THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

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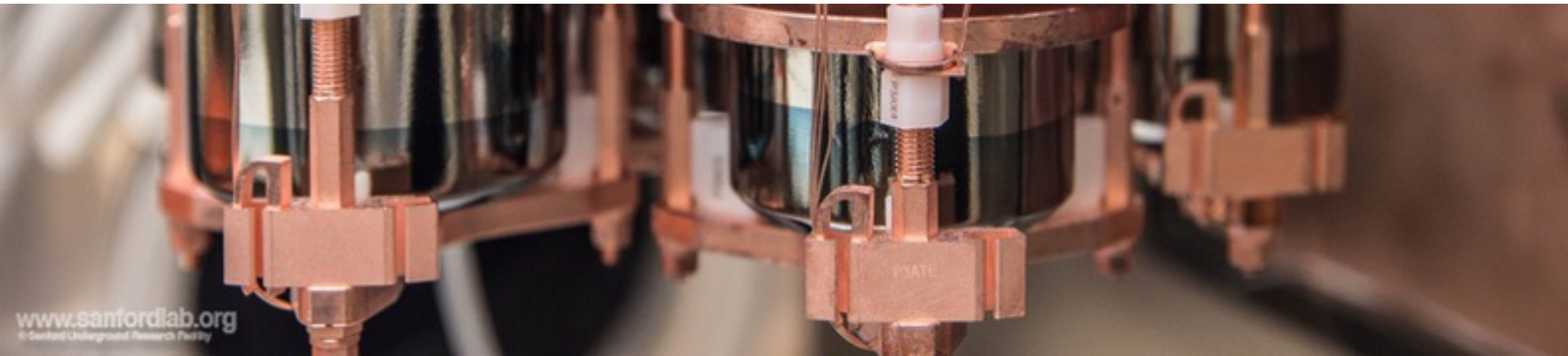
Recent Results from the MAJORANA DEMONSTRATOR

Tom Gilliss, for the MAJORANA Collaboration
University of North Carolina
Triangle Universities Nuclear Laboratory

