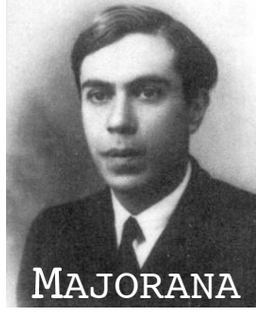
U.S. DEPARTMENT OF ENERGY | Office of Science

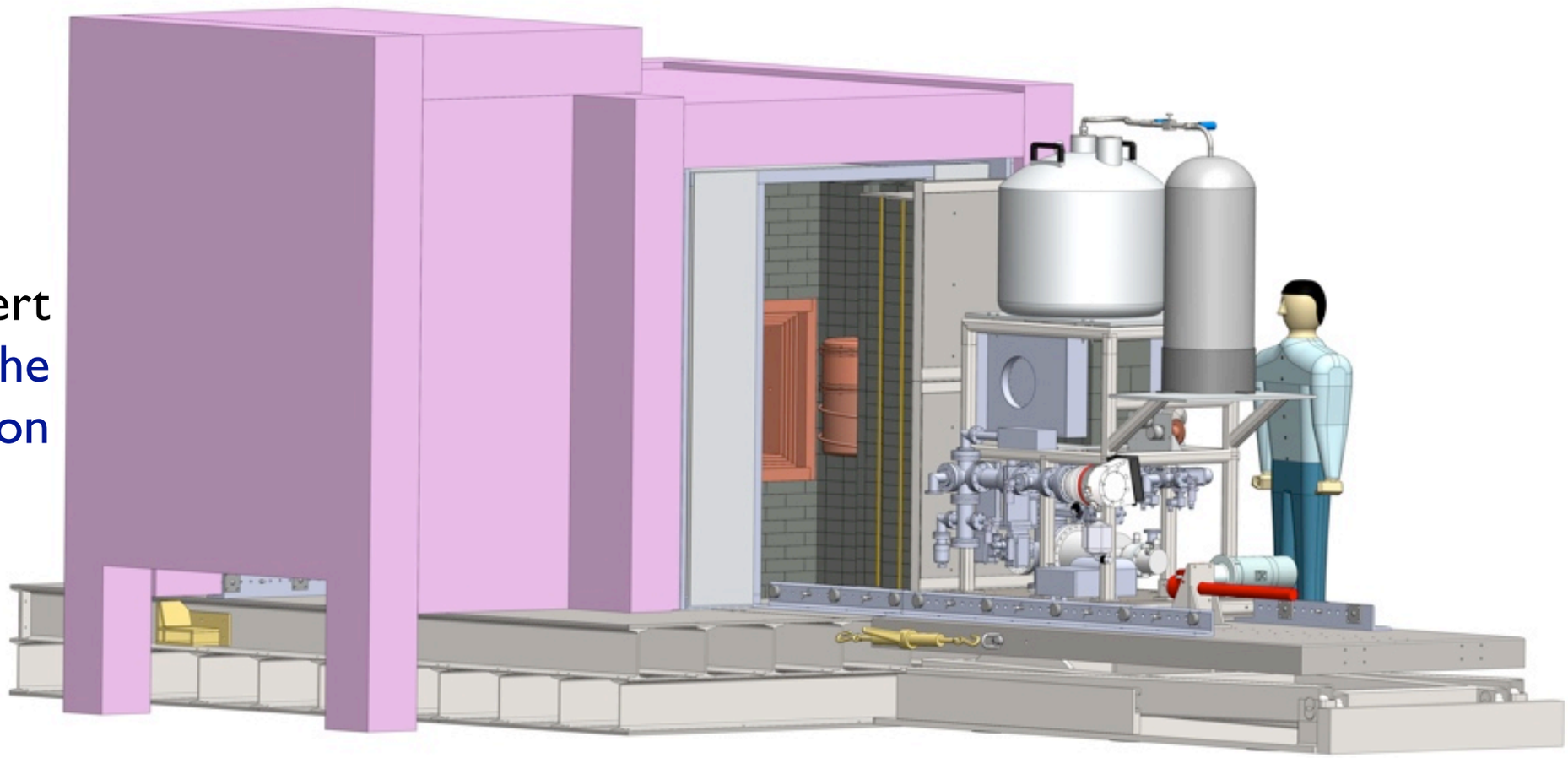
Office of Nuclear Physics



The MAJORANA DEMONSTRATOR

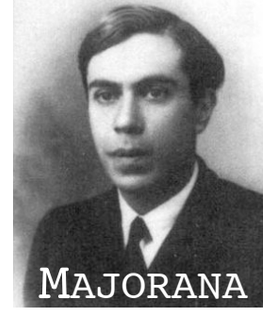
A search for neutrinoless double-beta decay of germanium-76

Alexis Schubert
on behalf of the
MAJORANA Collaboration



UNIVERSITY of WASHINGTON

CENPA
Center for Experimental Nuclear Physics and Astrophysics



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,
Igor Vanushin, Vladimir Yumatov

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

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Mark Amman, Marc Bergevin, Yuen-Dat Chan, Jason Detwiler,
James Loach, Paul Luke, Ryan Martin, Alan Poon, Gersende Prior,
Kai Vetter, Harold Yaver

Los Alamos National Laboratory, Los Alamos, New Mexico
Melissa Boswell, Steven Elliott, Victor M. Gehman,
Andrew Hime, Mary Kidd, Ben LaRoque, Keith Rielage, Larry
Rodriguez, Michael Ronquest, Harry Salazar, David Steele

North Carolina State University, Raleigh, North Carolina and TUNL
Dustin Combs, Lance Leviner, Albert Young

Oak Ridge National Laboratory, Oak Ridge, Tennessee
Fred Bertrand, Greg Capps, Ren Cooper, Kim Jeskie,
David Radford, Robert Varner, Chang-Hong Yu

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

Pacific Northwest National Laboratory, Richland, Washington
Craig Aalseth, Estanislao Aguayo, Jim Fast, Eric Hoppe,
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Juan Collar, Nicole Fields

University of North Carolina, Chapel Hill, North Carolina and TUNL
Padraic Finnerty, Florian Fraenkle, Graham Giovanetti, Matthew Green,
Reyco Henning, Mark Howe, Sean MacMullin, David G. Phillips II,
Jacqueline Strain, Kris Vorren, John F. Wilkerson

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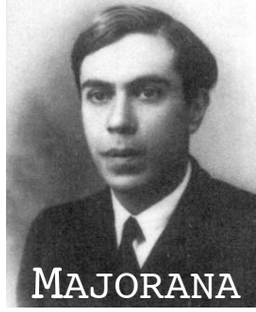
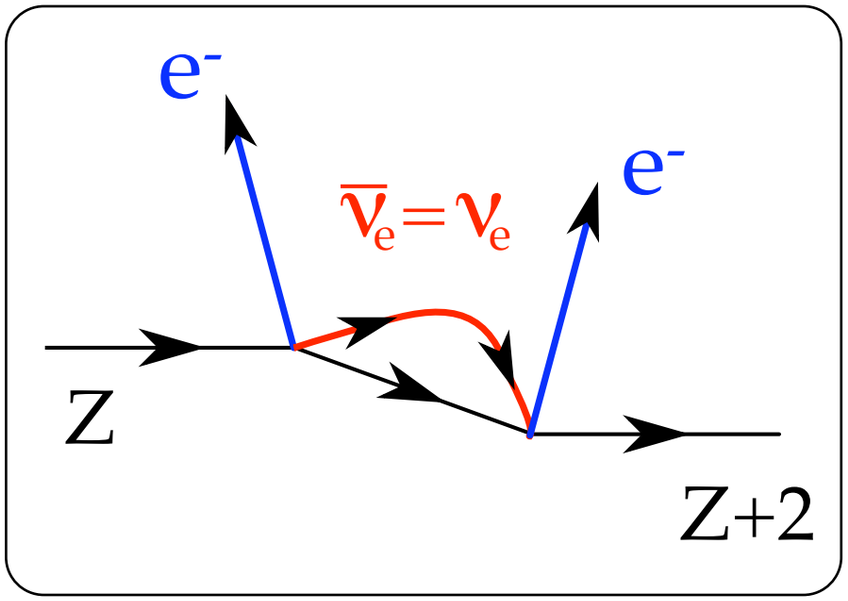
Vince Guiseppe, Tina Keller, Keenan Thomas, Dongming Mei,
Gopakumar Perumpilly, Chao Zhang

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

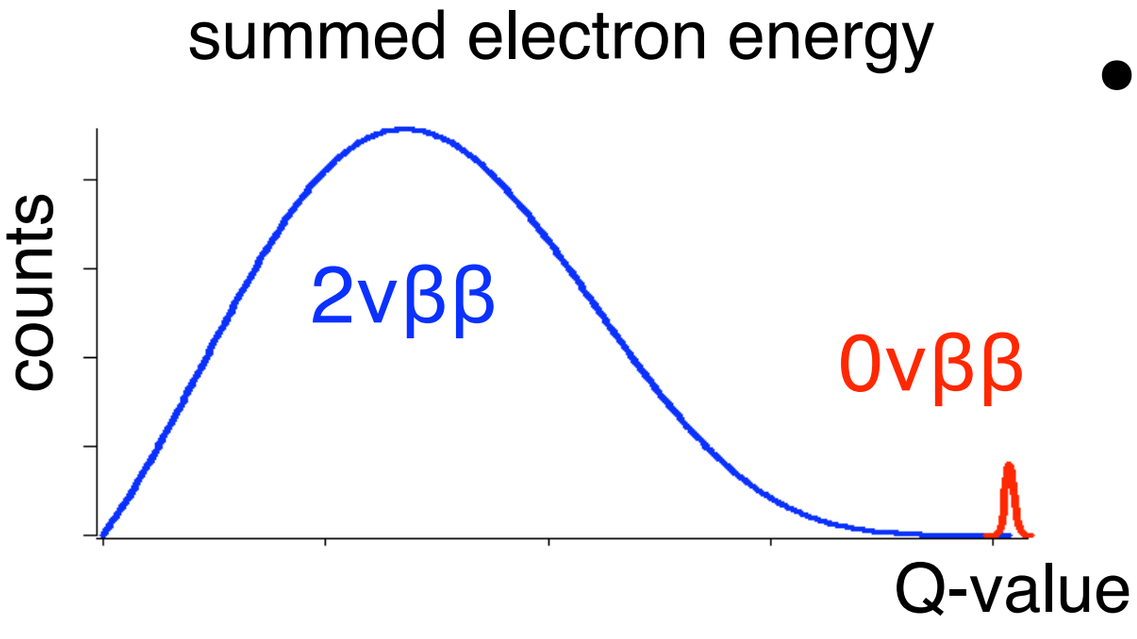
University of Washington, Seattle, Washington
Tom Burritt, Jonathan Diaz, Peter J. Doe, Greg Harper, Robert Johnson,
Andreas Knecht, Michael Marino, Mike Miller, David Peterson
R. G. Hamish Robertson, Alexis Schubert, Tim Van Wechel, Brett Wolfe

Neutrinoless double-beta decay (0νββ)

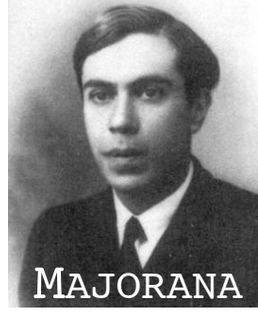




- Observation indicates:
  - Neutrino is a Majorana particle
  - Lepton number is not conserved
- Measurement of rate could provide information about neutrino mass



