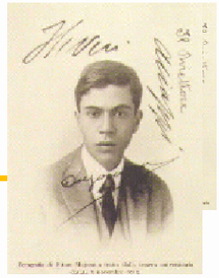


MAJORANA DEMONSTRATOR and Large-Scale Ge for 0νββ

Matthew P. Green

Oak Ridge National Laboratory

for the MAJORANA COLLABORATION

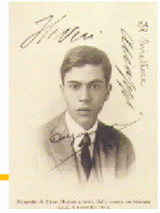
Using ^{76}Ge to search for 0νββ

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

- Ge as source & detector.
- Elemental Ge maximizes the source-to-total mass ratio.
- Intrinsic high-purity Ge diodes.
  - zone refining followed by Czochralski crystal growing reduces contaminants
  - highly efficient fiducial volume
- Reasonably slow 2νββ rate ($T_{1/2}$ = 1.4 × 10^{21} y).
- Demonstrated ability to enrich from natural, 7.83%, to ≥ 86%.

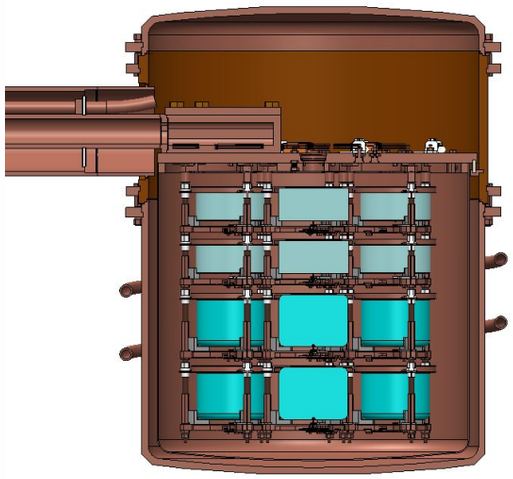
- Excellent energy resolution of 0.16% at 2.039 MeV ⇒ 4 keV ROI.
  - minimize irreducible 2νββ background
  - optimize signal to continuum backgrounds
  - spectroscopic resolution of potential gamma and neutron backgrounds
- Powerful background rejection.
  - pulse shape discrimination between single-site and multi-site events
  - array segmentation (granularity), including timing
- Well-understood, scalable technologies.
  - Commercial HPGe diodes
  - Large Ge arrays (Gammasphere, TIGRESS, AGATA, GRETINA)

The MAJORANA DEMONSTRATOR

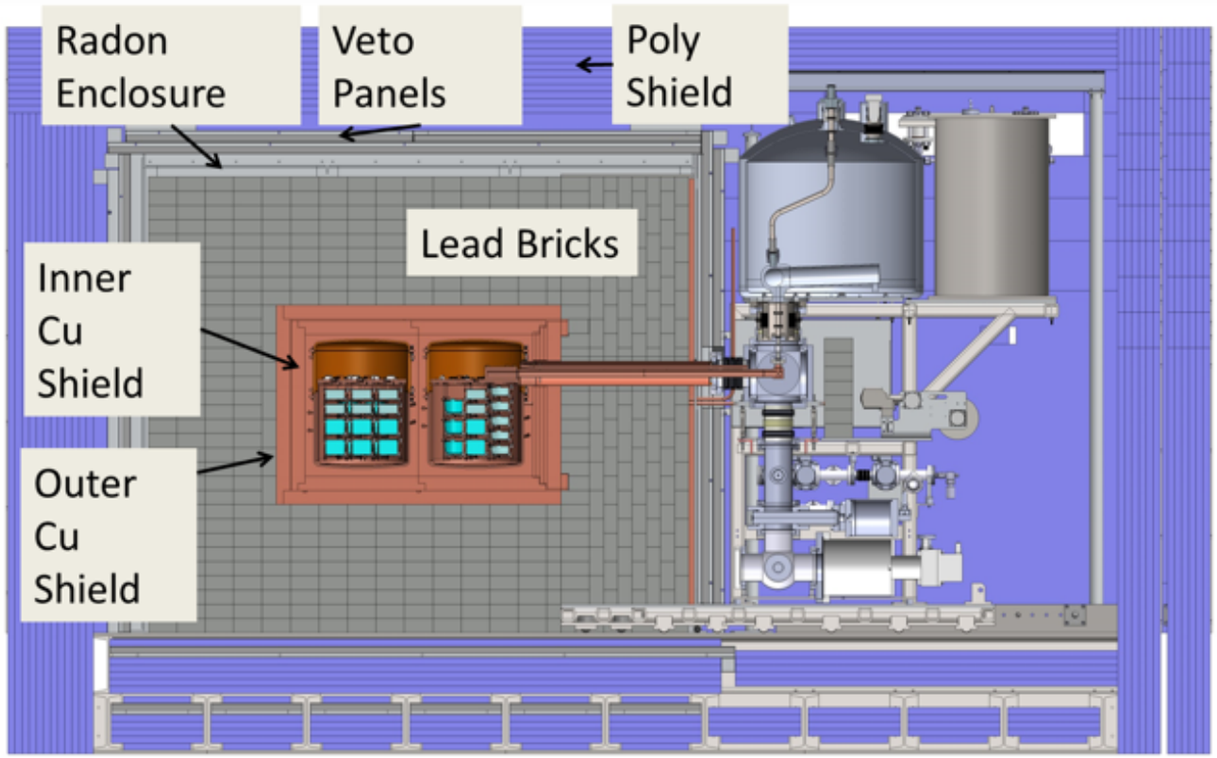


Funded by DOE Office of Nuclear Physics and NSF Particle Astrophysics,
with additional contributions from international collaborators.

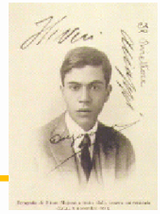
Goals:
- Demonstrate backgrounds low enough to justify building a tonne-scale experiment.
- Establish feasibility to construct & field modular arrays of Ge detectors.
- Searches for additional physics beyond the standard model.



- 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) Assay U.L. currently ≤ 3.1
  - 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, poly n shield