Particles & Nuclei International Conference
Beijing, China
September 1, 2017

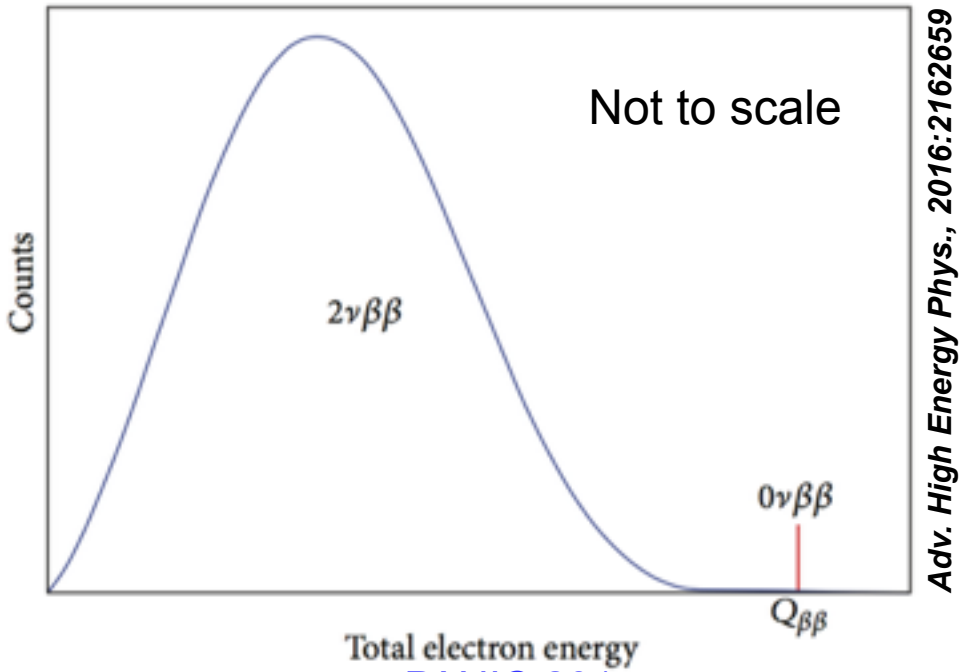


Neutrinoless Double-Beta Decay

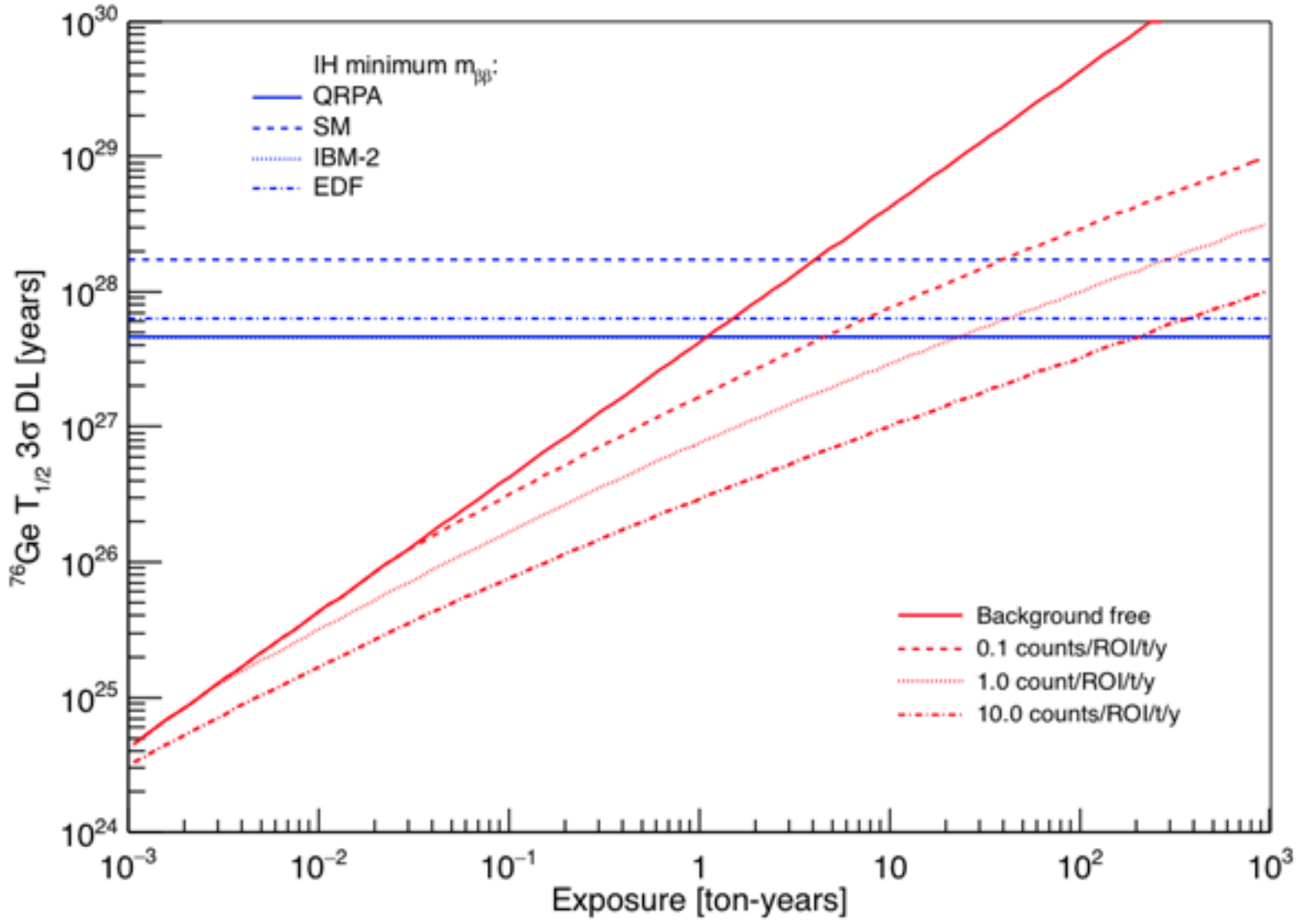
- Neutrinoless double-beta decay (0νββ) postulated in nuclei susceptible to double-beta decay. Eg. ^{76}Ge, ^{82}Se, ^{130}Te, ^{136}Xe
- 0νββ requires violation of lepton number conservation

$$(A, Z-2) \rightarrow (A, Z) + 2e^- + 2\bar{\nu}_e$$

- Observation of 0νββ would imply
  - lepton number is not conserved
  - neutrinos have majorana mass
- Experimental signal is peak at 2νββ endpoint, with all transition energy in the emitted electrons



Discovery, Background, and Exposure

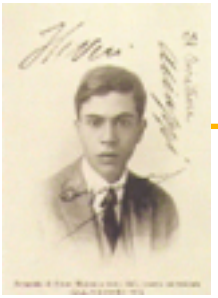


$$T_{1/2} \propto \frac{MT}{n_B}$$

for a background free experiment

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu} \left|M^{0\nu}\right|^2 \frac{\left|\langle m_{\beta\beta}\rangle\right|^2}{m_e^2}$$

assuming light majorana neutrino exchange



The MAJORANA Collaboration

Black Hills State University, Spearfish, SD
Kara Keeter

Duke University, Durham, North Carolina, and TUNL
Matthew Busch

Joint Institute for Nuclear Research, Dubna, Russia
Viktor Brudanin, M. Shirchenko, Sergey Vasilyev, E. Yakushev, I. Zhitnikov

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Nicolas Abgrall, Yuen-Dat Chan, Lukas Hehn, Jordan Myslik, Alan Poon, Kai Vetter

Los Alamos National Laboratory, Los Alamos, New Mexico
Pinghan Chu, Steven Elliott, Ralph Massarczyk, Keith Rielage, Larry Rodriguez, Harry Salazar, Brandon White, Brian Zhu

National Research Center *'Kurchatov Institute' Institute of Theoretical and Experimental Physics, Moscow, Russia*
Alexander Barabash, Sergey Konovalov, Vladimir Yumatov

North Carolina State University, and TUNL
Matthew P. Green

Oak Ridge National Laboratory
Fred Bertrand, Charlie Havener, Monty Middlebrook, David Radford, Robert Varner, Chang-Hong Yu

Osaka University, Osaka, Japan
Hiroyasu Ejiri

Pacific Northwest National Laboratory, Richland, Washington
Isaac Arnquist, Eric Hoppe, Richard T. Kouzes

Princeton University, Princeton, New Jersey
Graham K. Giovanetti

Queen's University, Kingston, Canada
Ryan Martin

South Dakota School of Mines and Technology, Rapid City, South Dakota
Colter Dunagan, Cabot-Ann Christofferson, Anne-Marie Suriano, Jared Thompson

Tennessee Tech University, Cookeville, Tennessee
Mary Kidd

Technische Universität München, and Max Planck Institute, Munich, Germany
Tobias Bode, Susanne Mertens

University of North Carolina, Chapel Hill, North Carolina, and TUNL
Thomas Caldwell, Thomas Gilliss, Chris Haufe, Reyco Henning, Mark Howe, Samuel J. Meijer, Christopher O'Shaughnessy, Gulden Othman, Jamin Rager, Anna Reine, Benjamin Shanks, Kris Vorren, John F. Wilkerson