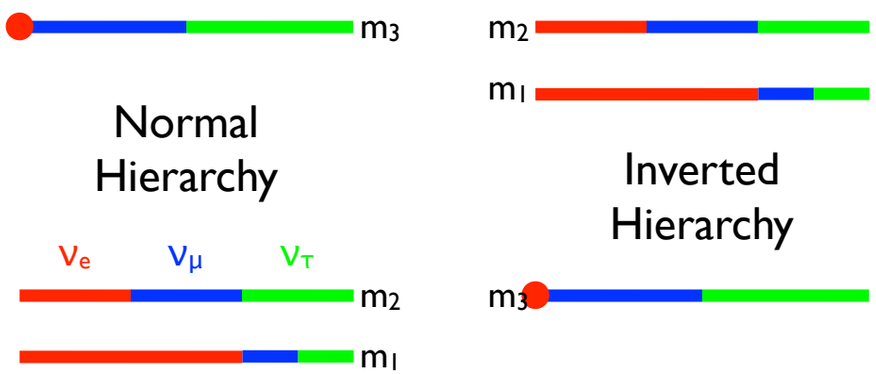
Neutrino mass and 0νββ



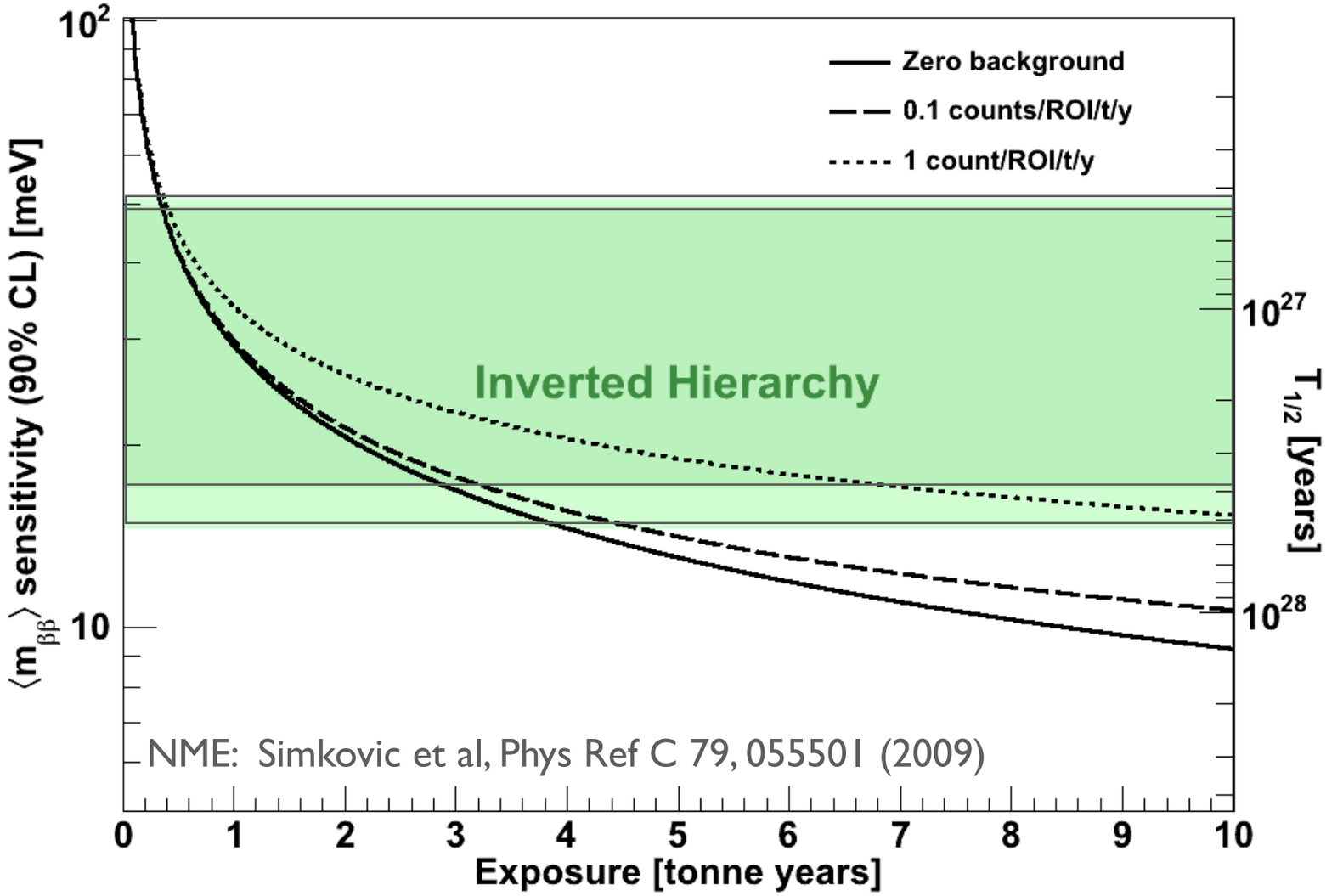
0νββ rate

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

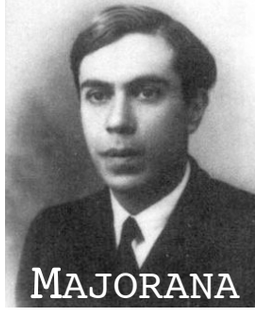
Neutrino mass hierarchy



Sensitivity of a tonne-scale ^{76}Ge experiment



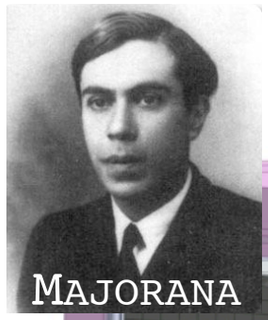
The GERDA and MAJORANA Experiments

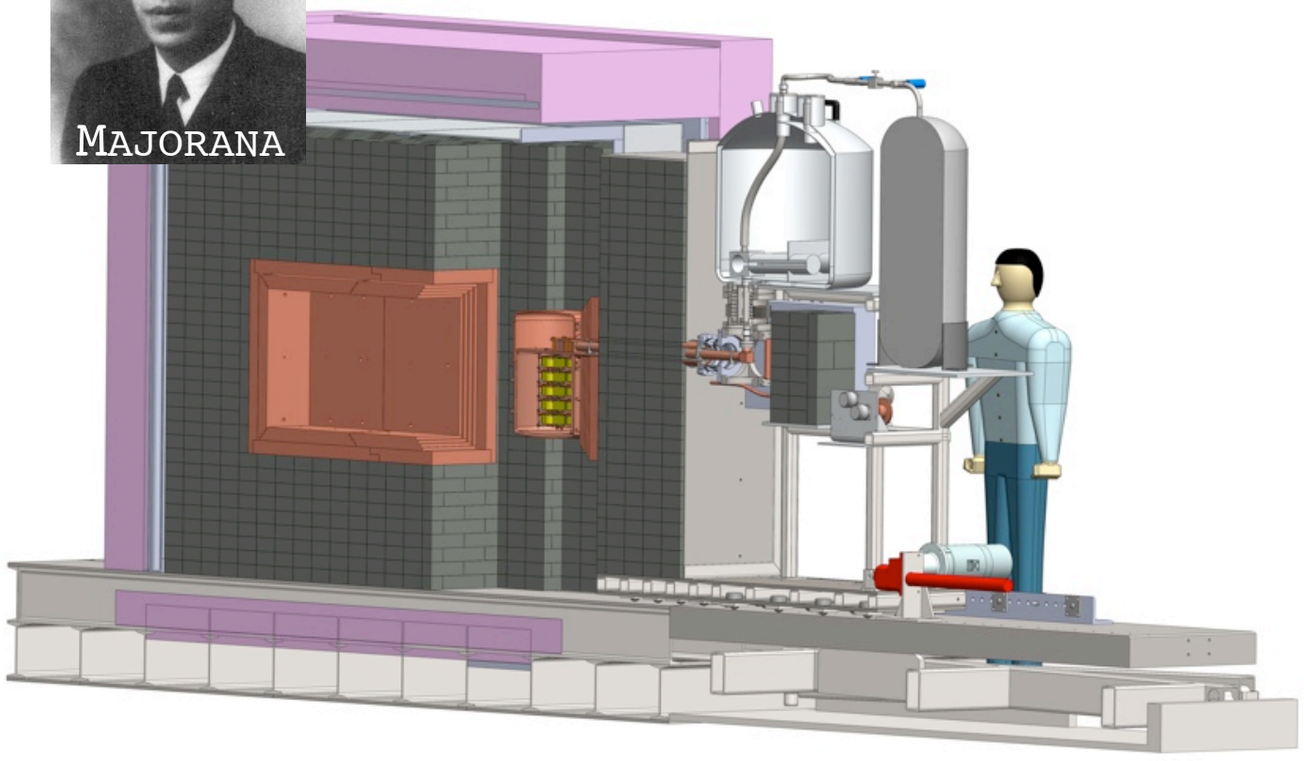


Detector array: enriched Ge crystals submerged in liquid argon

Shield: high-purity liquid argon, H_20

http://www.mpi-hd.mpg.de/gerda





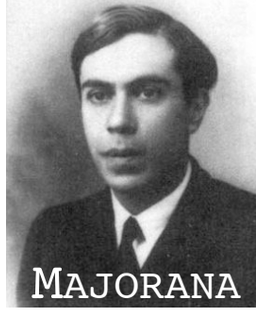
Detector array: enriched Ge crystals in vacuum cryostats

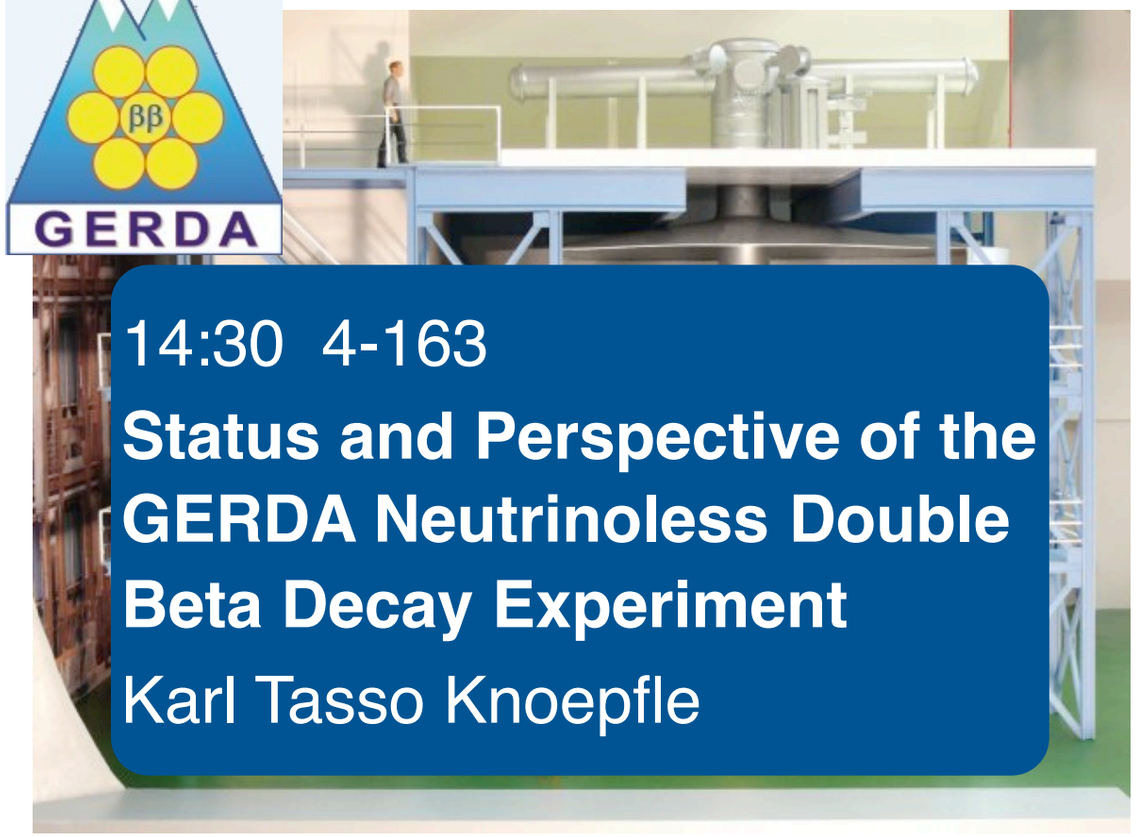
Shield: lead, copper

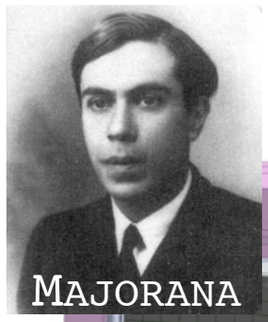
http://majorana.npl.washington.edu

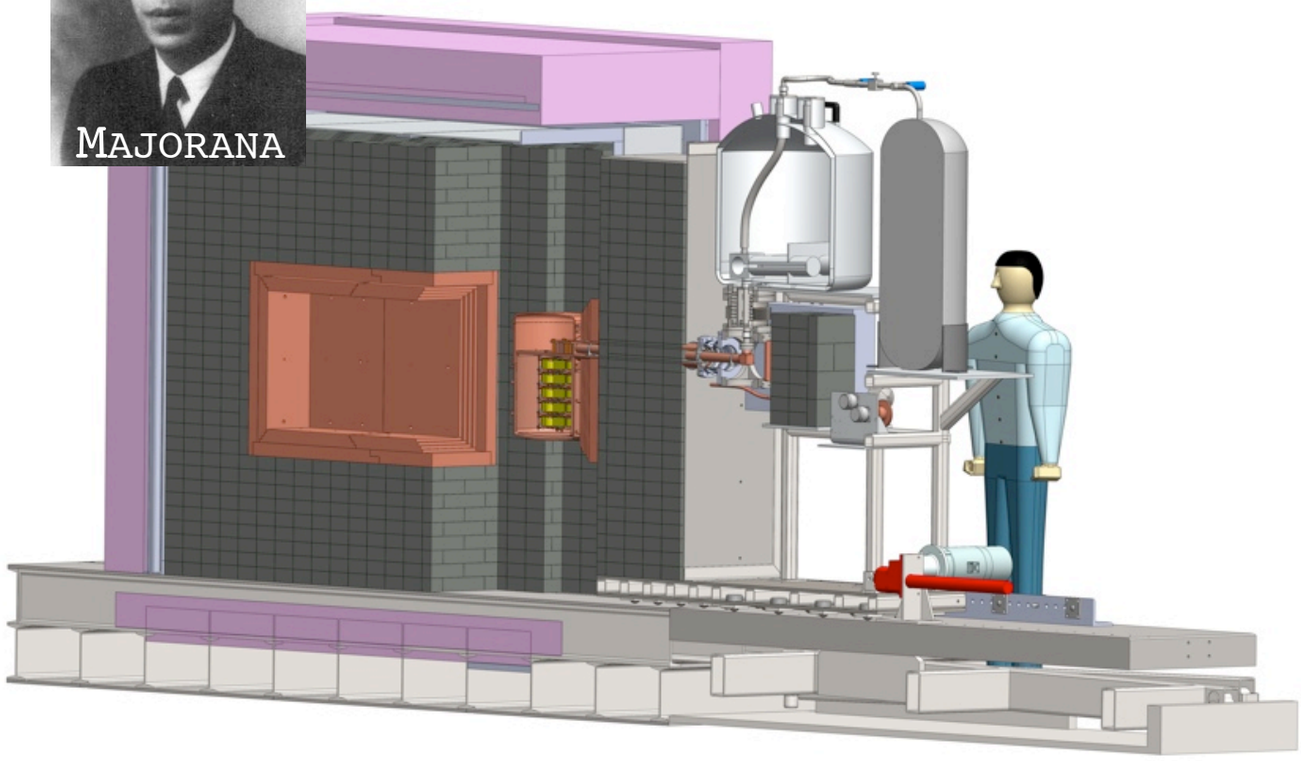
Goal: select best techniques developed in GERDA and MAJORANA for a joint tonne-scale Ge experiment