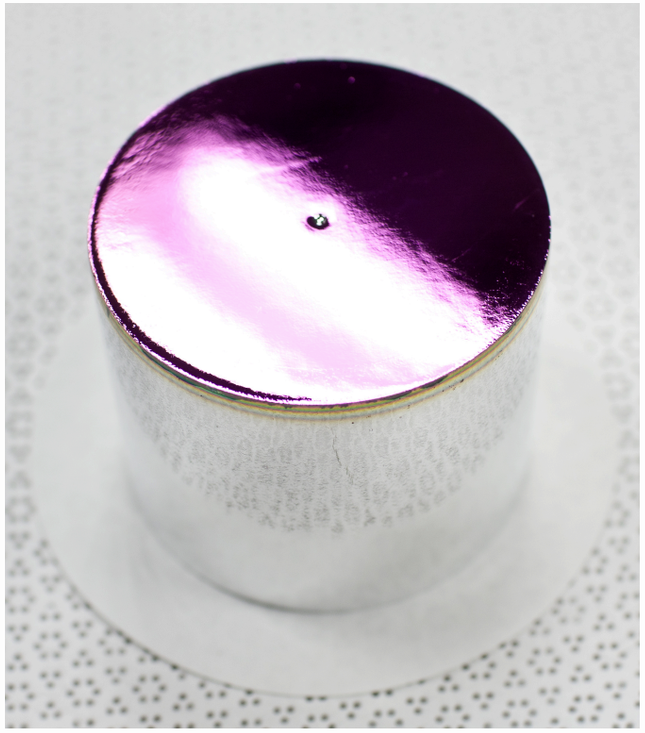


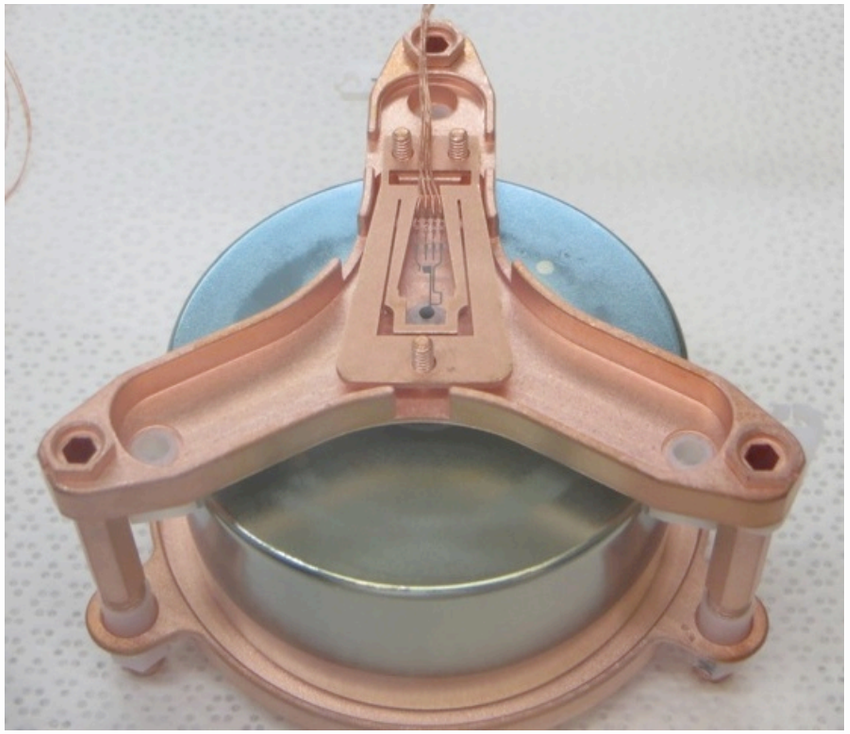
Point Contact Detectors (PPC)

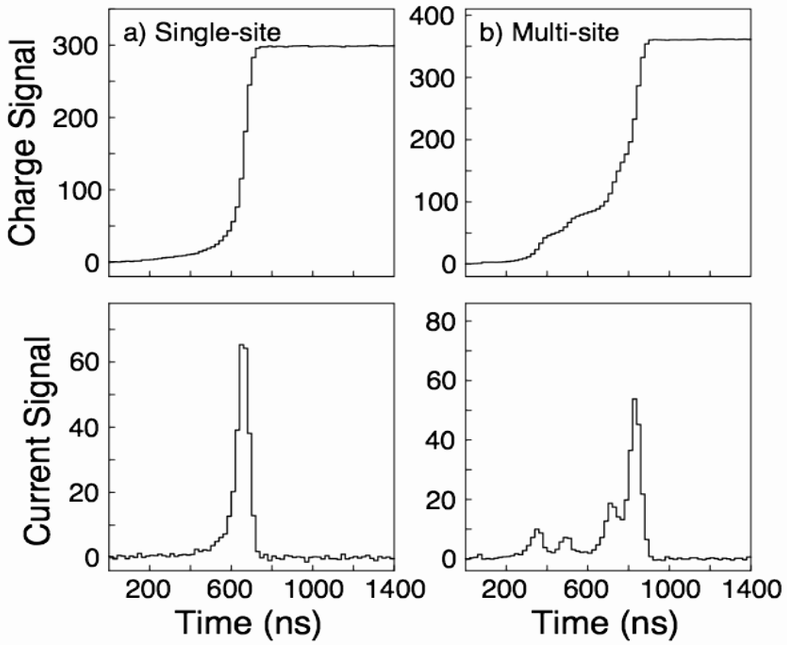


Luke et al., IEEE trans. Nucl. Sci. 36 , 926(1989); P. S. Barbeau, J. I. Collar, and O. Tench, J. Cosm. Astro. Phys. 0709 (2007).

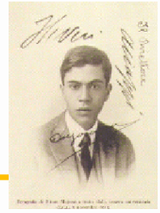
- Ultra-low background requires PSA rejection of multi-site gamma events
- Chose P-type Point-Contact (PPC) detectors
  - Small point-like central contact
  - Length is shorter than standard coaxial detector
  - Simple, cost-effective, low background
  - Localized weighting potential gives excellent multi-site rejection
  - Low capacitance (~ 1 pF) gives superb resolution at low energies