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

University of South Dakota, Vermillion, South Dakota
CJ Barton, Wenqin Xu

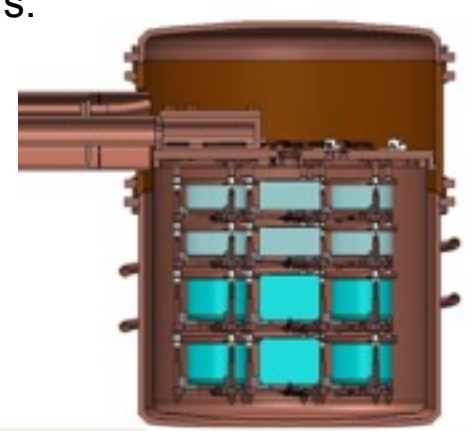
University of Tennessee, Knoxville, Tennessee
Yuri Efremenko, Andrew Lopez

University of Washington, Seattle, Washington
Sebastian Alvis, Tom Burritt, Micah Buuck, Clara Cuesta, Jason Detwiler, Julieta Gruszko, Ian Guinn, David Peterson, Walter Pettus, R. G. Hamish Robertson, Nick Rouf, Tim Van Wechel

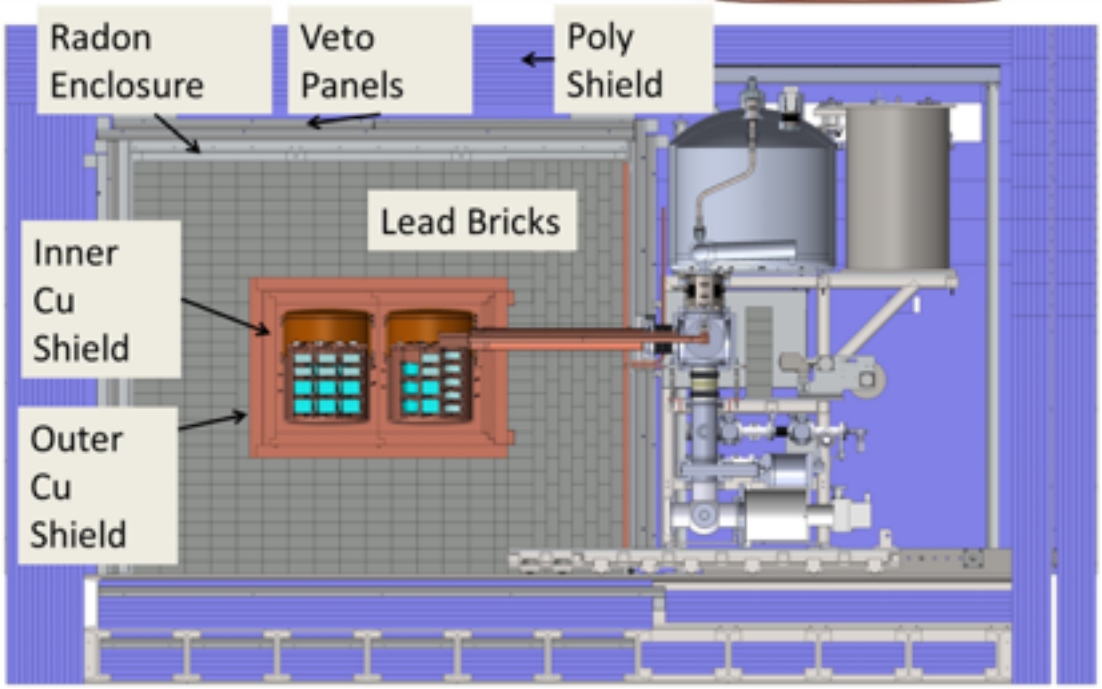
The Majorana Demonstator

Operating underground at the 4850' level of the Sanford Underground Research Facility, with the best energy resolution (2.4 keV FWHM at 2039 keV) of any ββ-decay experiment.

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.



- 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 ≤ 3.5
- 44.1-kg of Ge detectors
  - 29.7 kg of 88% enriched ^{76}Ge crystals
  - 14.4 kg of ^{nat}Ge
  - Detector Technology: P-type, point-contact.
- 2 independent cryostats
  - ultra-clean, electroformed Cu
  - 22 kg of detectors per cryostat
  - naturally scalable
- Compact Shield
  - low-background passive Cu and Pb shield with active muon veto