The GERDA and MAJORANA Experiments









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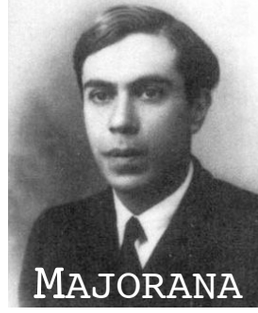
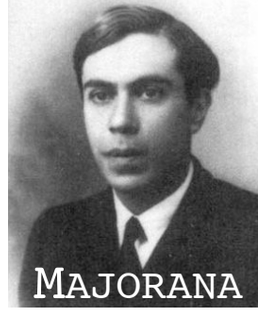
The MAJORANA Experiment



- Search for neutrinoless double-beta decay using an array of germanium detectors enriched in ^{76}Ge
- First phase of MAJORANA under construction: the DEMONSTRATOR, 40-kg R&D detector
- Attempt to achieve a background rate 100x lower than previous Ge experiments

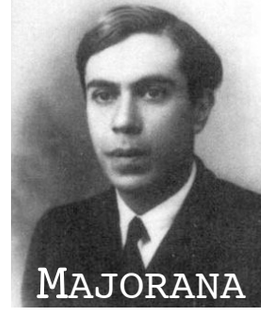


The MAJORANA Experiment

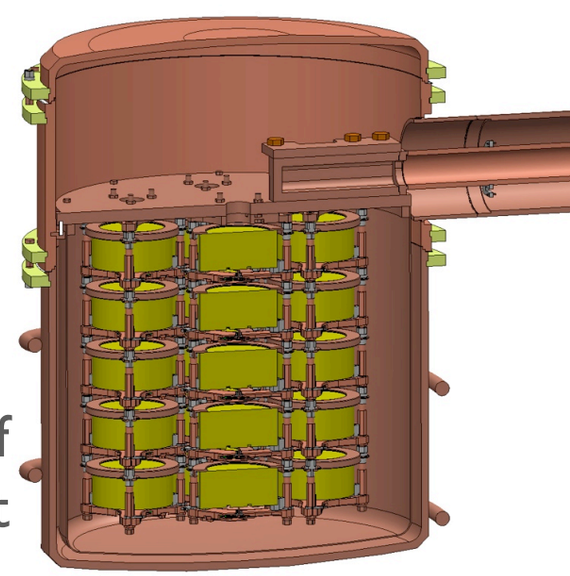
- Search for neutrinoless double-beta decay using an array of germanium detectors enriched in ^{76}Ge
- First phase of MAJORANA under construction: the DEMONSTRATOR, 40-kg R&D detector
- Attempt to achieve a background rate 100x lower than previous Ge experiments

Background goal for tonne-scale:
1 count per tonne-year in 4-keV region surrounding Q-value

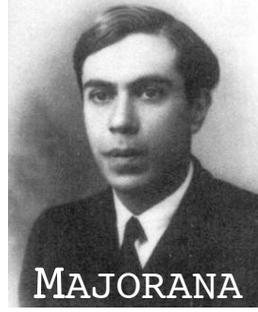
The MAJORANA DEMONSTRATOR



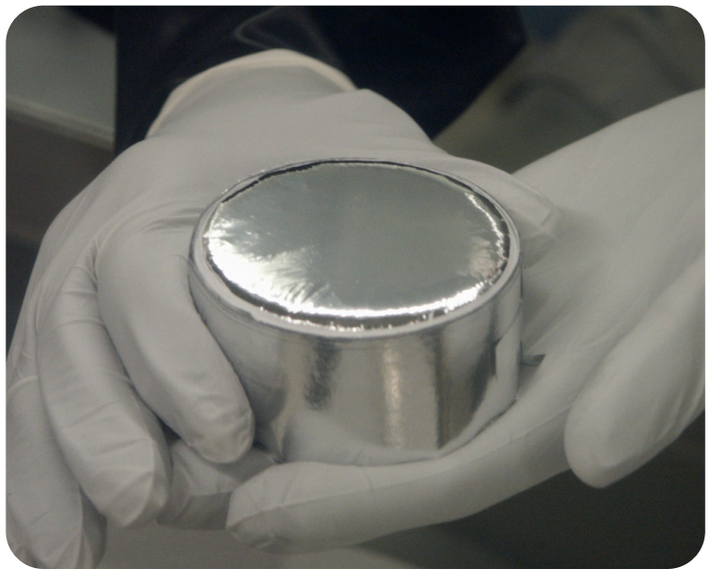
- First phase of the MAJORANA experiment
- 40-kg ultra-clean Ge detector array deployed in two cryostats at 4850' level of Sanford Lab
  - 20 to 30 kg of crystals enriched to 86% ^{76}Ge
- **Technical goal:** demonstrate background levels that justify construction of tonne-scale experiment
- **Science goal:** test recent claim of 0νββ observation - Phys. Lett. B 586 198 (2004)



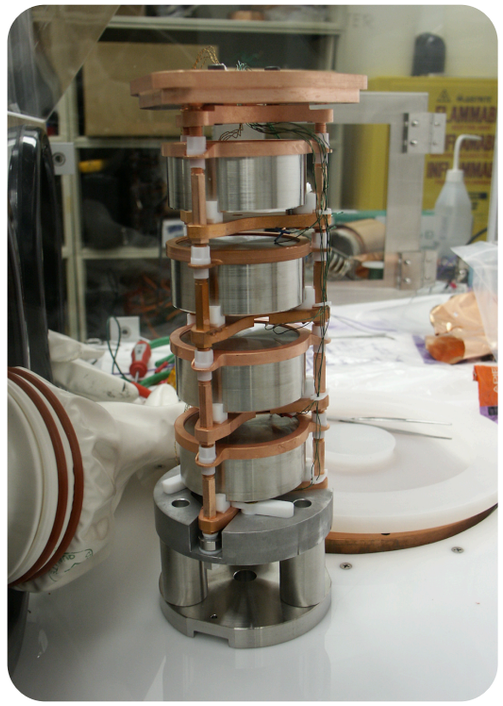
the inside of
a cryostat



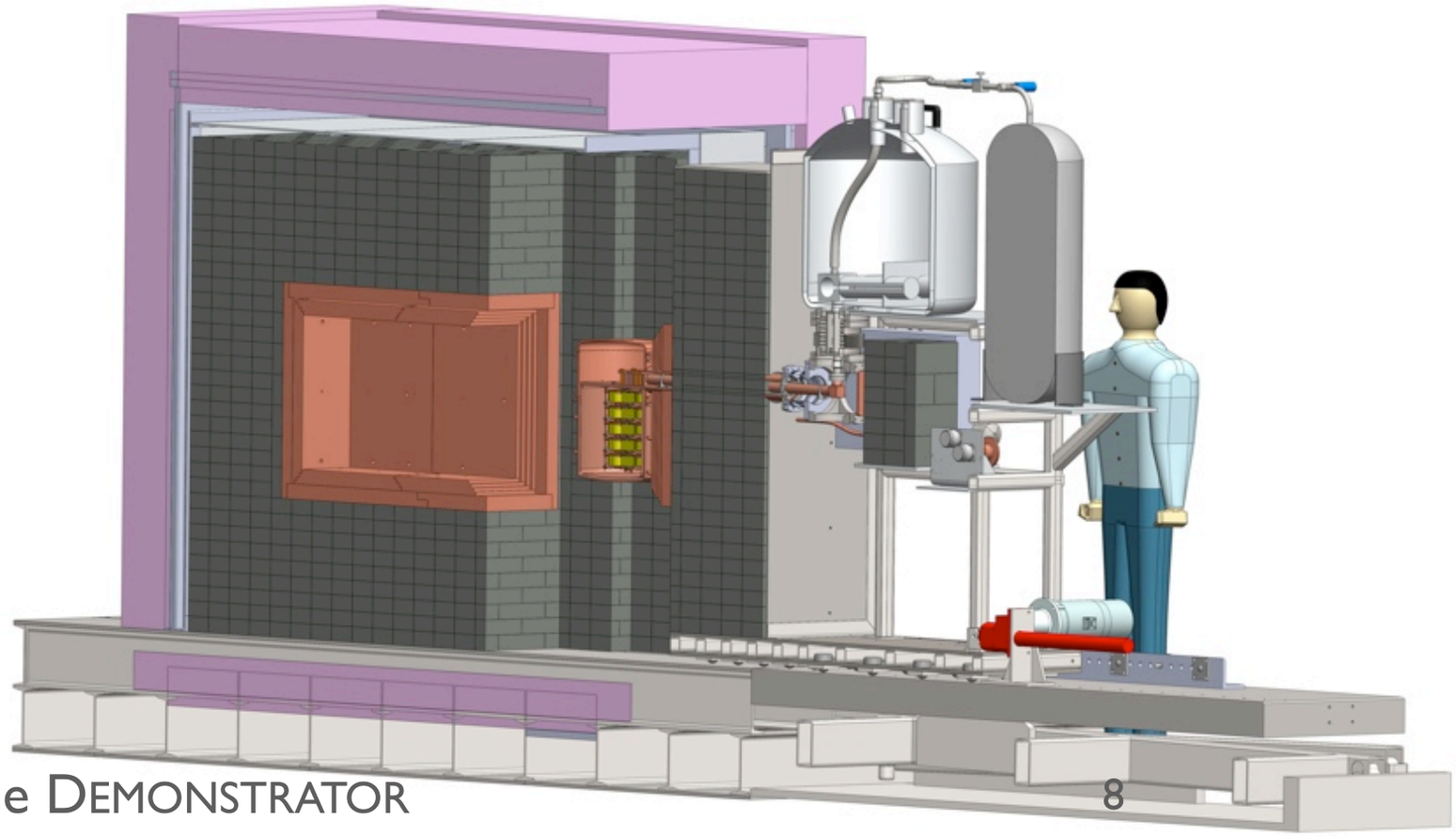
The MAJORANA DEMONSTRATOR

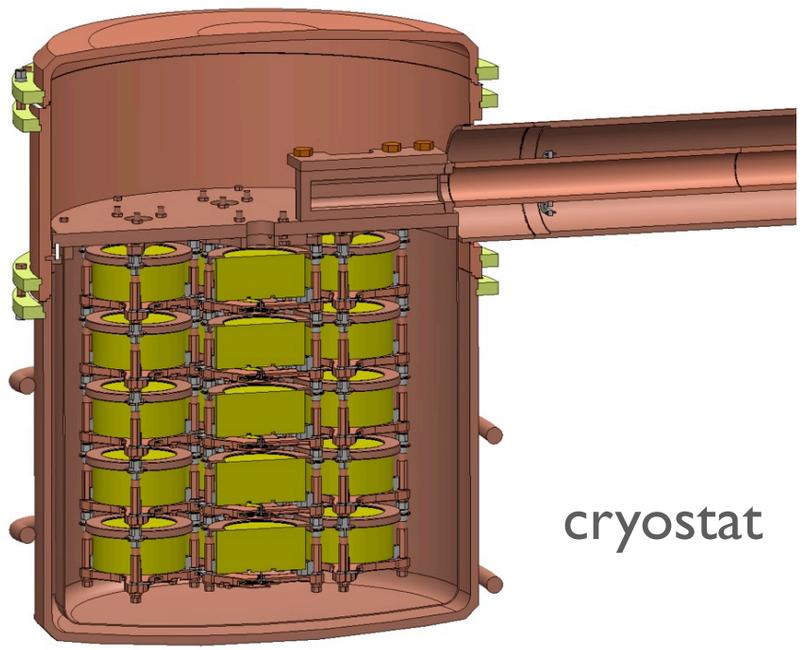


Ge detector

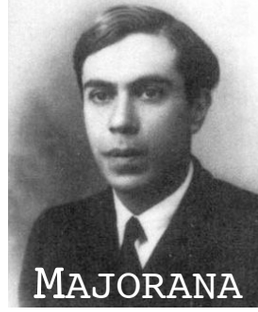


detector string





cryostat



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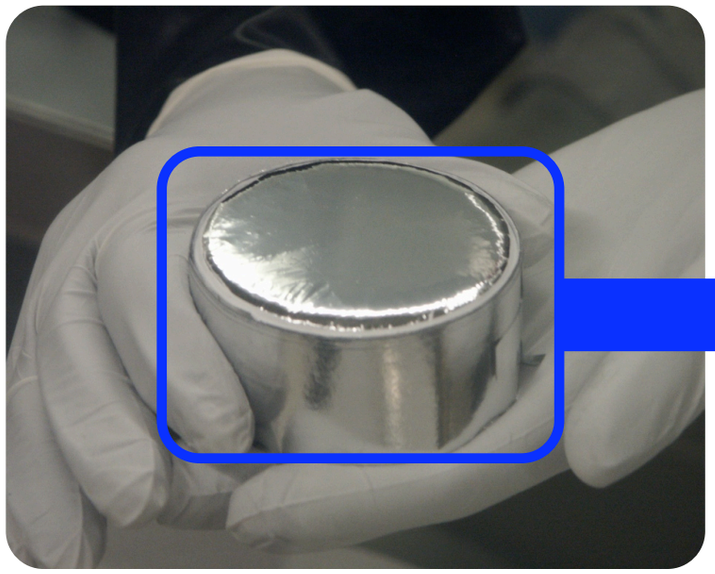
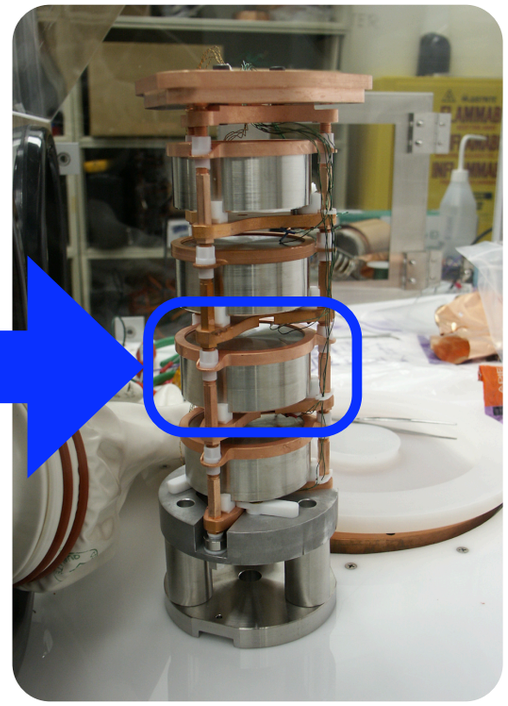