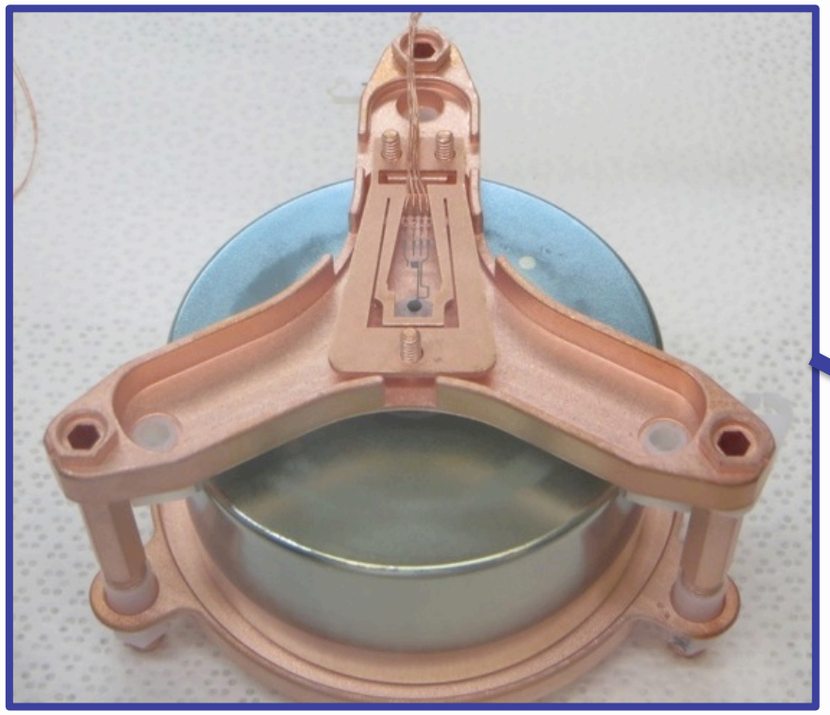


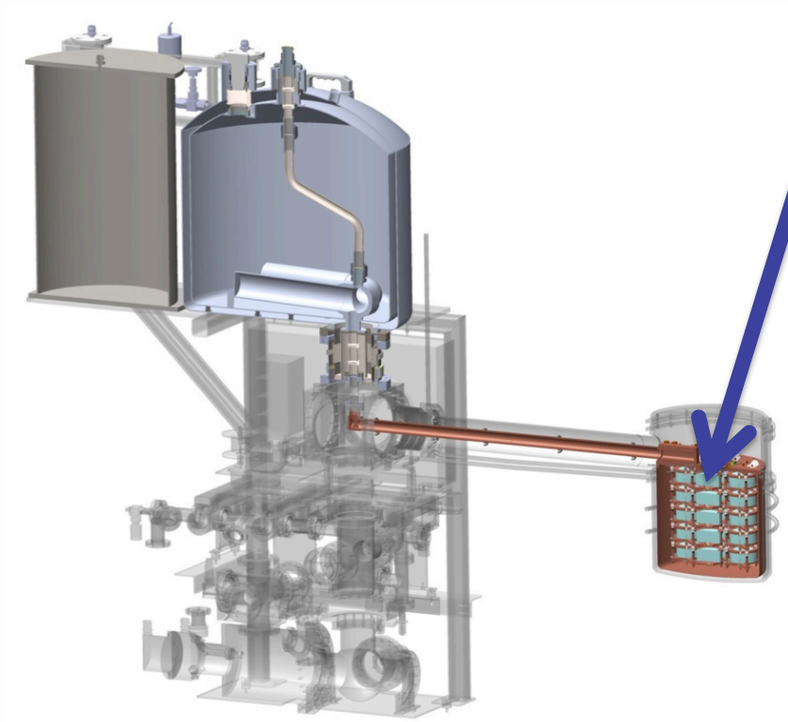


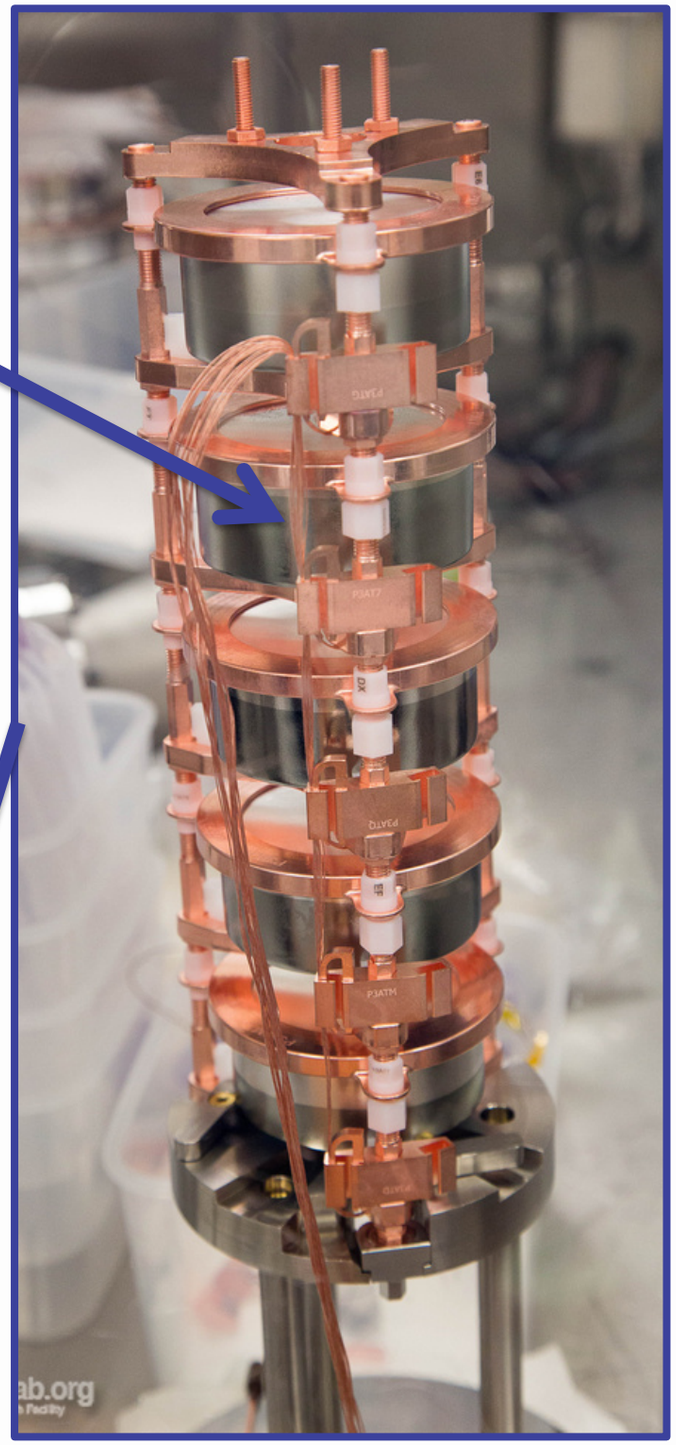
MJD Detector Array Overview



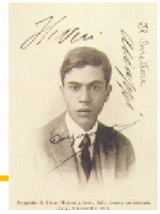
- Detector Units
  - Low mass PPC detector mounting structure
  - Adaptable to a range of form factors
  - Copper and PTFE construction
- Stacked into “Strings” of 4-5 detectors
- Modular Cryostats:
  - Capacity: 7 strings, up to 22.5kg
  - Form factor driven by compact shielding capability
  - Demonstrated operation in 2 cooling configurations:
    - Thermosyphon
    - Pulse-tube cooler