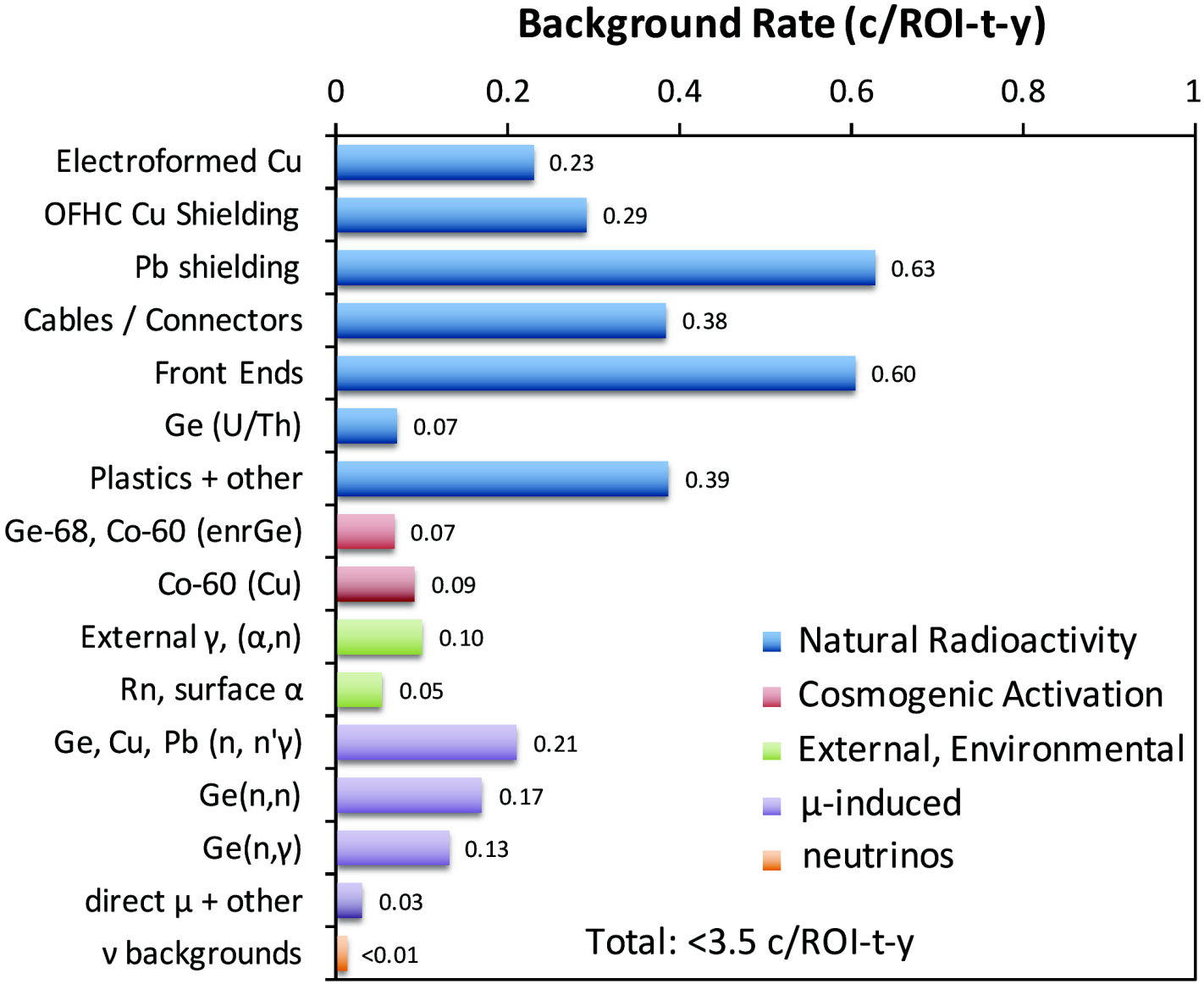


N. Abgrall et. al., Adv. High Ener. Phys. 2014, 365432 (2013) arXiv:1308.1633

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

DEMONSTRATOR Backgrounds

Based on assay results and scaled according to efficiencies determined by Geant4 Monte Carlo simulations. When upper limit, use upper limit as contribution.

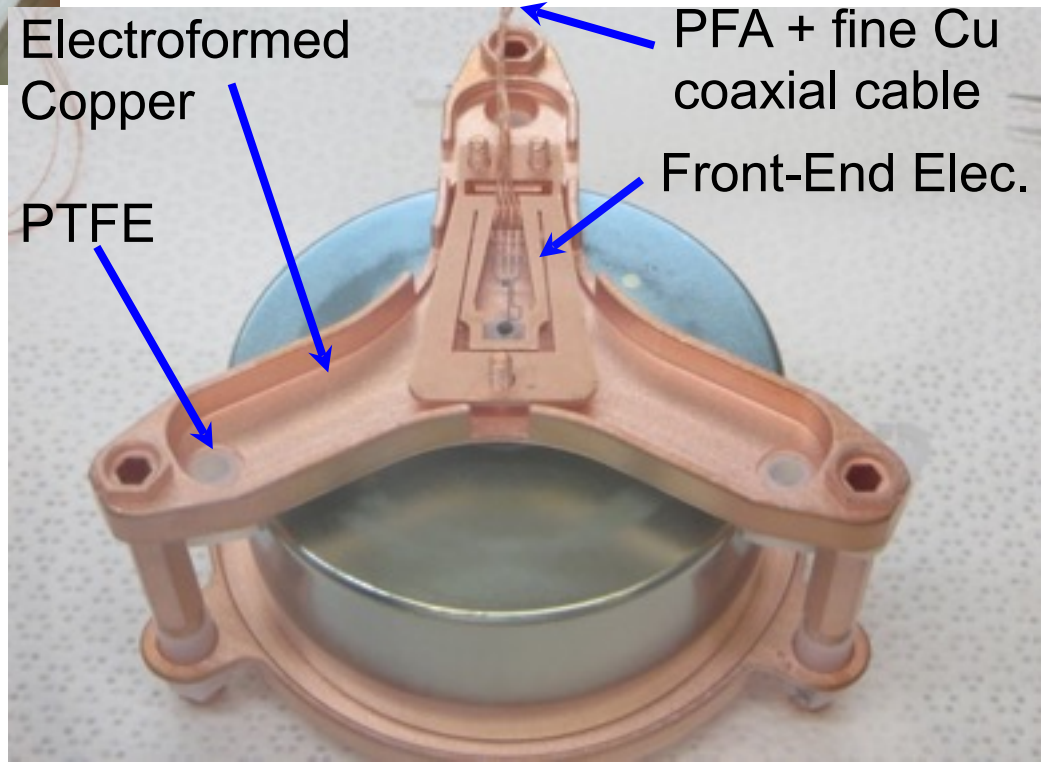


N. Abgrall et. al., Nucl. Instrum. Meth. A, Volume 828, 22-36 (2016)

Electroformed Cu and Enriched Ge

- Electroformed underground
- Average Th decay chain ≤ 0.1 μBq/kg
- Average U decay chain ≤ 0.1 μBq/kg
- ~1.1 tons used in the DEMONSTRATOR
  - String components
  - Cryostats/thermosyphon
  - Inner layers of shielding