Ge detector



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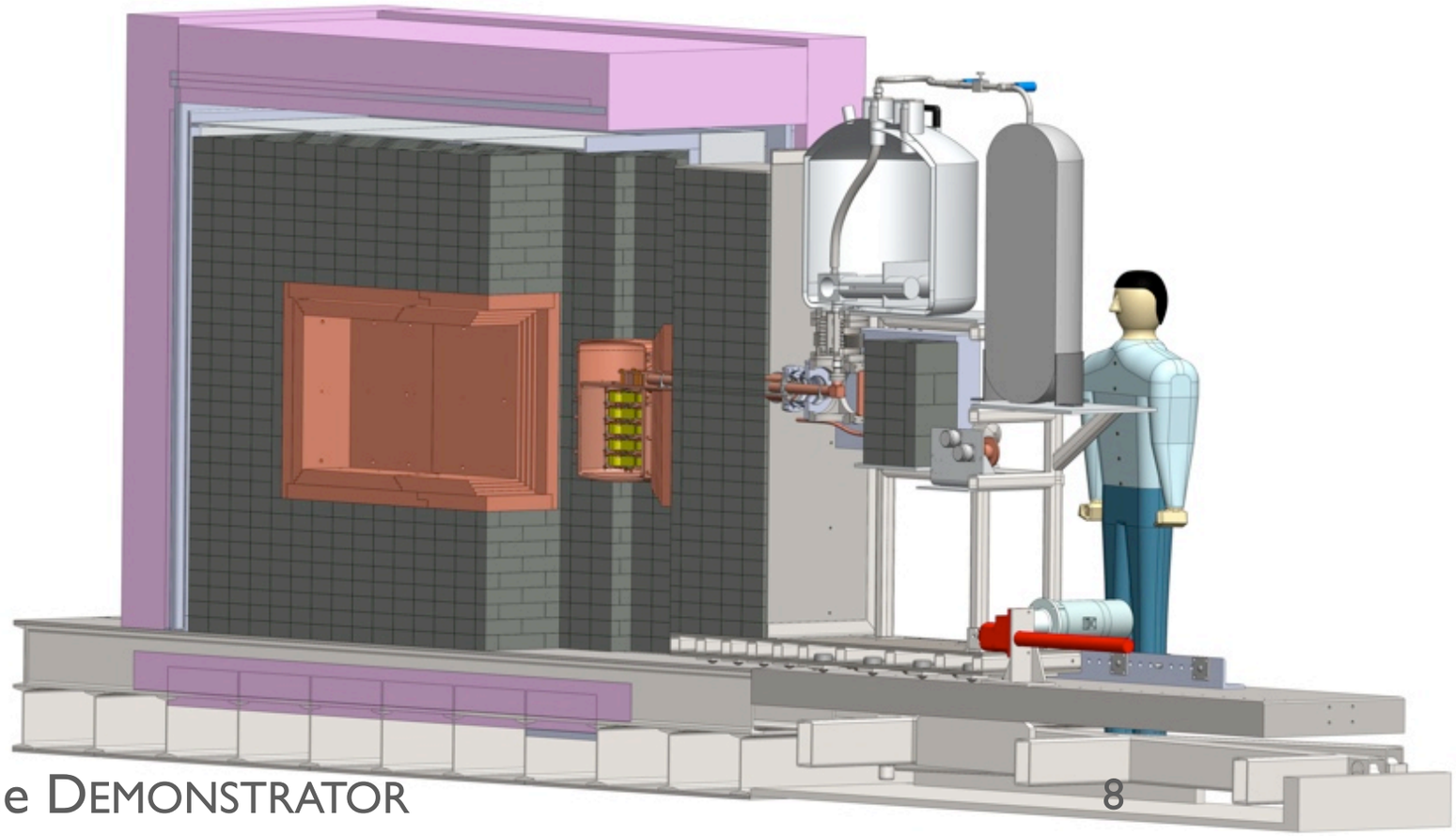

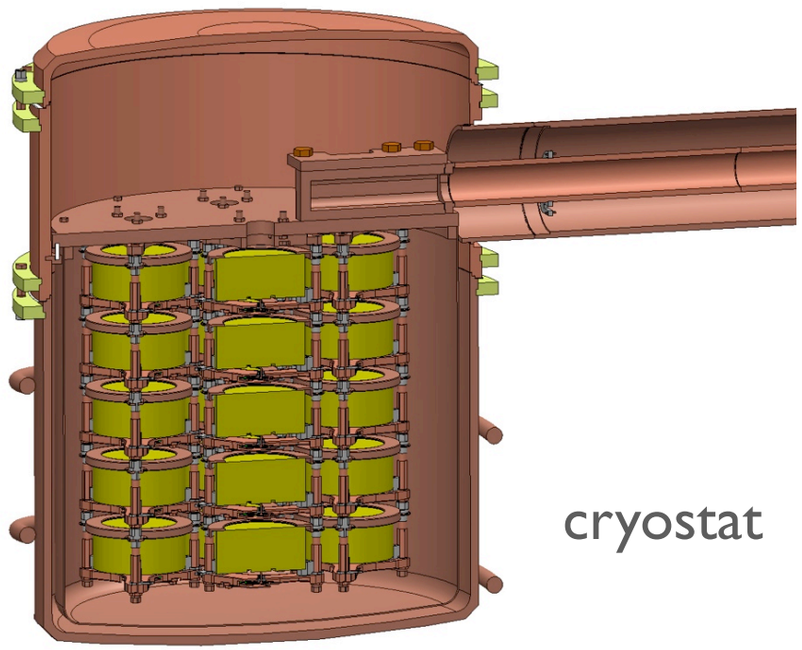

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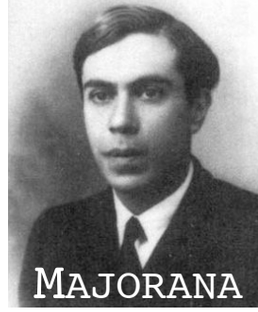

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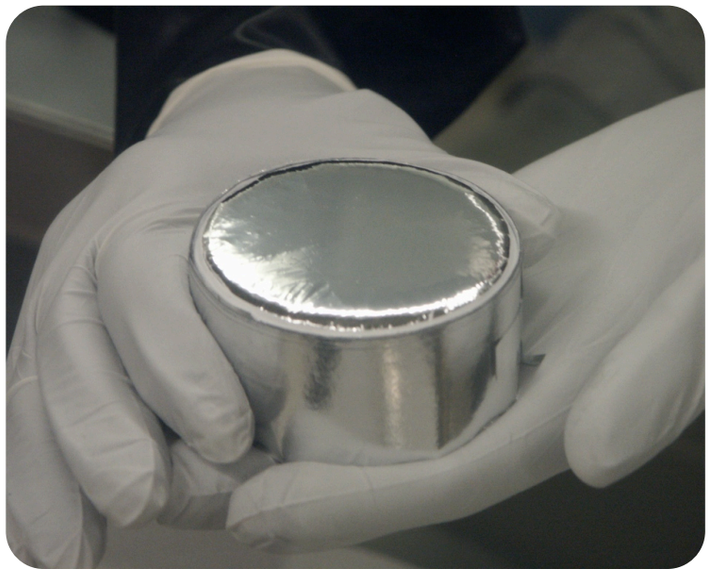
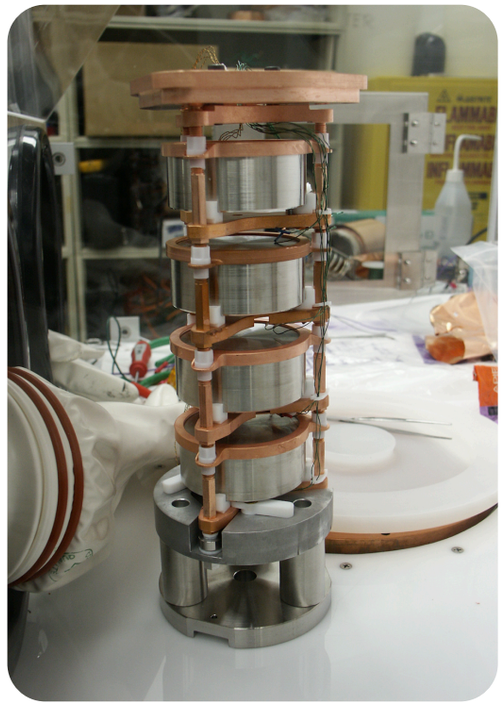


Ge detector



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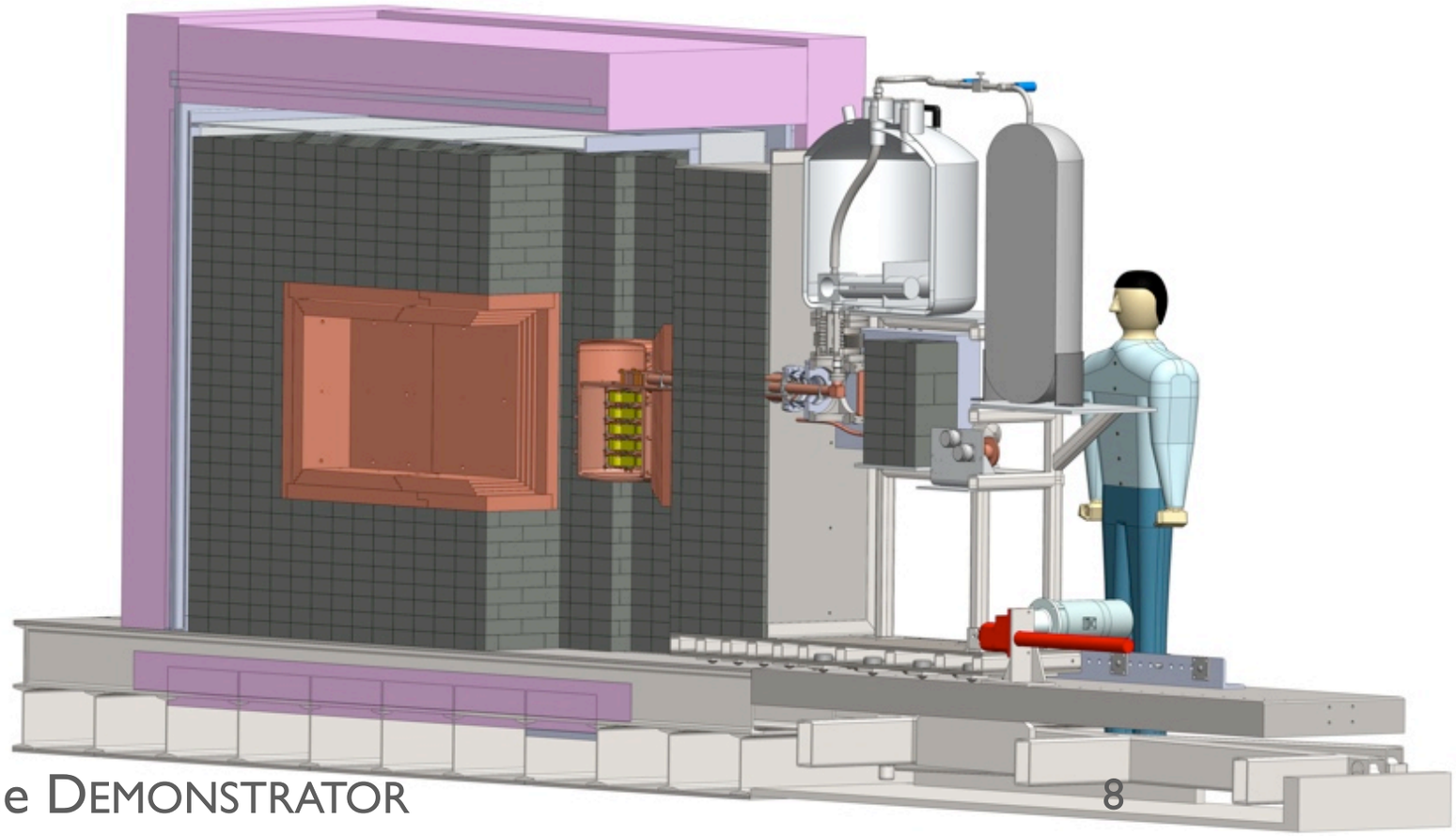