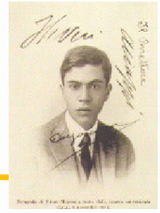


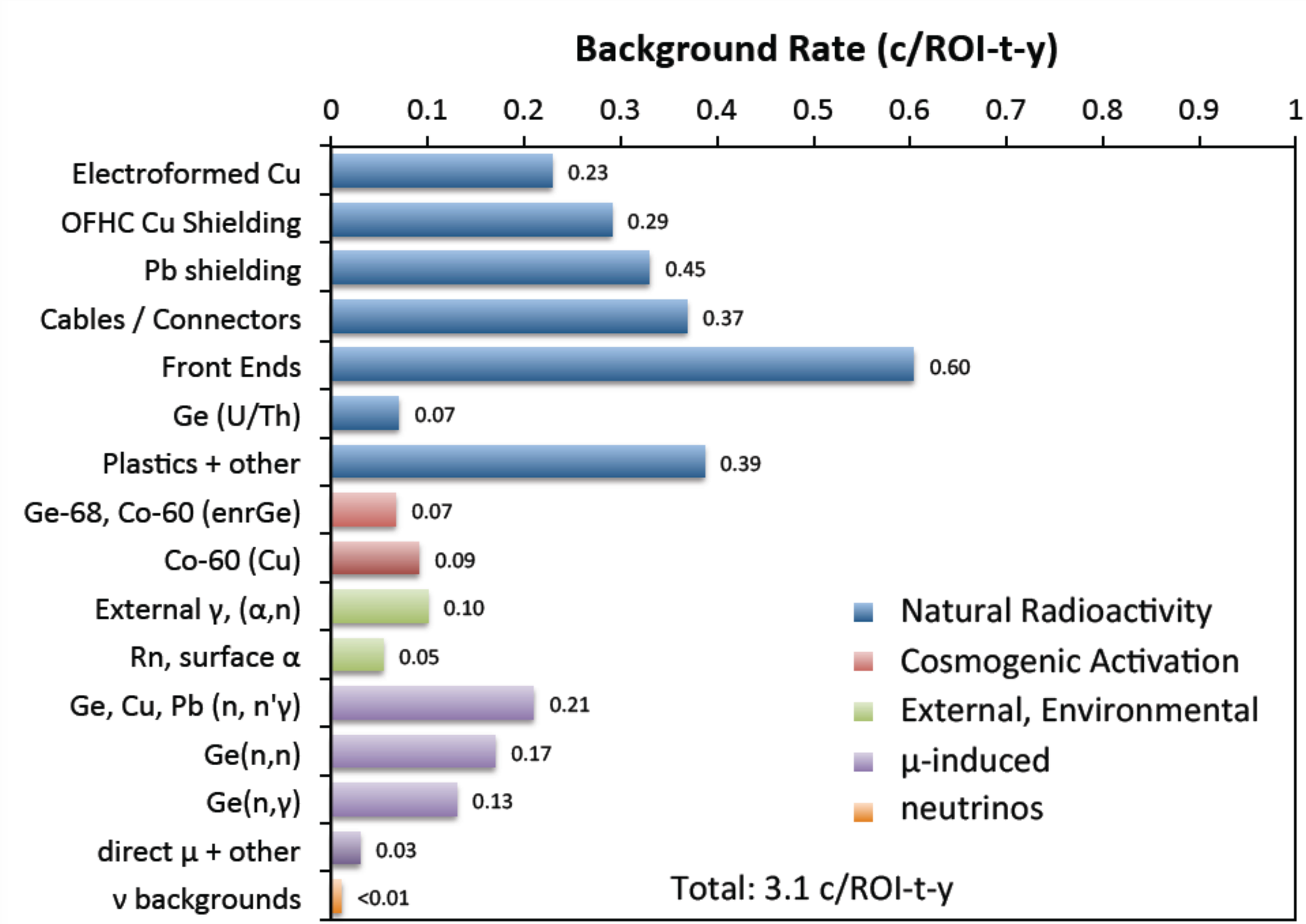
Radiopure Materials



- Extensive campaigns to qualify, procure, produce clean materials
  - NAA, ICPMS, γ-counting used for material assay
  - Ultra-pure electroformed copper, produced underground for detector components, cryostats, shielding
  - High-purity PTFE insulators
- UG manufacturing for reduction of cosmogenic activation
  - Fully-outfitted machine shop
  - Chemistry lab for cleaning and surface treatment

MJD Projected Backgrounds



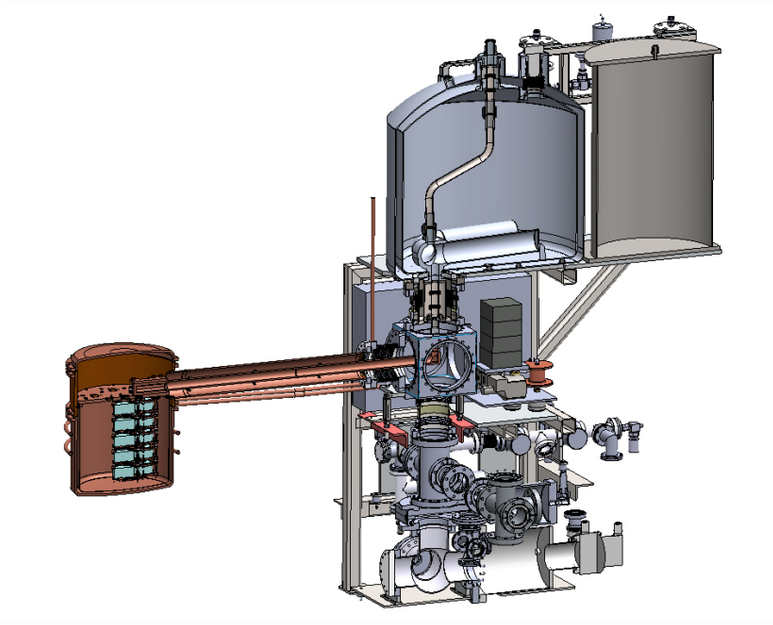


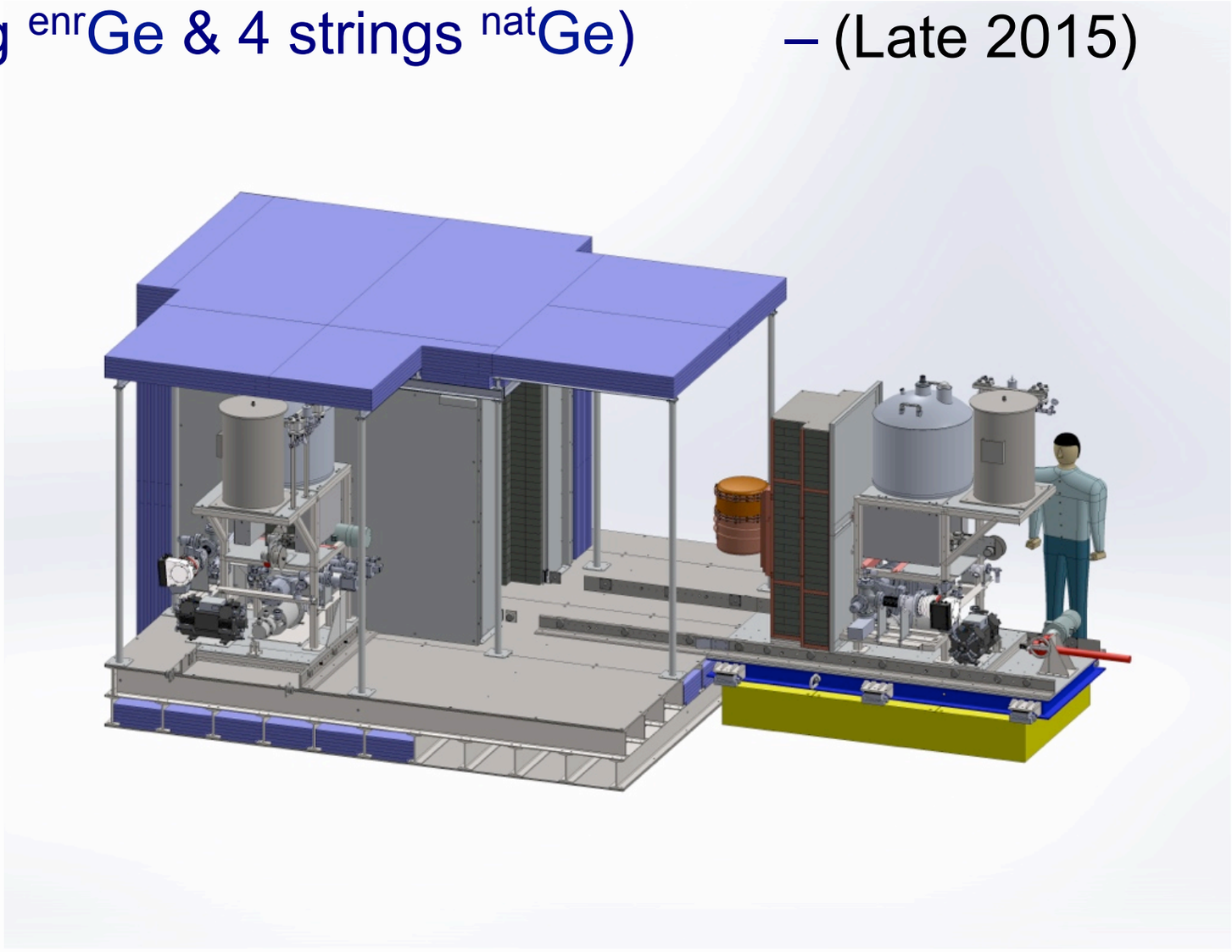
MJD Implementation

Phased Deployment

Commissioning start dates (Estimated)

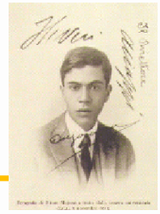
- Prototype Module* (3 strings, ^{nat}Ge) – Nov. 2013
  - Decommissioning Spring 2015; redeployment for CEvNS possible
- Module 1 (7 strings, 20 kg ^{enr}Ge) – Sept 2014
- Module 2 (3 strings, 10 kg ^{enr}Ge & 4 strings ^{nat}Ge) – (Late 2015)