- AMTEK (ORTEC) fabricated enriched detectors
- 35 enriched point contact detectors (29.7 kg), 88% ^{76}Ge
- 33 Canberra modified natural BEGe detectors (20 kg)
- Tracked and minimized surface exposure of enriched material to determine cosmogenic activation



N. Abgrall et. al., Nucl. Instrum. Meth. A, Volume 779, 52-62 (2015)

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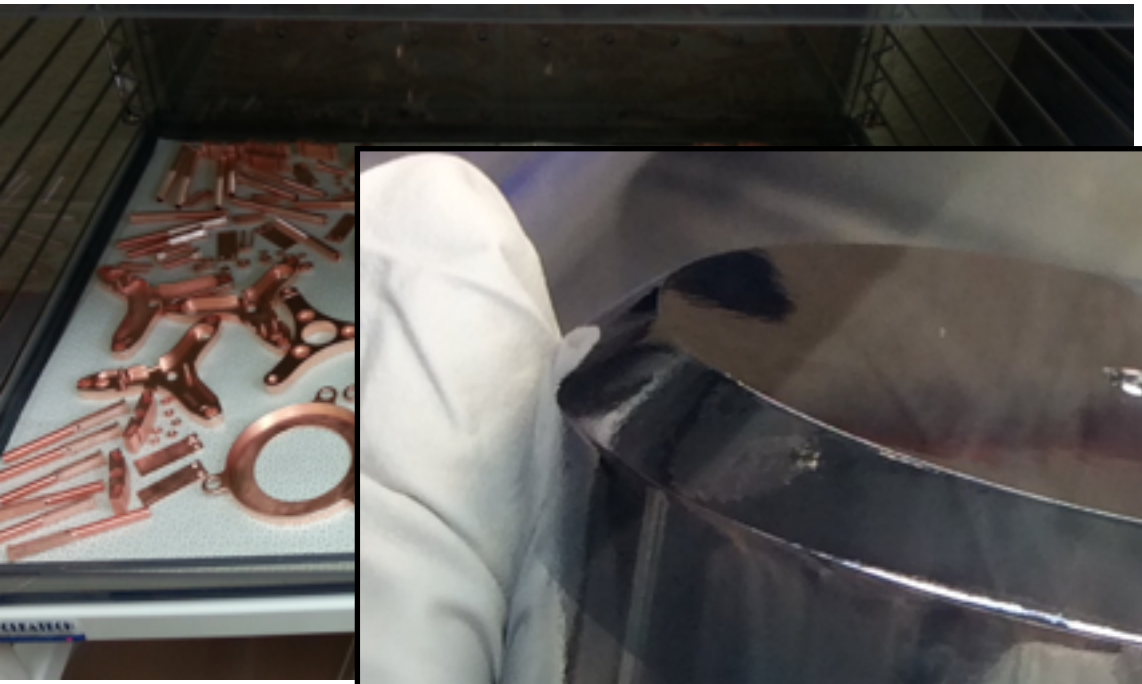

- Electroformed underground
  ≤ 0.1 μBq/kg
  ≤ 0.1 μBq/kg
  MONSTRATOR
  on
  ng
  PFA + fine Cu
  coaxial cable
  ront-End Elec.
- AMTEK (OR
  detectors
- 35 enriched
  (29.7 kg), 88
- 33 Canberra
  detectors (2
- Tracked and
  of enriched
  cosmogenic