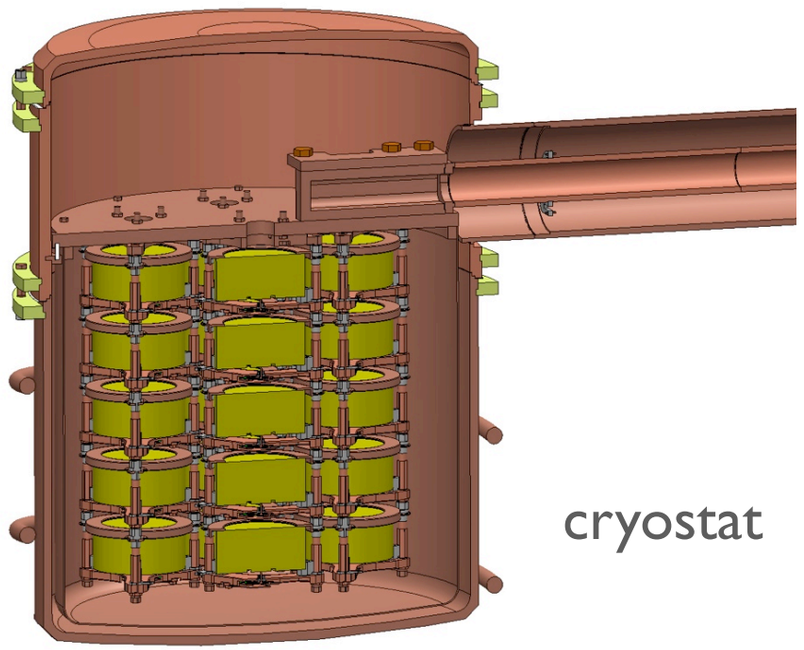

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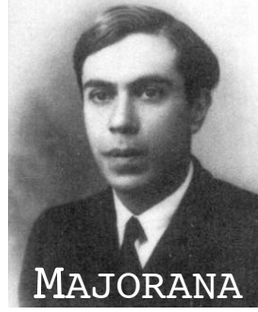
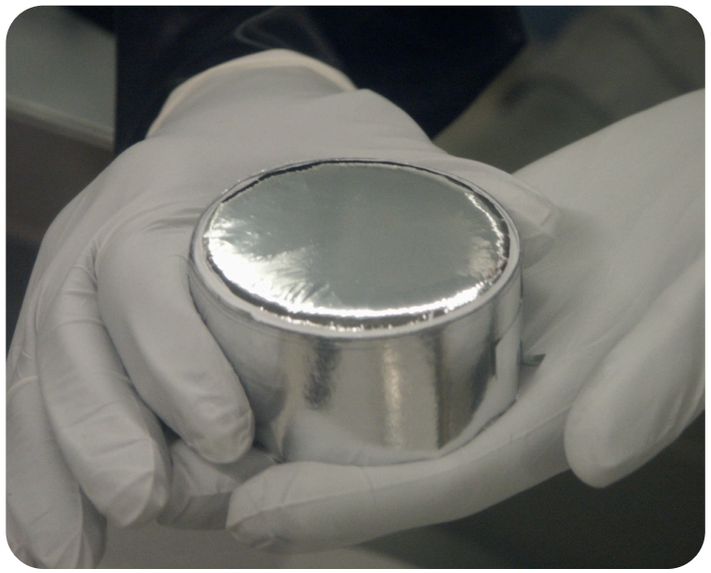
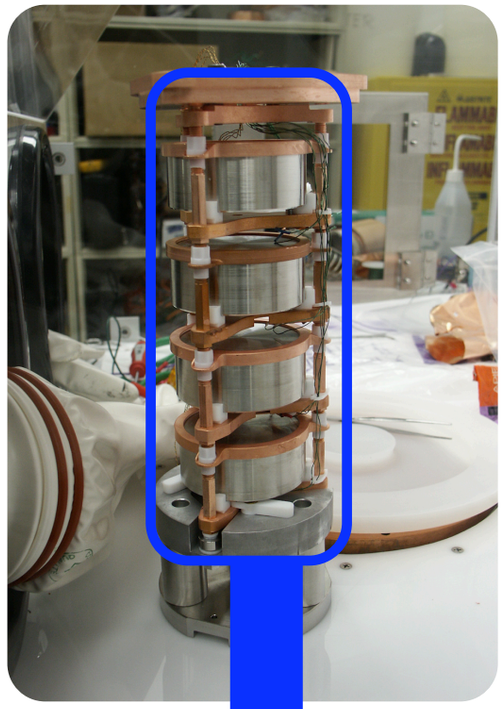


The MAJORANA DEMONSTRATOR

Ge detector





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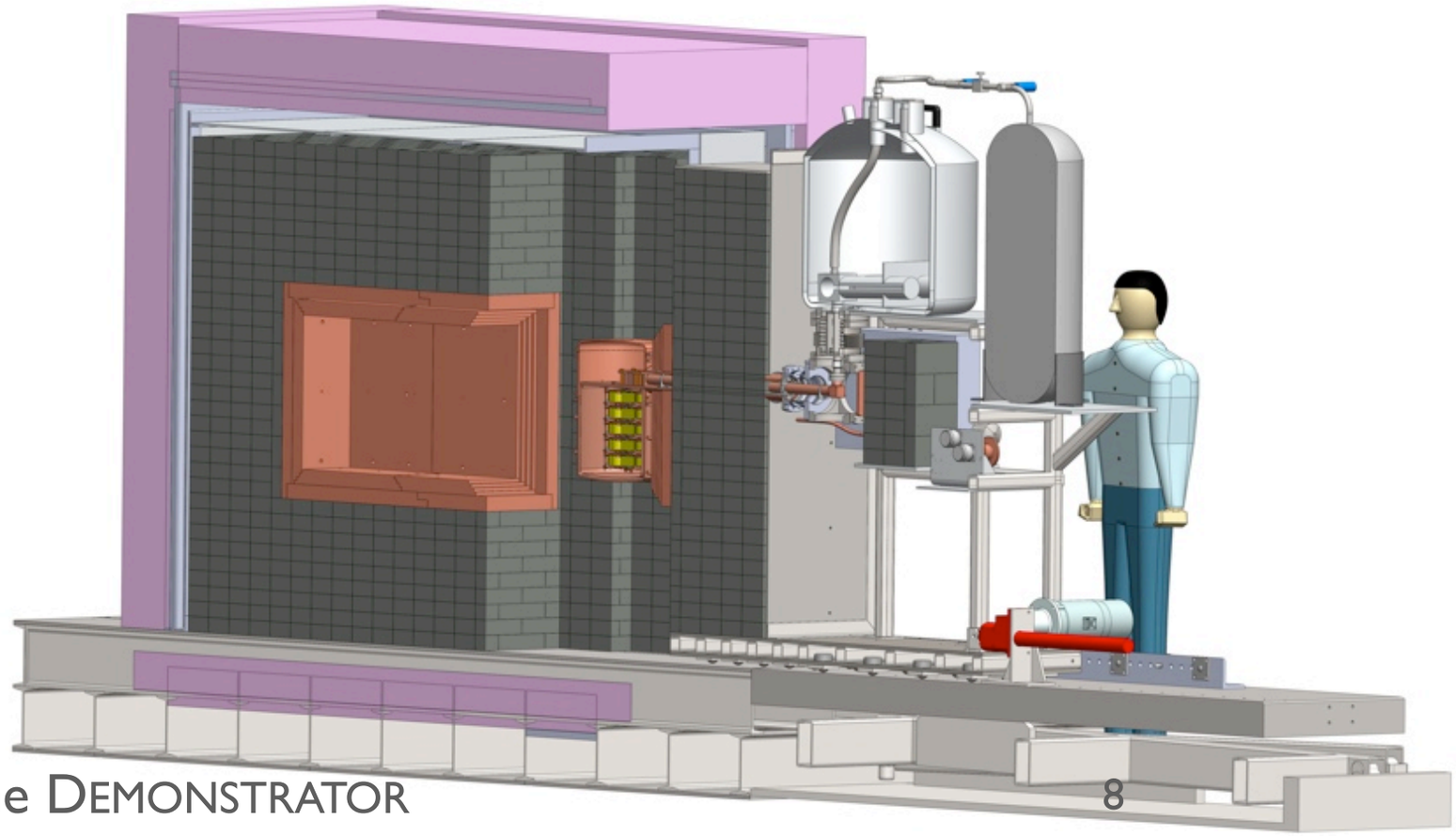

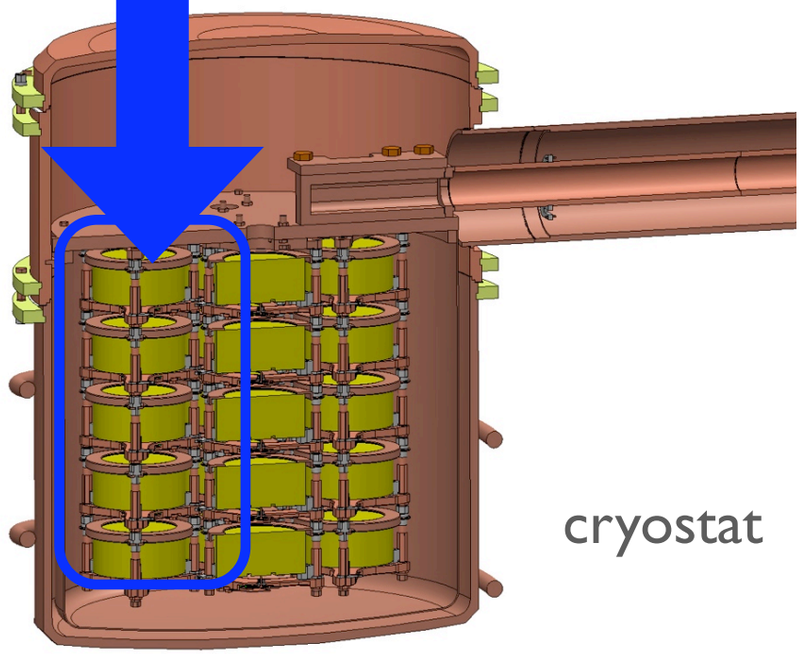

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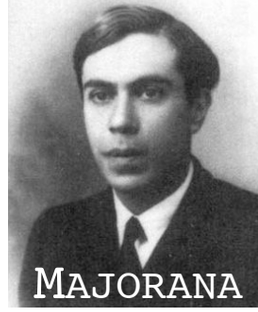

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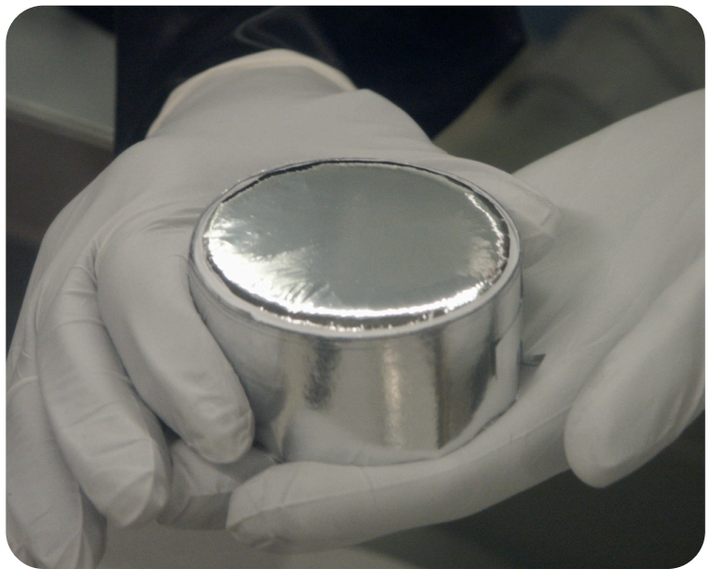

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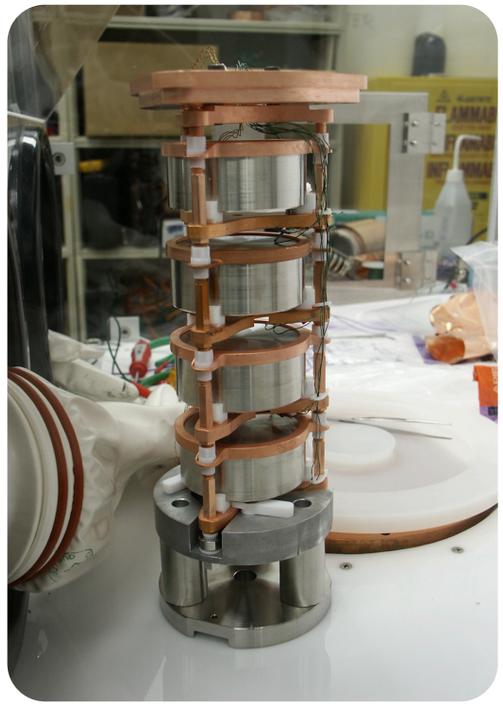