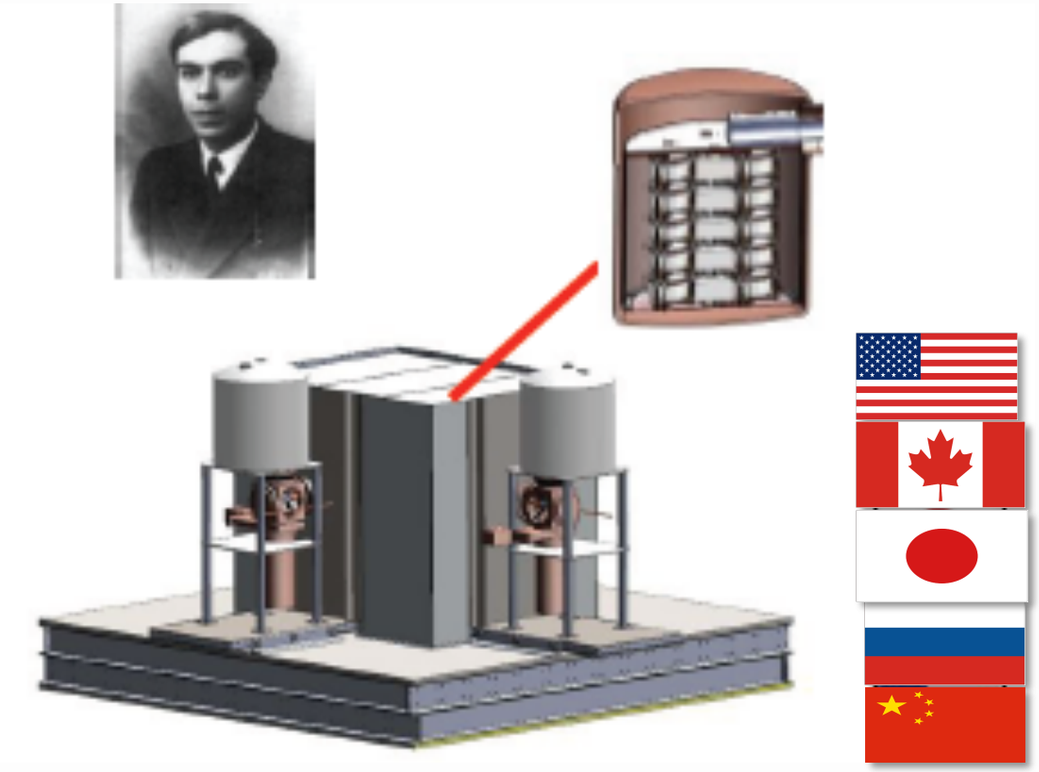


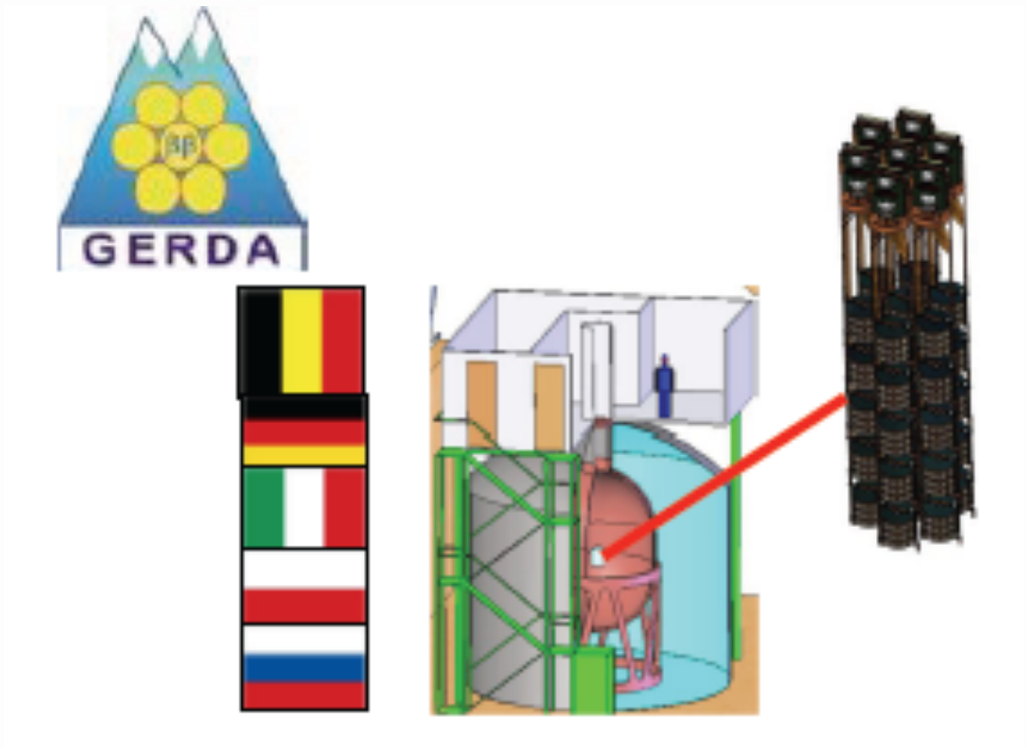


* Same design as Cryos 1 & 2, but fabricated using OFHC Cu (non-electroformed) components.

MAJORANA DEMONSTRATOR and GERDA







- ^{76}Ge modules in electroformed Cu cryostat, Cu / Pb passive shield
- 4π plastic scintillator μ veto
- DEMONSTRATOR: 30 kg ^{76}Ge and 10 kg ^{nat}Ge PPC detectors

- ^{76}Ge array submersed in LAr
- Water Cherenkov μ veto
- Phase I: ~18 kg (H-M/IGEX xtals)
- Phase II: +20 kg PPC detectors

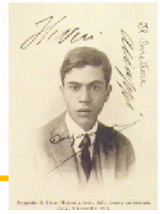
Joint Cooperative Agreement:

Open exchange of knowledge & technologies (e.g. MaGe, R&D)

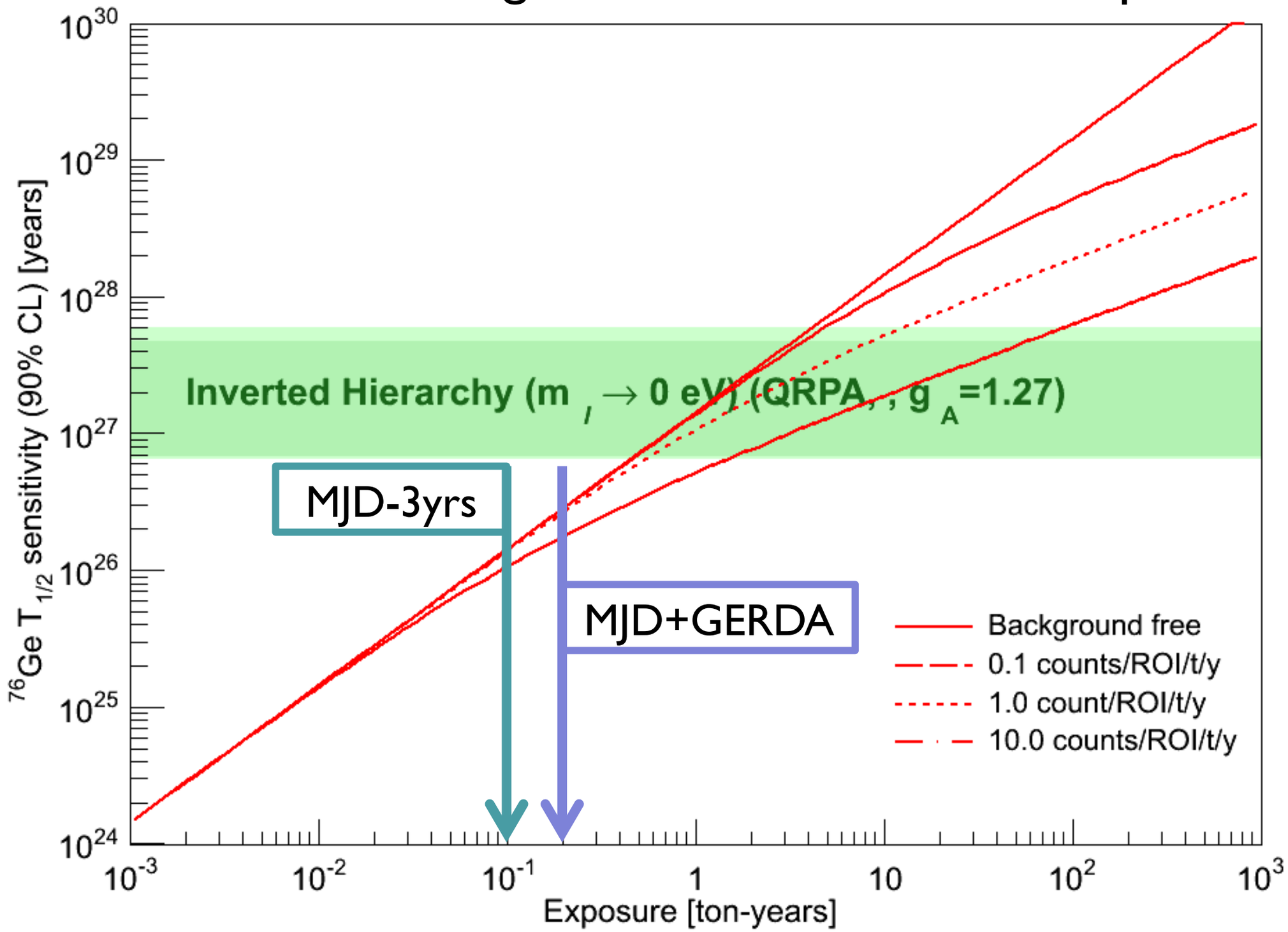
Intention to merge for larger scale experiment