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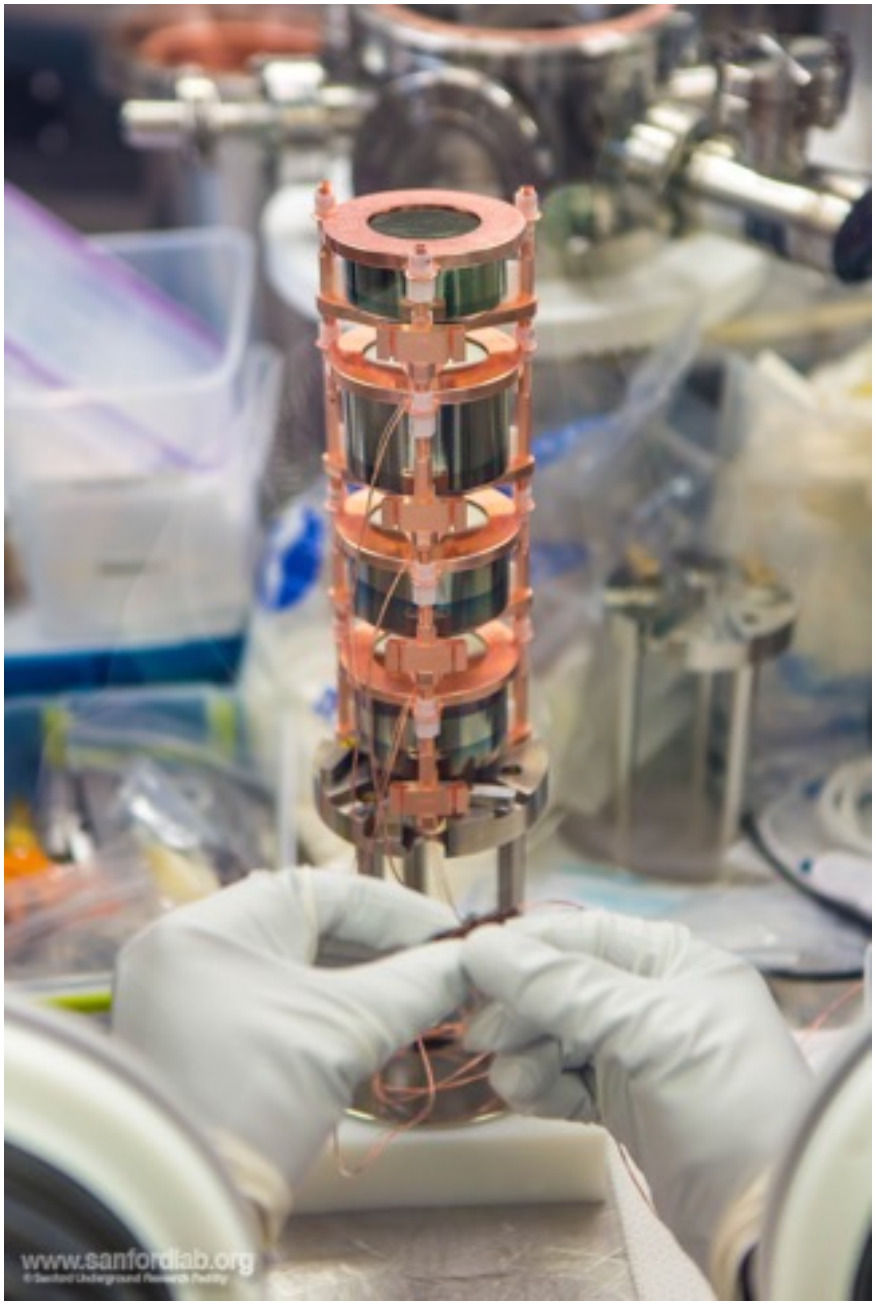
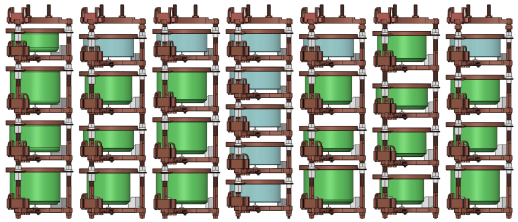
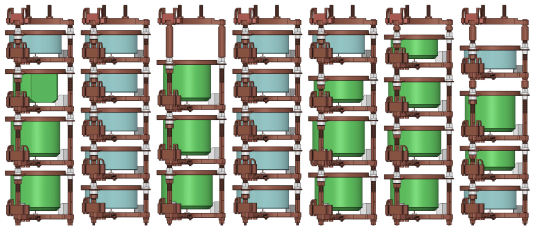
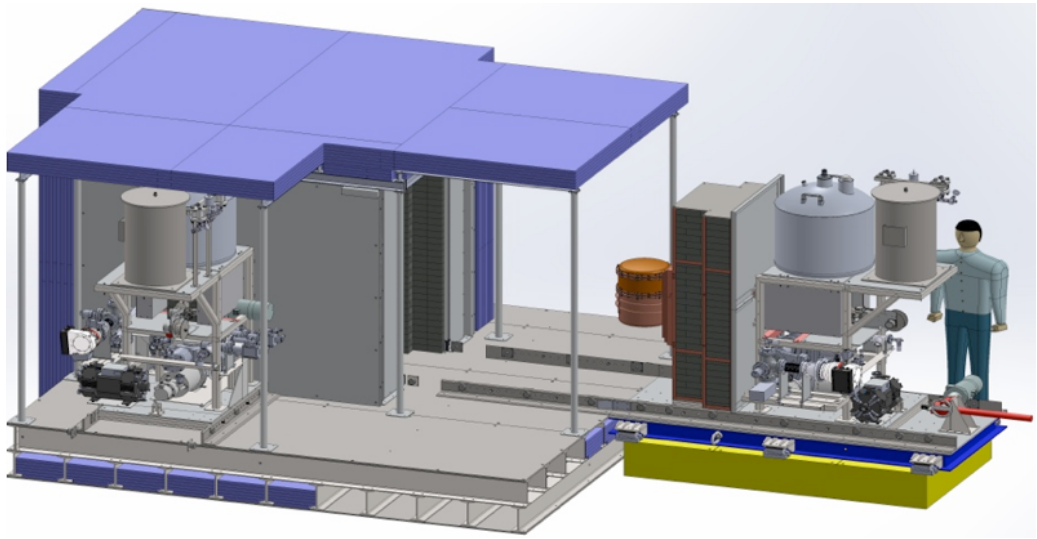
Electroformed Cu and Enriched Ge



DEMONSTRATOR Implementation

Module 1	16.9 kg (20) ^{enr}Ge 5.6 kg (9) ^{nat}Ge		In-shield running 5/2015 - 10/2015 Out-of-shield Improvements In-shield running 1/2016 - present
Module 2	12.9 kg (15) ^{enr}Ge 8.8 kg (14) ^{nat}Ge		In-shield running 7/2016 - present