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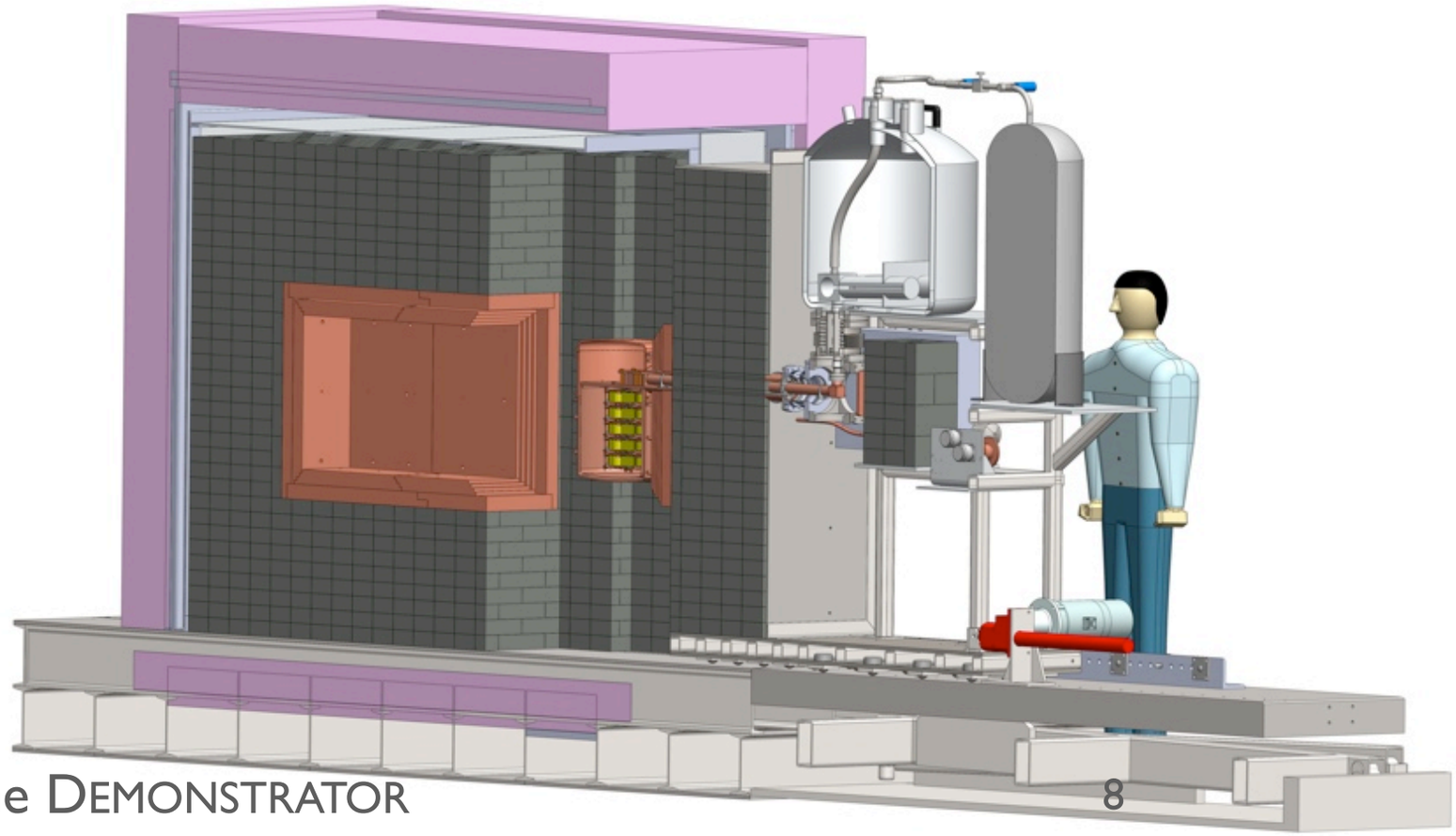

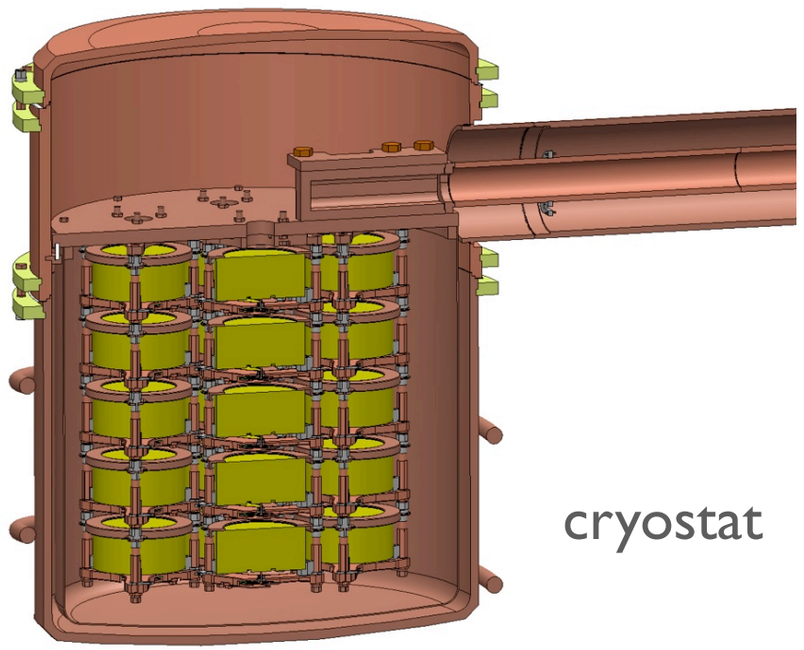

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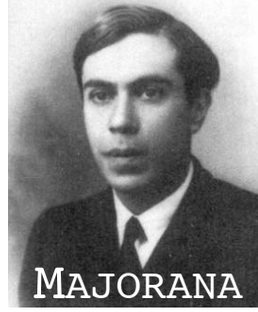

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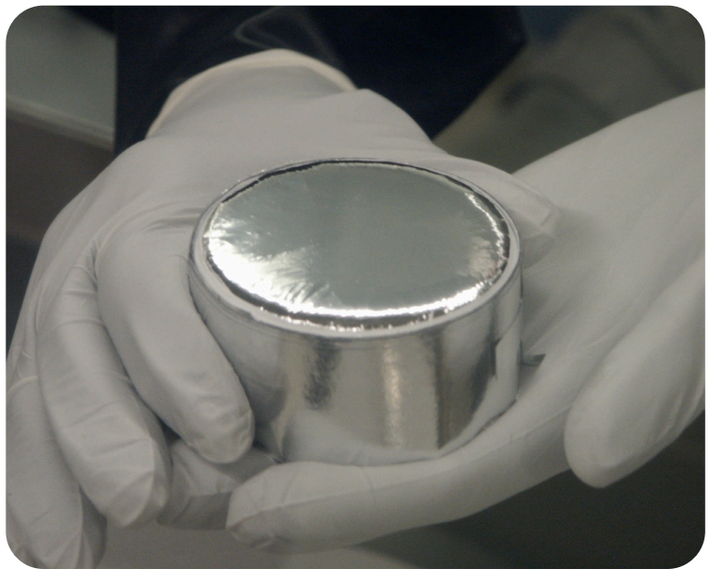

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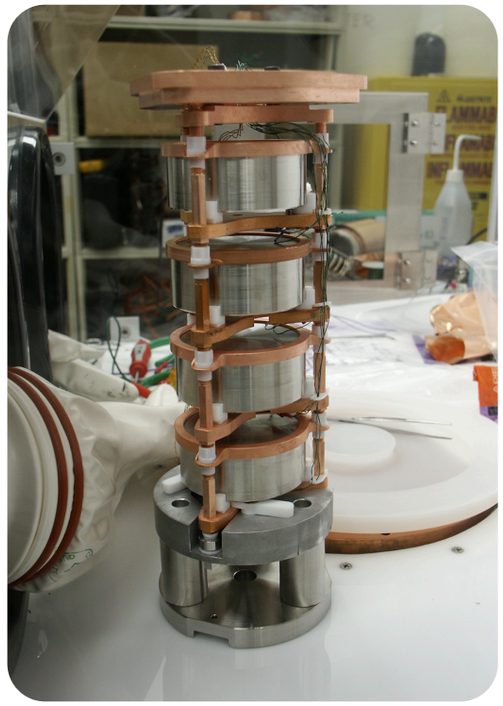

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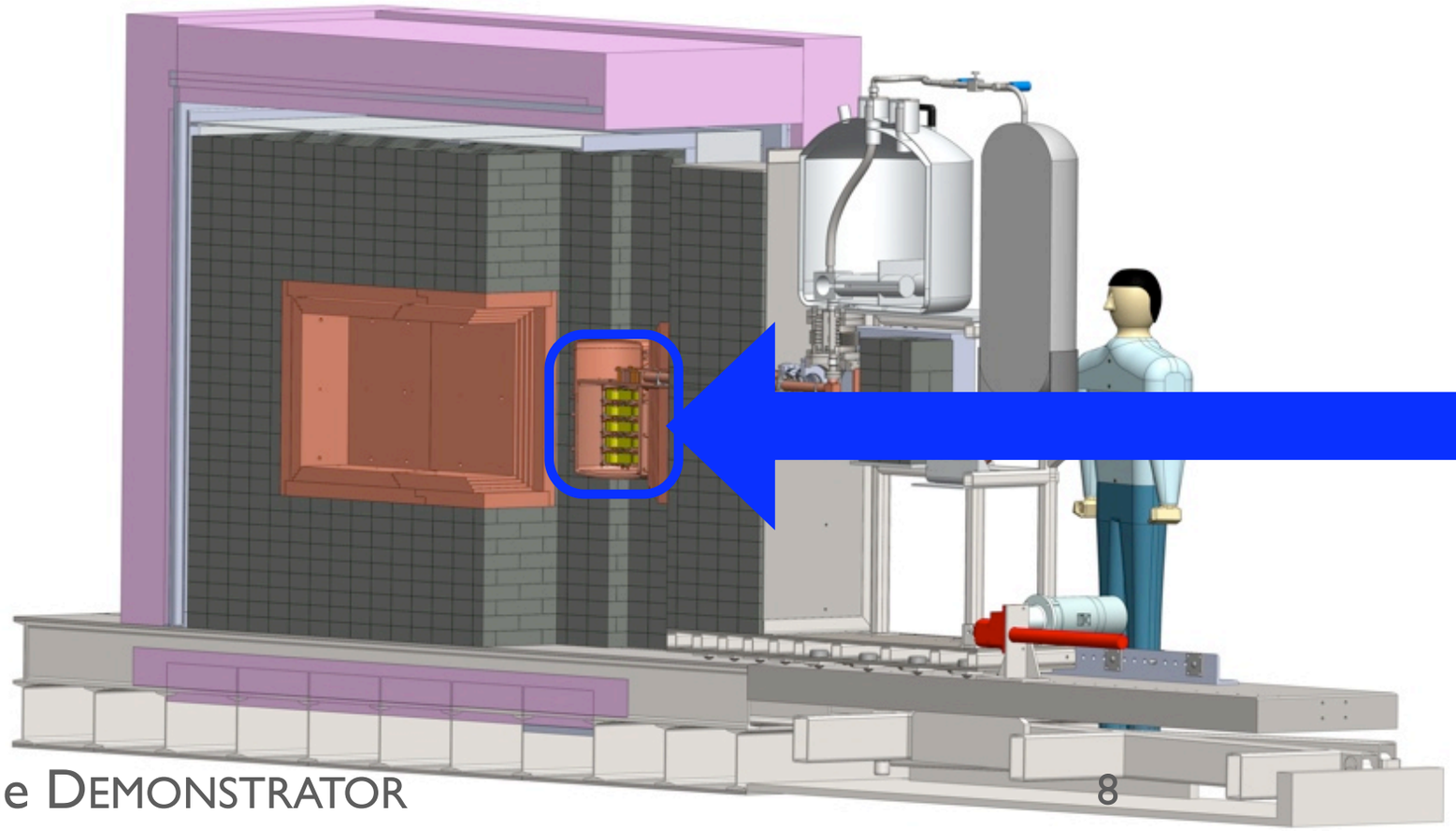
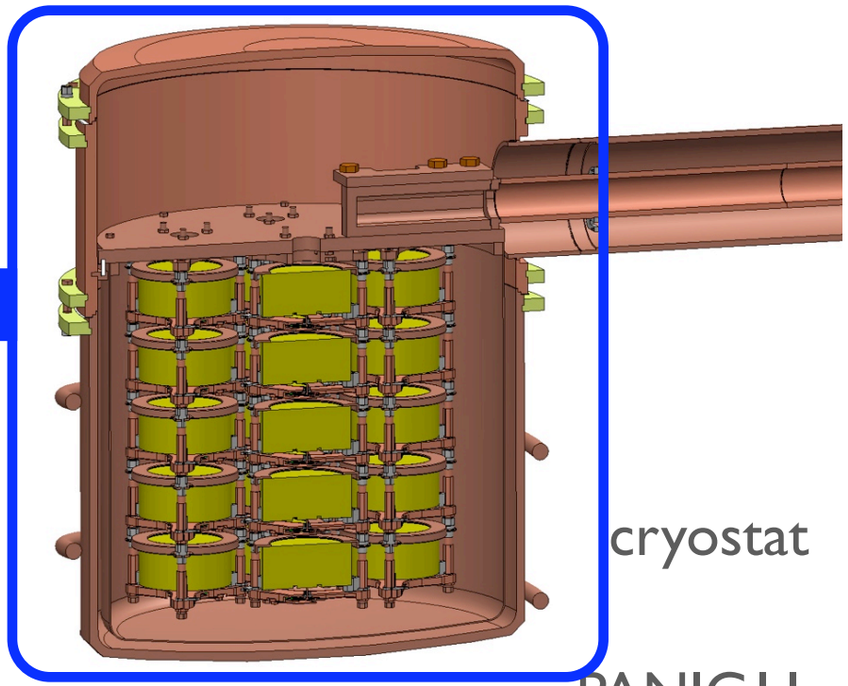




cryostat

The MAJORANA DEMONSTRATOR

Passive and active shielding:

polyethylene

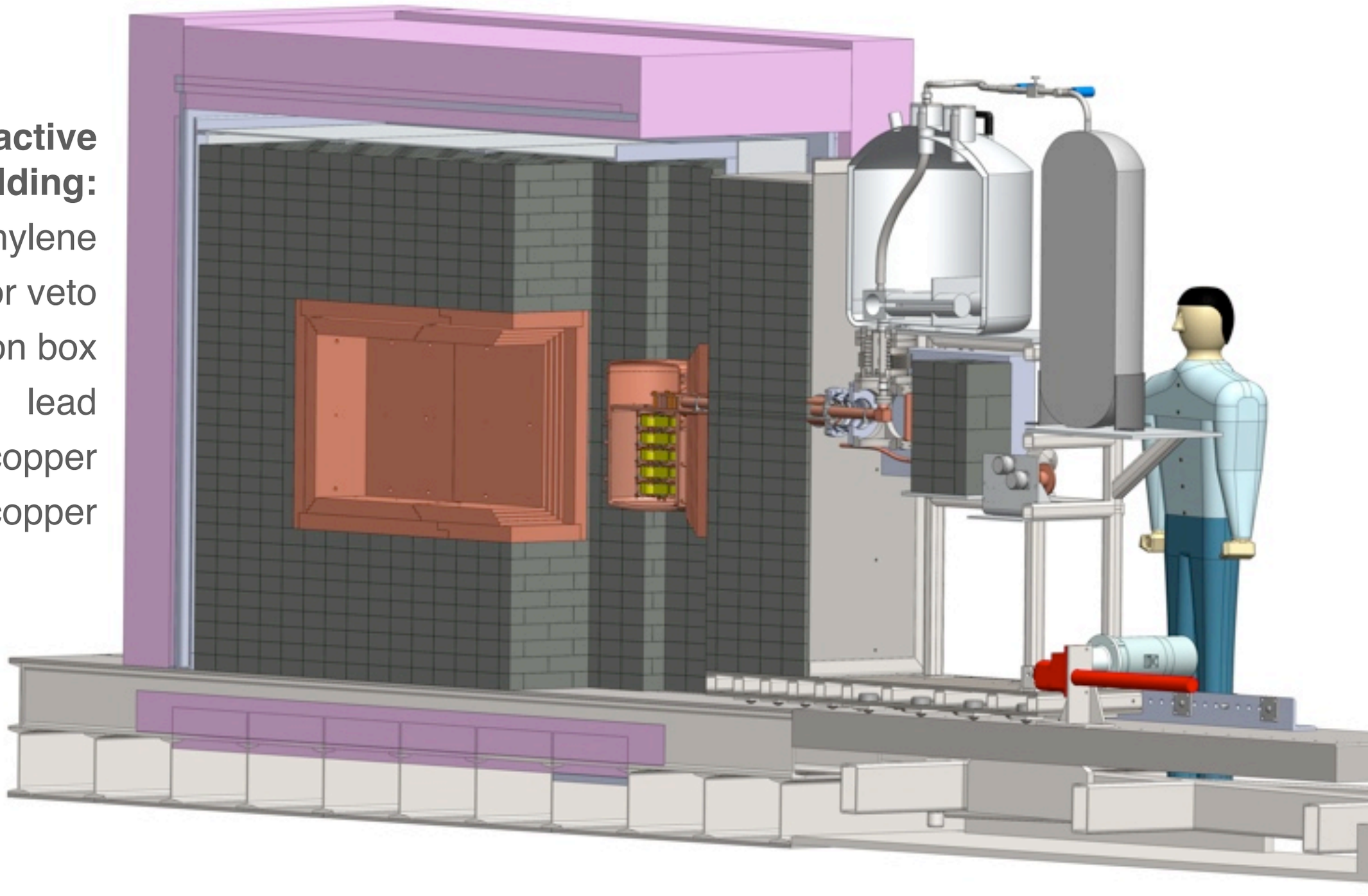
scintillator veto

radon exclusion box

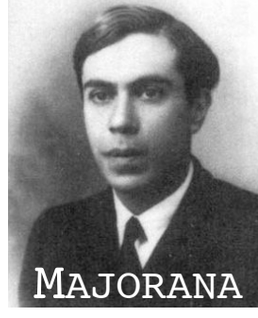
lead

commercial copper

electro-formed copper

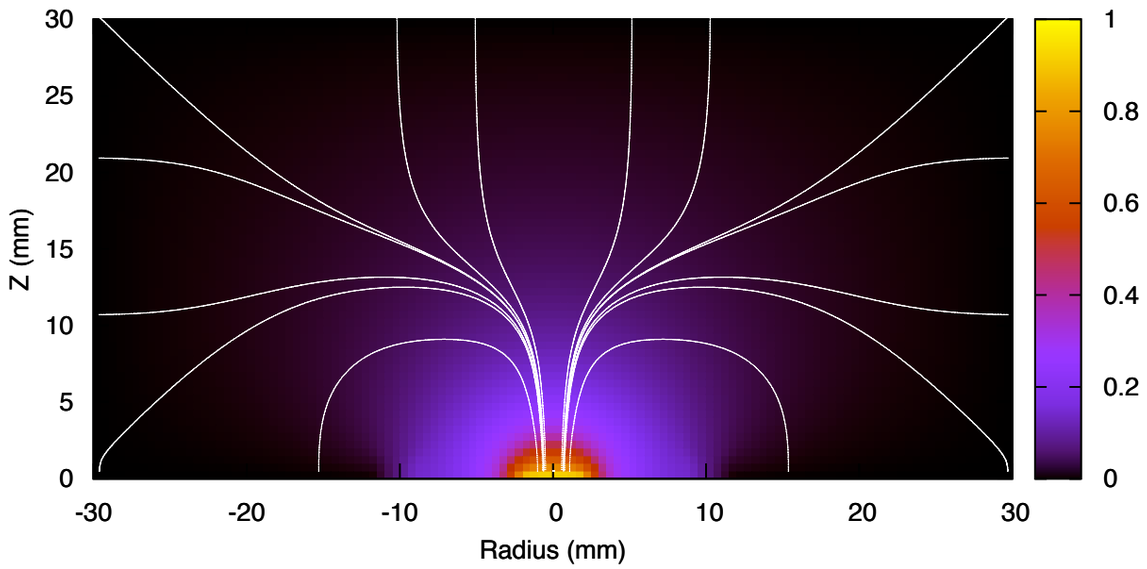


Germanium detectors

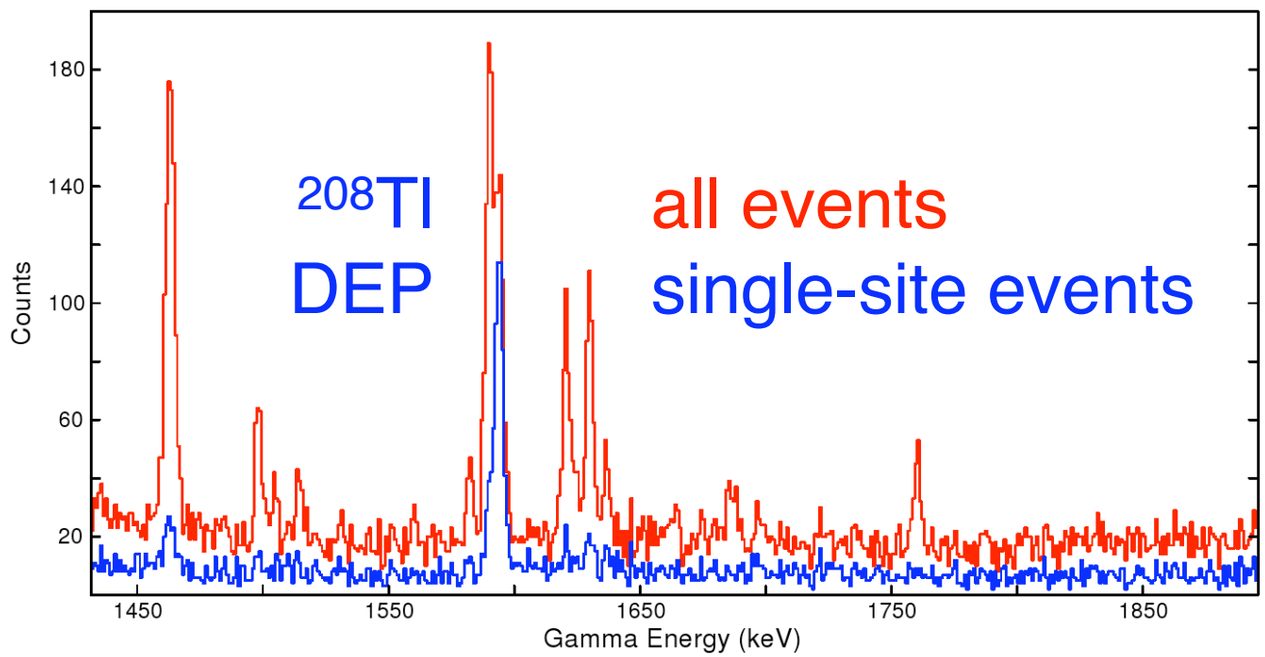


- MAJORANA will use p-type point contact Ge detectors
- Excellent energy resolution: 0.16% FWHM at 2039 keV Q-value
- Can be enriched to 86% in ^{76}Ge: source is detector
- Pulse-shape analysis can distinguish multi-site backgrounds from single-site signal events
- Low energy threshold allows opportunistic physics: dark matter search

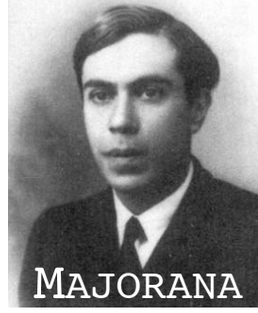
model of electric field in PPC detectors



energy spectrum with pulse-shape analysis



Backgrounds



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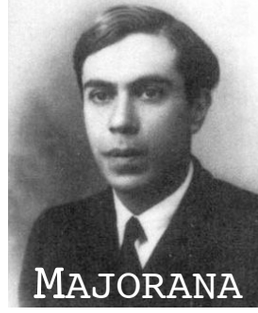


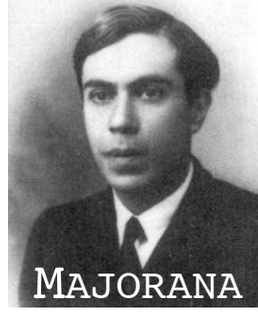
Expected backgrounds

Intrinsic radiation: U and Th decay chains, 2νββ

Cosmic rays:

- Activation at surface creates unstable isotopes in Ge, copper
- Muons, muon-induced neutrons can interact in detectors and apparatus

Backgrounds



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Passive and active shielding: copper, lead, polyethylene, scintillator

Ultra-clean materials: Ge, copper, parylene

Depth: experiment will be conducted deep underground

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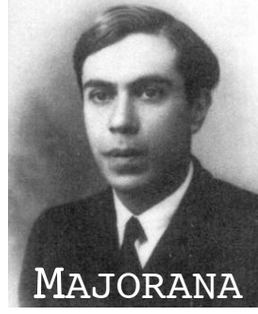

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Passive and active shielding: copper, lead, polyethylene, scintillator

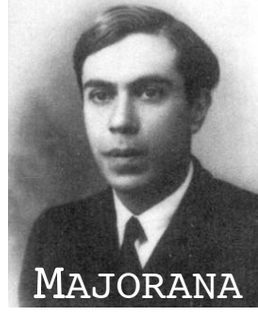
Ultra-clean materials: Ge, copper, parylene

Depth: experiment will be conducted deep underground

Background mitigation techniques

Analysis cuts: 0νββ should deposit energy in a small region of a single detector; other events can be flagged:

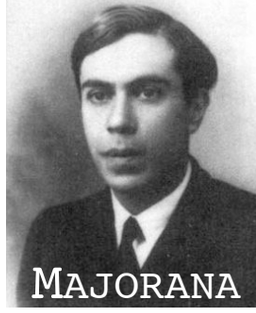
- events that deposit energy in multiple detectors
- events that deposit energy in multiple locations in one detector
- events that are time correlated with other events



Recent progress

- DOE and NSF funding started in FY 2010
- November 2010: 19 of 36 natural Ge detectors delivered to Sanford Lab
- April 2011: All 36 natural Ge detectors characterized and accepted by Los Alamos National Lab
- June 2011: Isoflex completed enrichment of 20 kg Ge; delivery by Sept. 2011
- August 2010: Production of electro-formed copper started in shallow site at Pacific Northwest National Lab
- July 2011: Ten electro-forming baths operational at Sanford 4850' level
- Preparation of lab in Davis Campus at Sanford 4850' level is underway

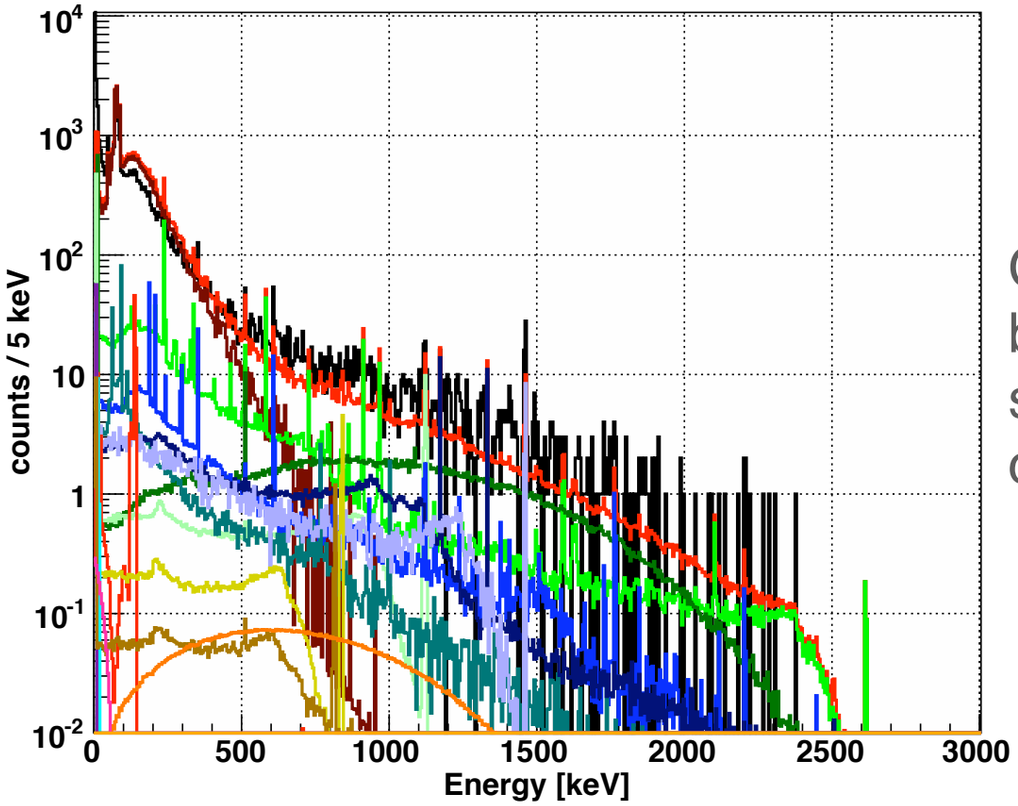
Recent progress: germanium detectors



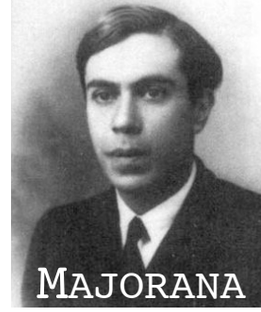
Facility established for reduction of GeO_2 to metal, zone refinement of Ge metal