Select best techniques developed and tested in GERDA and MAJORANA

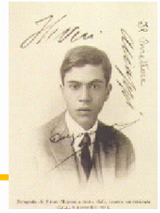
Limit Sensitivity



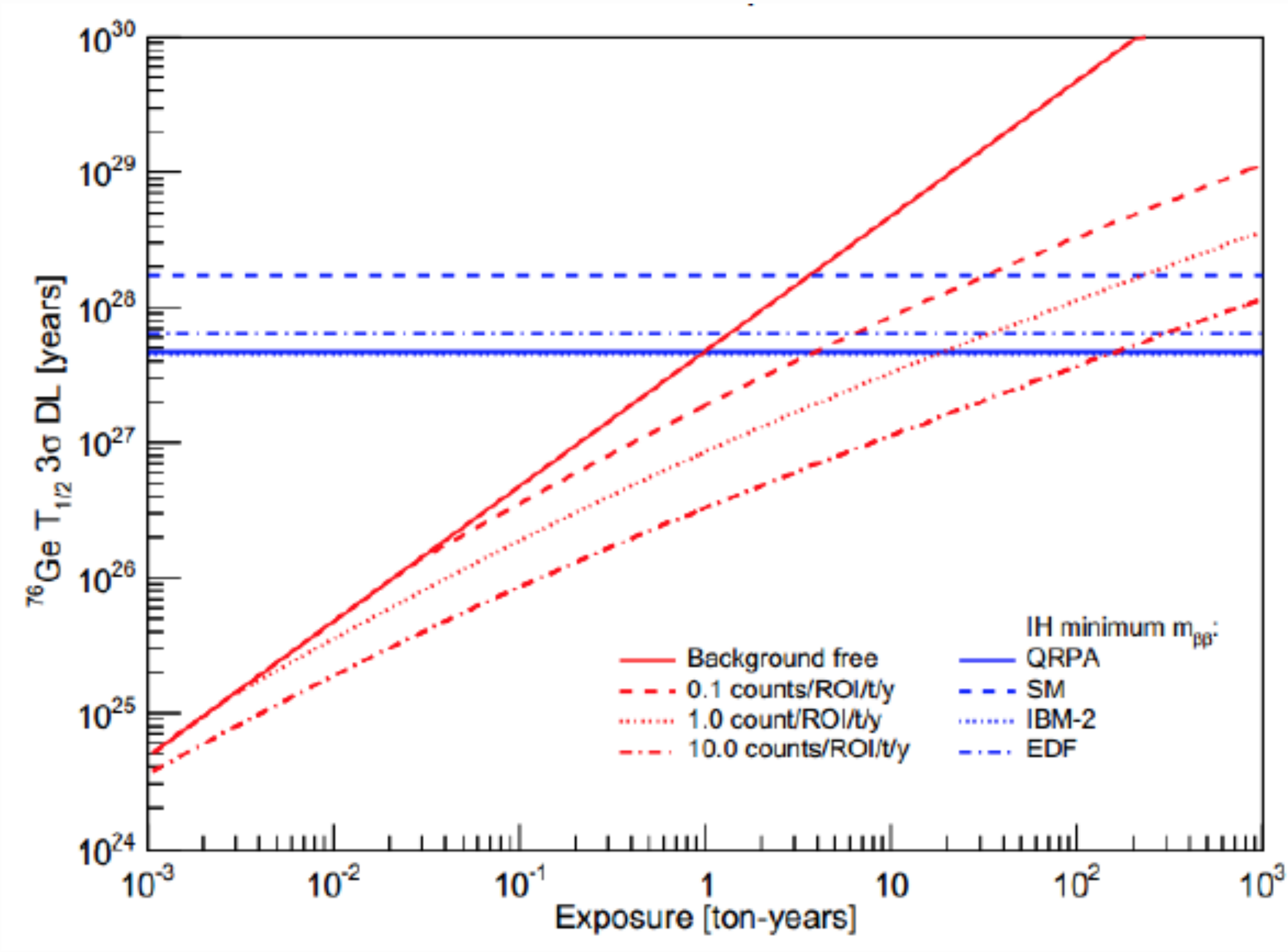
Discovery level requires more exposure, but the good energy resolution is an advantage over lower resolution experiments.