Data Sets and Duty Cycles

M1 Commissioning, no inner shield

M1 inner shield

M1 Multi-sampling

Modules 1 and 2 Together in-shield

Module 1 & 2 Integrated DAQ

Physics *

High radon

Disruptive Activities *

Calibration

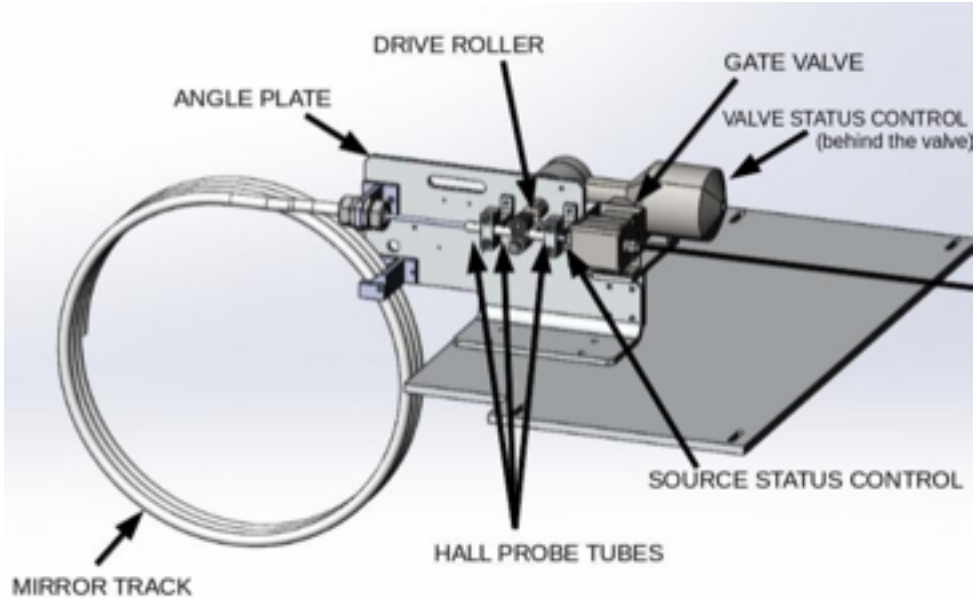
Down time

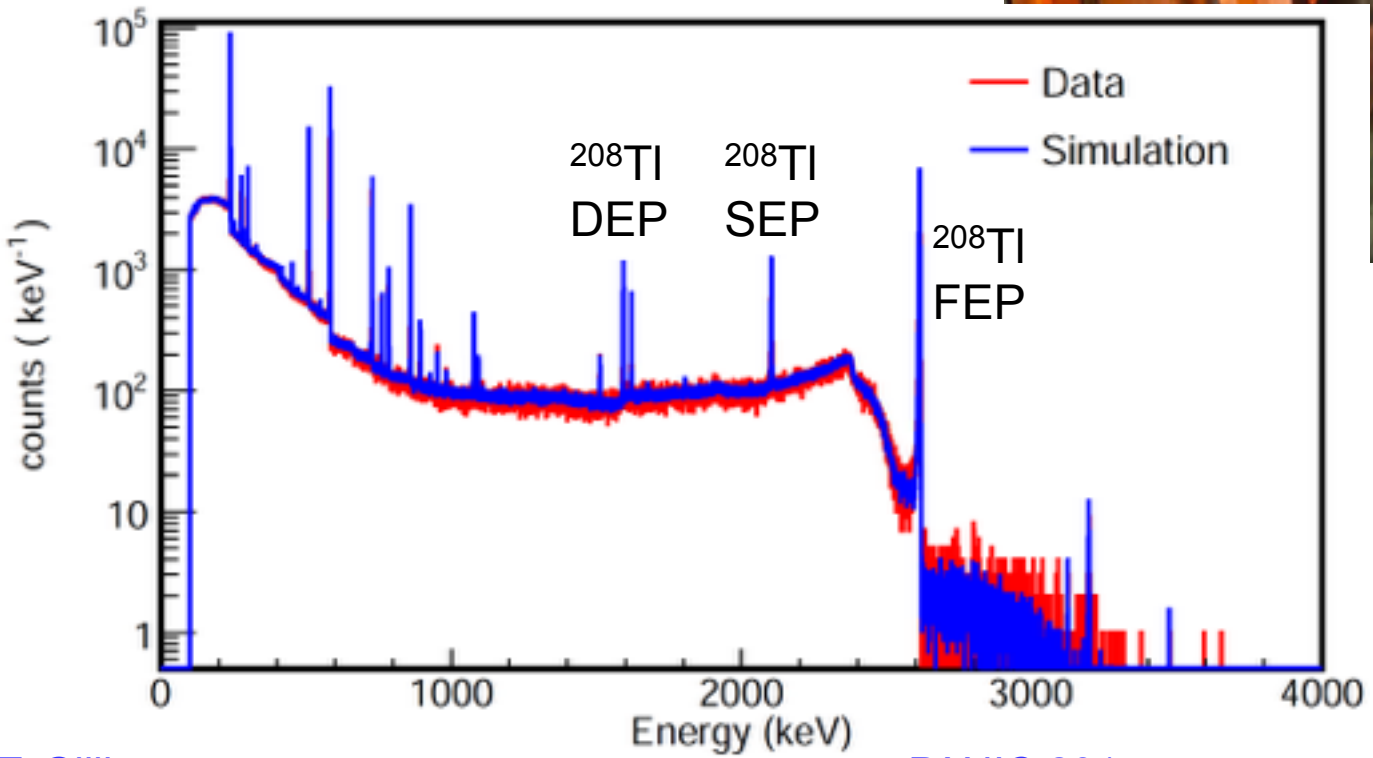
DS0	DS1	DS2	DS3	DS4	DS5
Module1	Module 1	Module 1	Module 1	Module 2	Module 1 & 2
June 26, – Oct. 7, 2015	Dec. 31, 2015 – May 24, 2016	May 24 – July 14, 2016	Aug. 25, – Sept. 27, 2016	Aug. 25, – Sept. 27, 2016	Oct. 13, 2016 – May 5, 2017

- Currently taking blind data in DS6 with multi-sampling
- Exposure to-date of > 20 kg-yr

