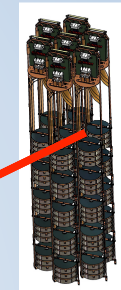
Towards 1TGe

MAJORANA



GERDA





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

- 'Bare' ^{enr}Ge array in liquid argon
- Shield: high-purity liquid Argon / H_2O
- Phase I (2011): ~18 kg (HdM/IGEX diodes)
- Phase II (2012): 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 1 ton exp. Select best techniques developed and tested in GERDA and MAJORANA

Off-line analysis (background reduction)

- Muon veto
- Granularity
- Pulse-shape analysis
- Others