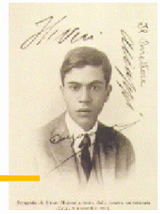
^{76}Ge Discovery vs. Background



J. Detwiler

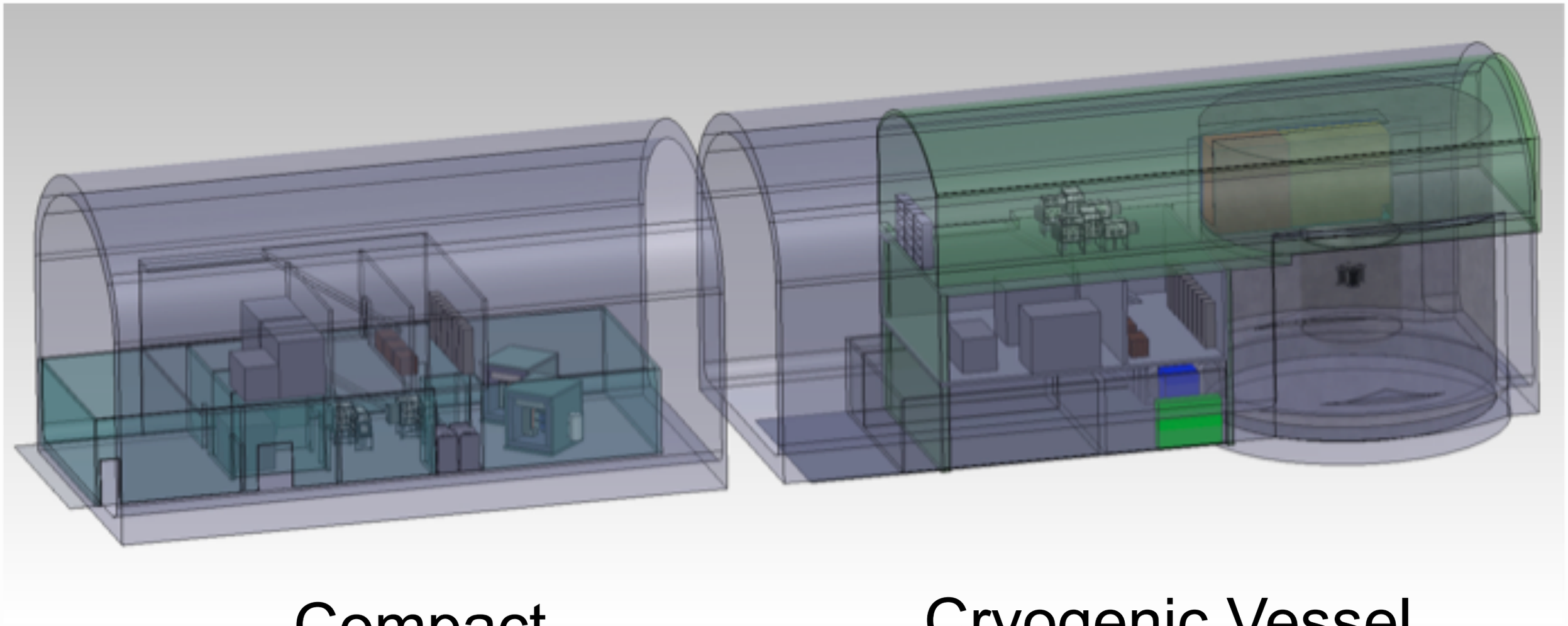


Large-Scale 0νββ ^{76}Ge Experiment



- Majorana and GERDA are working towards the establishment of a single international ^{76}Ge 0νββ collaboration
- Envision a phased, stepwise implementation;
  e.g. 250 → 500 → 1000 kg
- Moving forward predicated on demonstration of projected backgrounds by MJD and/or GERDA
- Anticipate down-select of best technologies, based on results of the two experiments
- During 2015 both GERDA Phase II and MJD Module 1 should be collecting data
- A Large-Scale ^{76}Ge double beta decay experiment would have a lot in common with the present generation experiments.
- A large and experienced collaboration is expected to form from the present-generation experimental groups.

Baseline Experimental Configurations



Compact

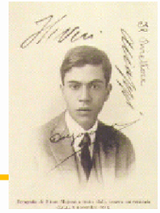
Two shields, each with 8 EFCu vacuum cryostats

Cryogenic Vessel

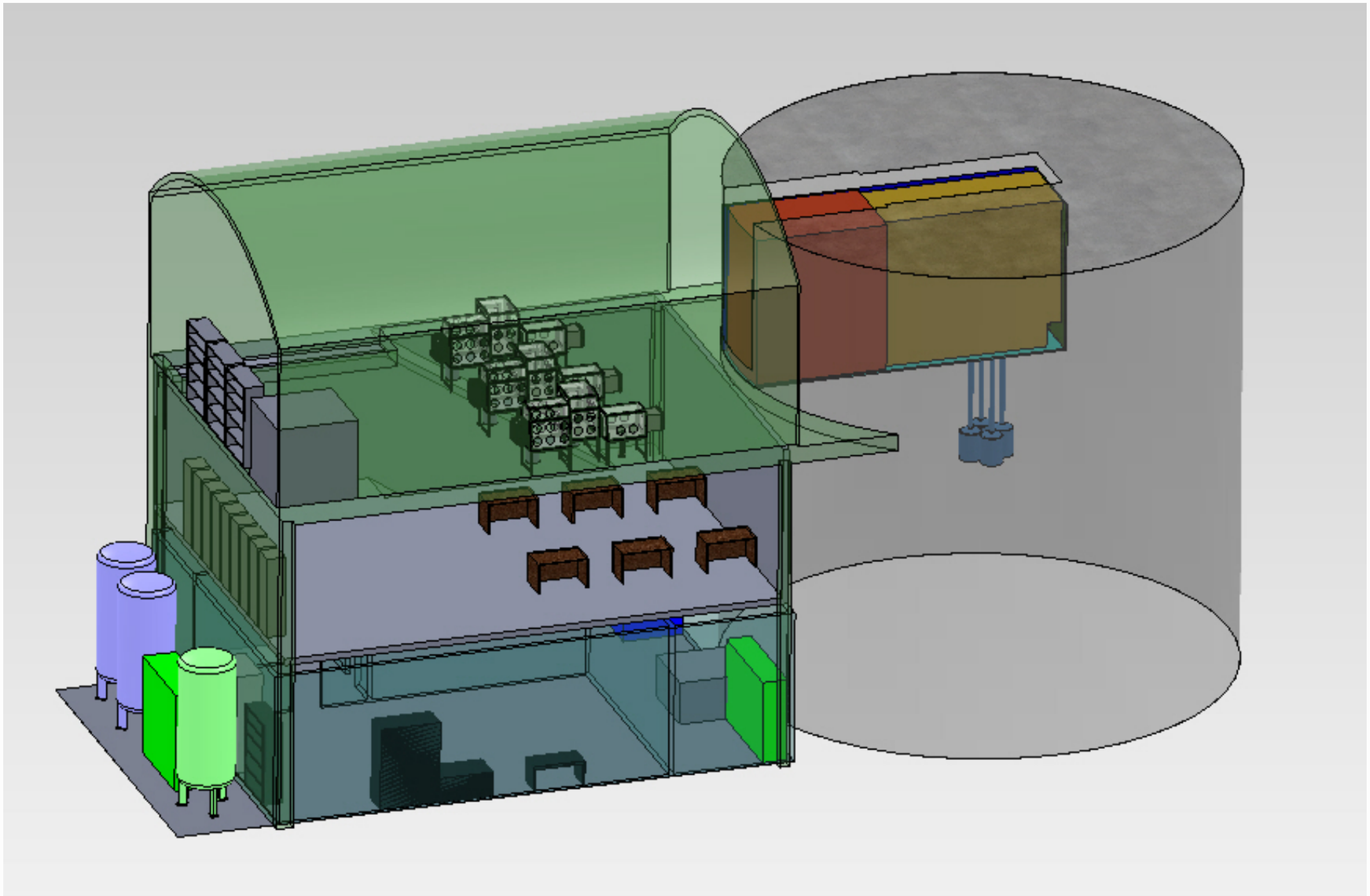
Diameter of water tank:

- ~11 m for LAr,
- ~15 m for LN (shown)

Alternative Shield Concepts

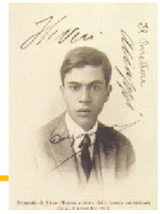


Hybrid: Vacuum cryostats in LAr, liquid scintillator or water



- Required purity of scintillator or water is within the bounds of what has previously been achieved