Underground storage facility in Cherokee Caverns

19 natural Ge detectors delivered to Sanford in November 2010

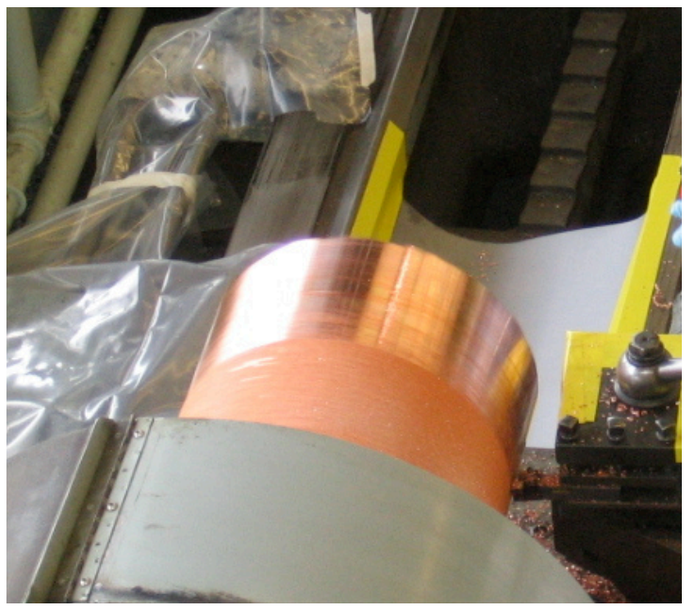


Ongoing MC background simulation campaign



Recent progress: production of ultra-clean copper

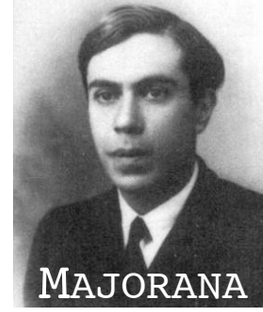
electro-forming laboratory at Sanford



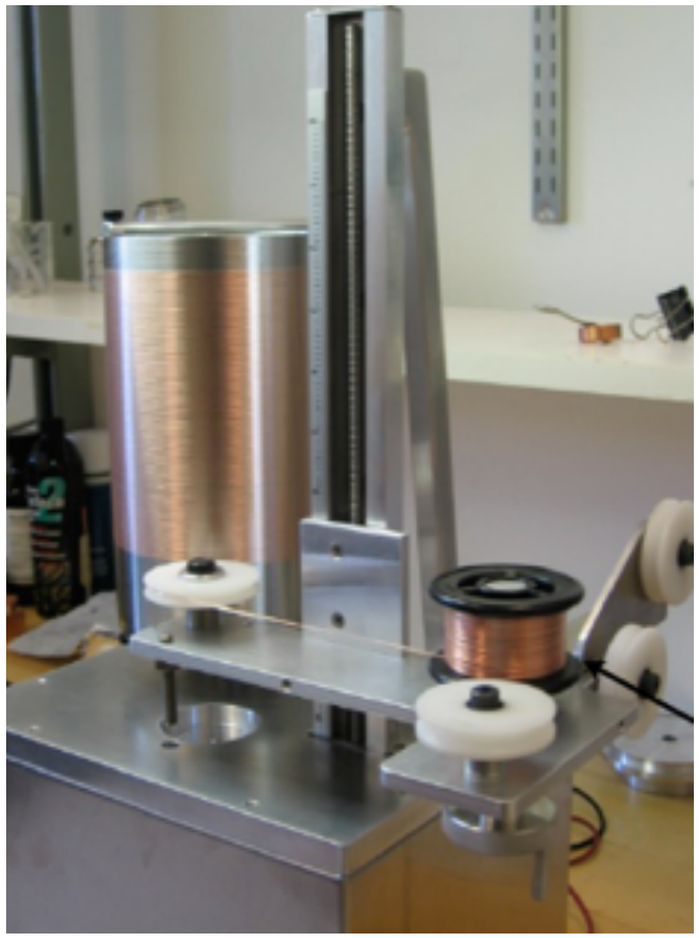
machining of electro-formed copper from PNNL

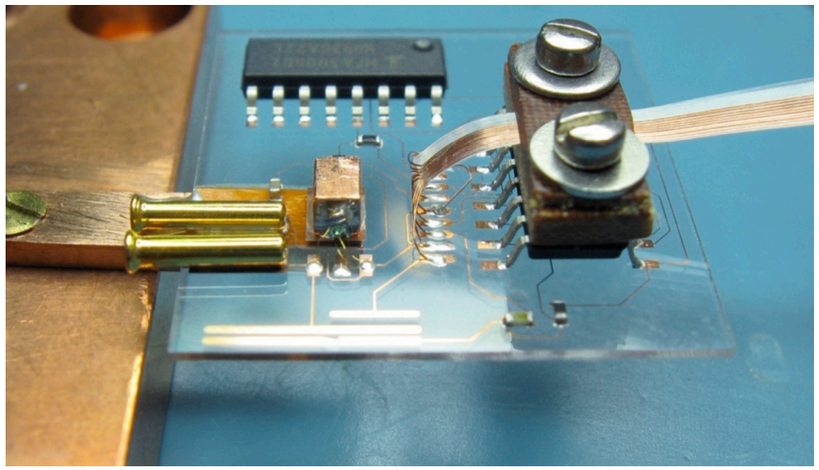
electro-forming baths in the underground clean room at 4850' level of Sanford Lab

Recent progress: electronics and cabling



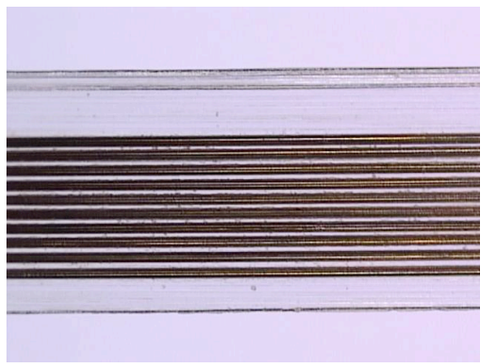
clean parylene cable production

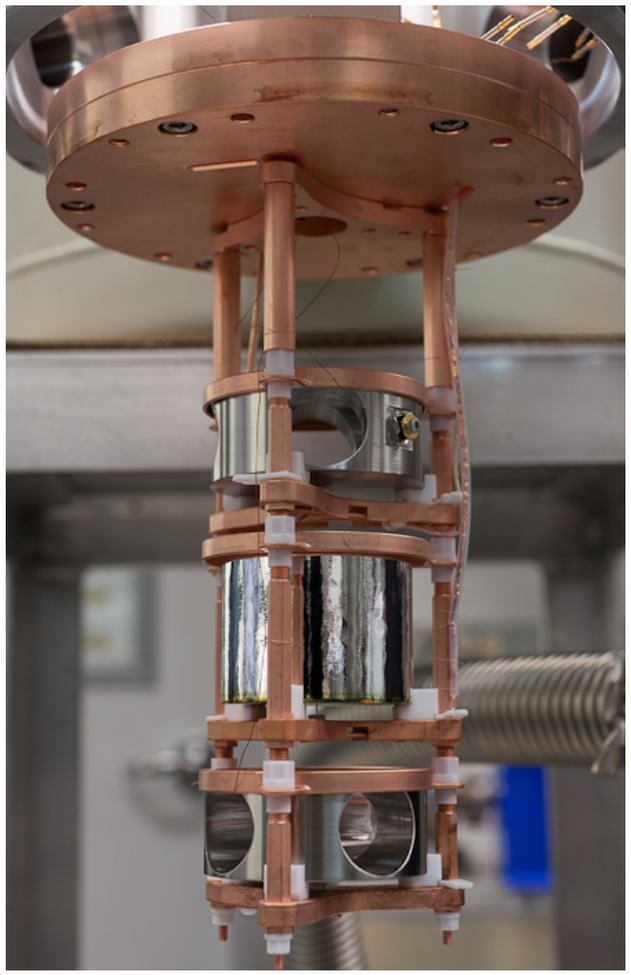




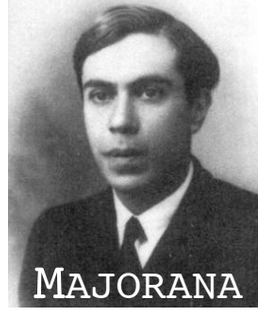
prototype front-end electronics

parylene ribbon cable ~ 3 mm





multiple-detector electronics test string

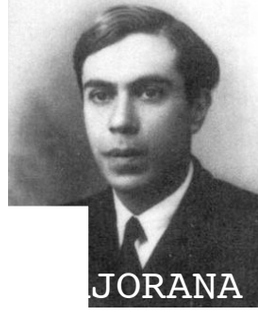


Summary and Outlook

- Observation of neutrinoless double-beta decay would determine Majorana nature of the neutrino and could provide information about neutrino mass
- MAJORANA will search for 0νββ of ^{76}Ge with an array of Ge detectors
- Construction of the first phase of MAJORANA, the DEMONSTRATOR, is underway:
  - Beneficial occupancy of MJD lab by May 2012
  - Prototype cryostat of natural Ge by late summer 2012
  - Enriched material ready for detector fabrication by February 2012
  - First module with enriched Ge in 2013

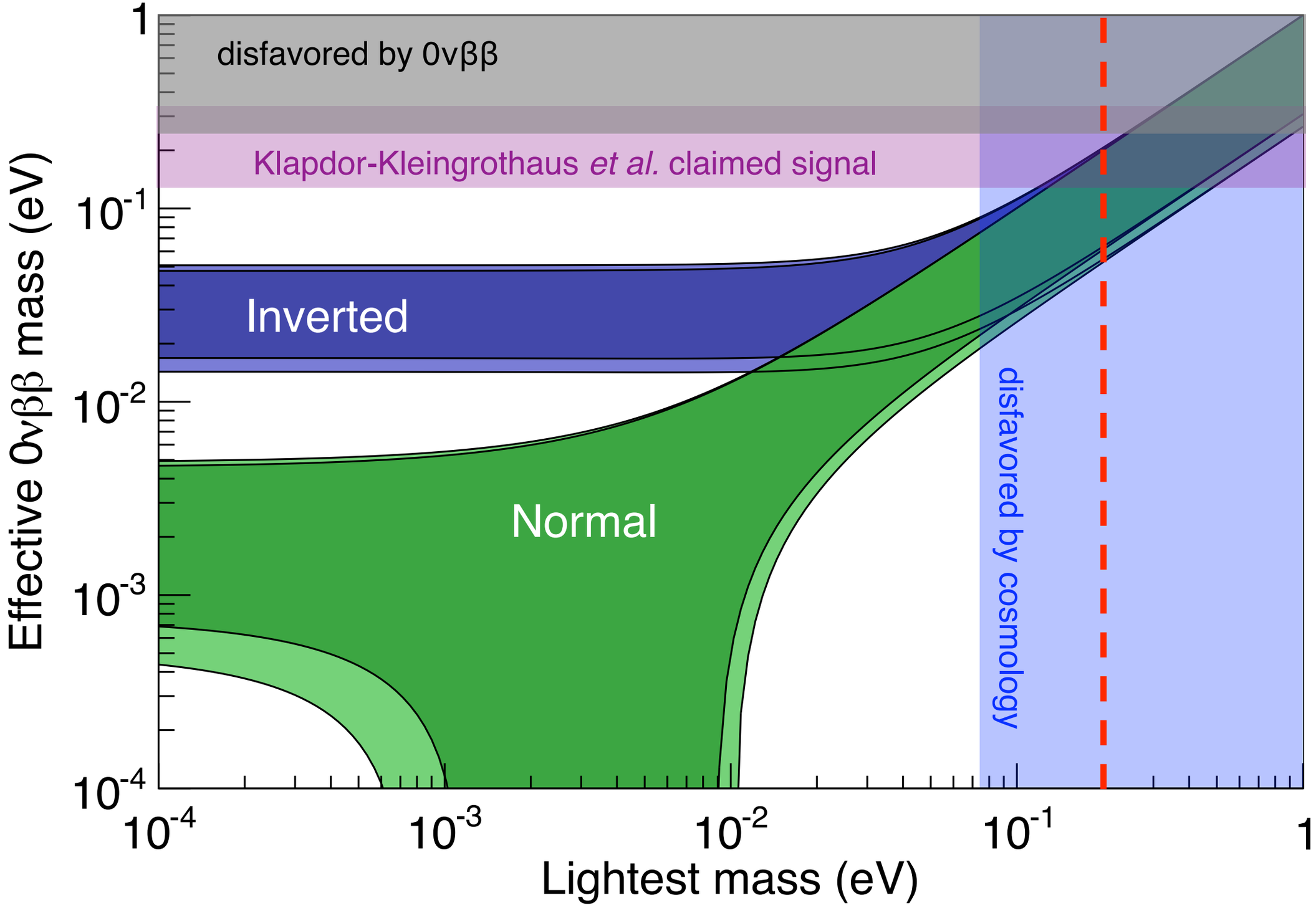
Thank you!

The MAJORANA Collaboration



neutrino mass

Estimated KATRIN Sensitivity



Isotopic concentrations of enriched material

Isotope	Fractional Composition
70Ge	0.00006(1)
72Ge	0.00011(1)
73Ge	0.00033(3)
74Ge	0.086(5)
76Ge	0.914(5)

PNNL measurement of material from ECP