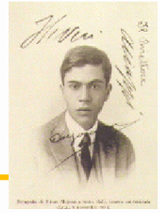
Baseline Shield Comparisons

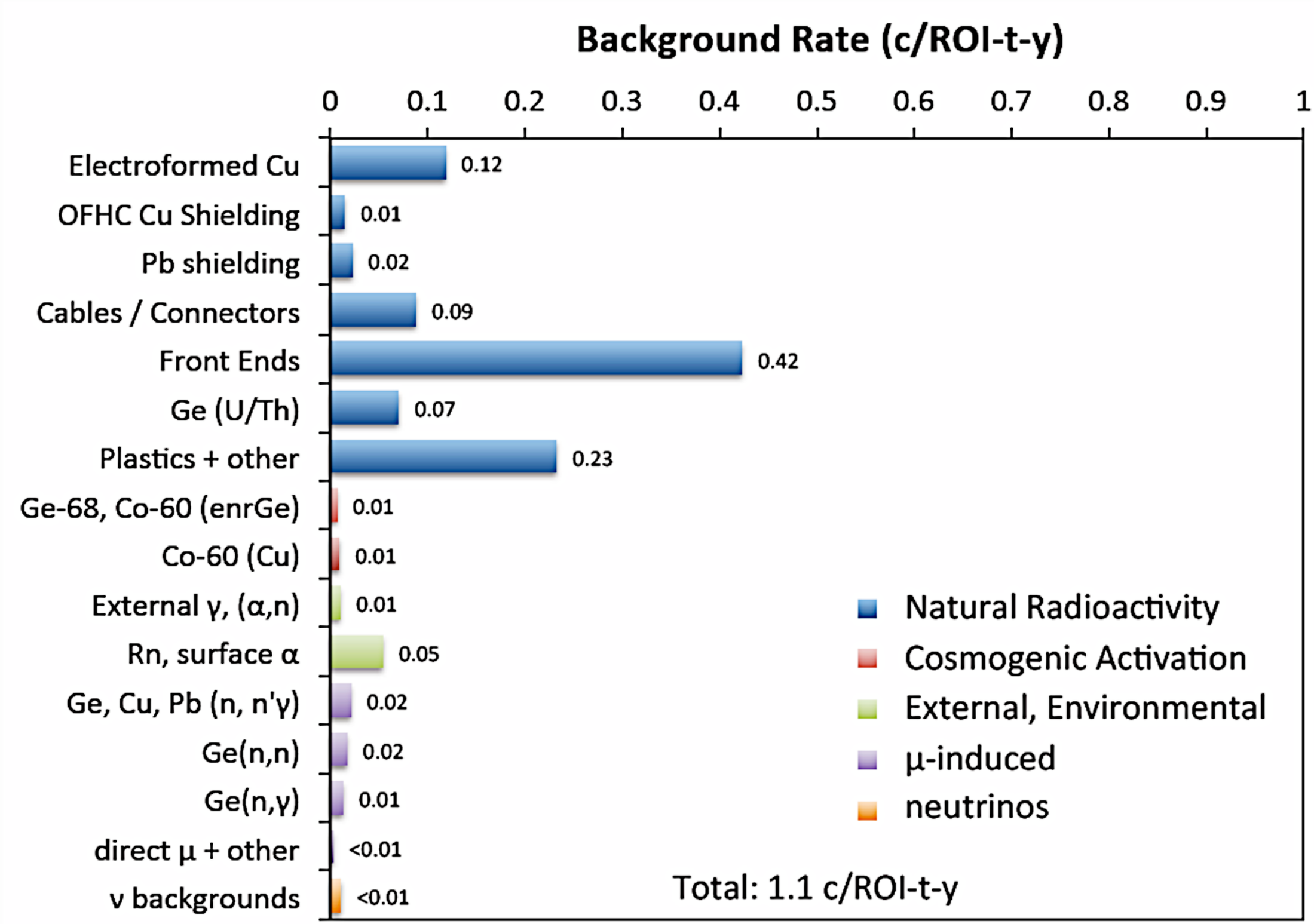


- Both configurations can adequately suppress external radiation, and have similar estimates of background rates from internal sources (crystals, mounts, etc.)
- Cryogenic Vessel requires more space
- Compact Shield may need to be sited deeper to achieve desired cosmic-ray induced background rate.
- Cryogenic Vessel approach is more technically complex

Large-scale technology down-select will be driven by the background suppression performance achieved in the MAJORANA DEMONSTRATOR and GERDA Phase II efforts.

Large-Scale Backgrounds (proj. from MJD)





Large-Scale R&D Efforts

Several areas of needed R&D for a tonne-scale experiment have been identified and will be explored over the next several years.

- Ge Detector Development
  - Large detectors
  - Field shaping geometries
  - Small contacts
  - Ge recovery and reprocessing
- Detector Assemblies
  - Additive manufacturing
  - Cables & connectors
- Materials & Assay
  - Improved copper assay
  - Improved electroforming methods
  - New dielectrics
- Array Shielding
  - Instrumented liquid cryogen
  - Investigation of hybrid design
  - Alternative shield materials
    - Lead purification
    - Depleted germanium
- Simulations and Analysis
  - Background budgets
  - Neutron backgrounds
  - Required experimental depth
  - Shielding simulations
  - Radon-daughter backgrounds

A technically-constrained schedule would allow construction of a large-scale Ge 0νββ experiment to begin in 2018/2019.

The MAJORANA Collaboration

Black Hills State University, Spearfish, SD
Kara Keeter

Duke University, Durham, North Carolina , and TUNL
Matthew Busch, James Esterline, Gary Swift, Werner Tornow

Institute for Theoretical and Experimental Physics, Moscow, Russia
Alexander Barabash, Sergey Konovalov, Vladimir Yumatov

Joint Institute for Nuclear Research, Dubna, Russia
Viktor Brudanin, Slava Egorov, K. Gusev,
Oleg Kochetov, M. Shirchenko, V. Timkin, E. Yakushev

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Nicolas Abgrall, Mark Amman, Paul Barton, Yuen-Dat Chan,
Paul Luke, Susanne Mertens, Alan Poon, Kai Vetter, Harold Yaver

Los Alamos National Laboratory, Los Alamos, New Mexico
Melissa Boswell, Steven Elliott,, Johnny Goett, Keith Rielage, Larry Rodriguez, Michael Ronquest, Harry Salazar, Wenqin Xu

North Carolina State University, Raleigh, North Carolina and TUNL
Dustin Combs, Lance Leviner, David G. Phillips II, Albert Young

Oak Ridge National Laboratory, Oak Ridge, Tennessee
Fred Bertrand, Kathy Carney, Alfredo Galindo-Uribarri,
Matthew P. Green, David Radford, Elisa Romero-Romero,
Robert Varner, Brandon White, Timothy Williams, Chang-Hong Yu

Osaka University, Osaka, Japan
Hiroyasu Ejiri, Ryuta Hazama, Masaharu Nomachi, Shima Tatsuji

Pacific Northwest National Laboratory, Richland, Washington
Jim Fast, Eric Hoppe, Richard T. Kouzes, Brian LaFerriere, John Orrell, Nicole Overman

Shanghai Jiaotong University, Shanghai, China
James Loach

South Dakota School of Mines and Technology, Rapid City, South Dakota
Adam Caldwell, Cabot-Ann Christofferson, Stanley Howard,
Anne-Marie Suriano, Jared Thompson

Tennessee Tech University, Cookeville, Tennessee
Mary Kidd

University of Alberta, Edmonton, Alberta
Aksel Hallin

University of North Carolina, Chapel Hill, North Carolina and TUNL
Graham K. Giovanetti, Reyco Henning, Mark Howe, Jacqueline MacMullin, Benjamin Shanks, Christopher O' Shaughnessy, Kris Vorren, John F. Wilkerson

University of South Carolina, Columbia, South Carolina
Frank Avignone, Vince Guiseppe, Clint Wiseman

University of South Dakota, Vermillion, South Dakota
Dana Byram, Ben Jasinski, Ryan Martin, Nathan Snyder

University of Tennessee, Knoxville, Tennessee
Yuri Efremenko, Sergey Vasilyev

University of Washington, Seattle, Washington
Tom Burritt, Micah Buuck, Clara Cuesta, Jason Detwiler, Peter J. Doe, Julieta Gruszko,
Ian Guinn, Greg Harper, Jonathan Leon, David Peterson, R. G. Hamish Robertson,
Tim Van Wechel