- 0νββ analysis underway on ~10 kg-yr of exposure

Energy Calibration

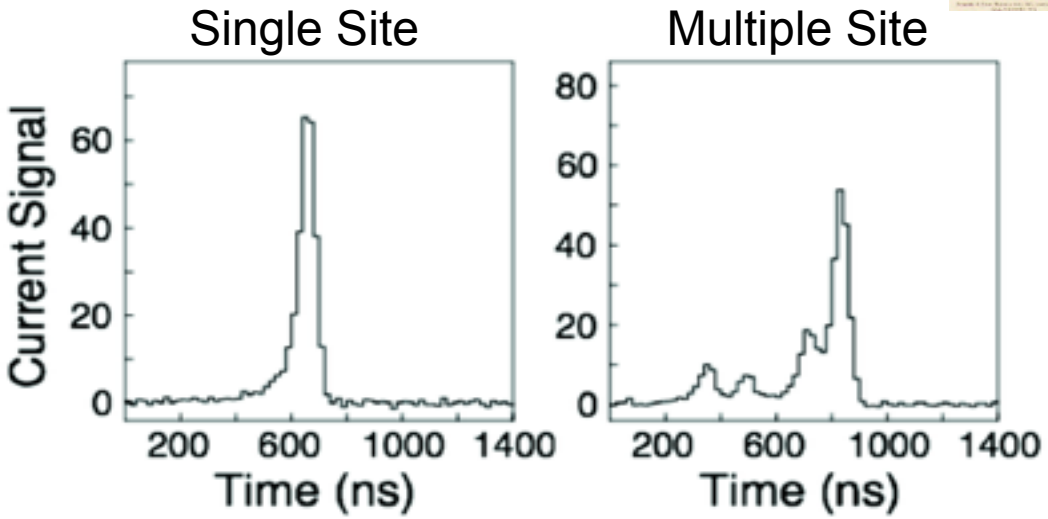


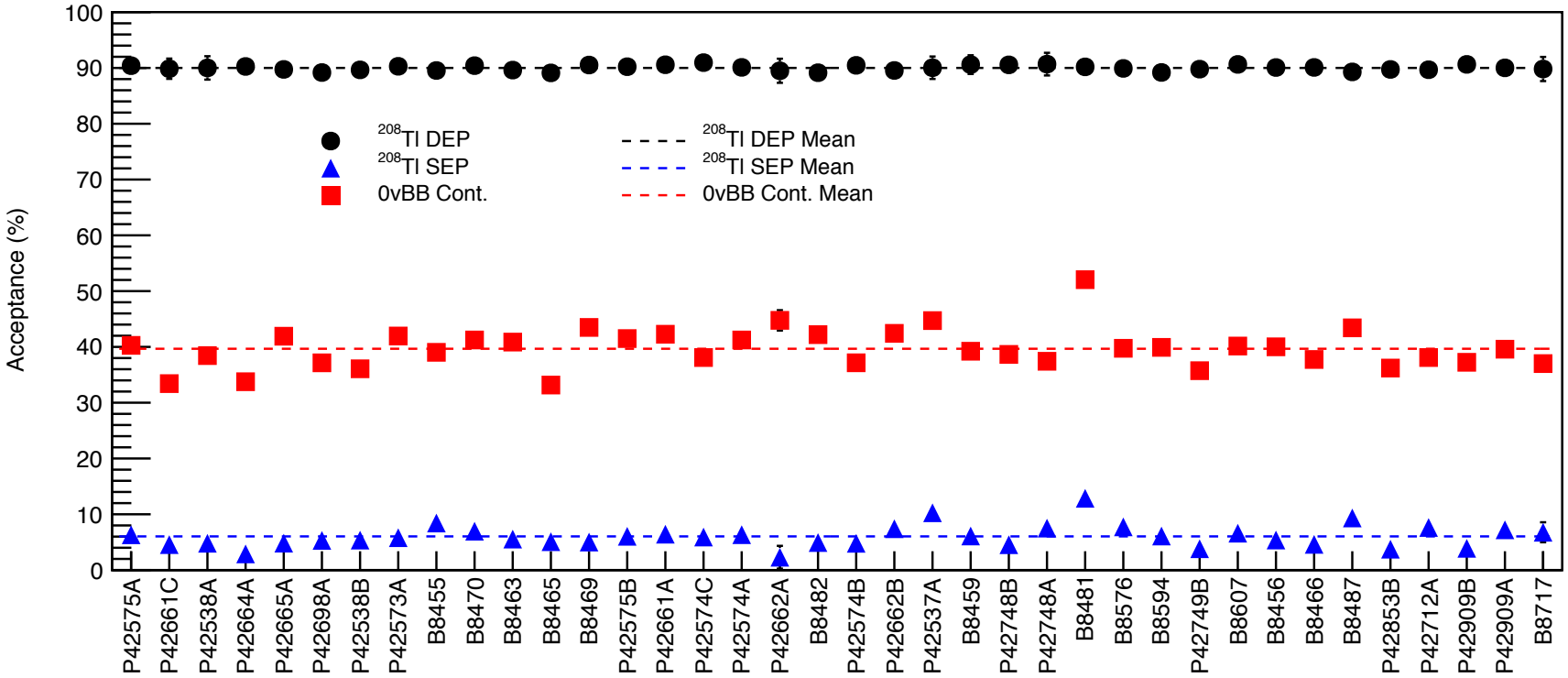


N. Abgrall et. al., Nucl. Instrum. Meth. A, Volume 872, 16-22 (2017)

Multiple Site Event Rejection

- ββ decays appear as single site in the Ge crystals (~1mm^3 energy deposition)
- Point-contact detectors have sufficient differences in drift times throughout the bulk to identify multiple site interactions
- Tune current amplitude-to-energy relationship (AvsE) to accept 90% of single site double escape peak events from ^{208}Tl in calibrations



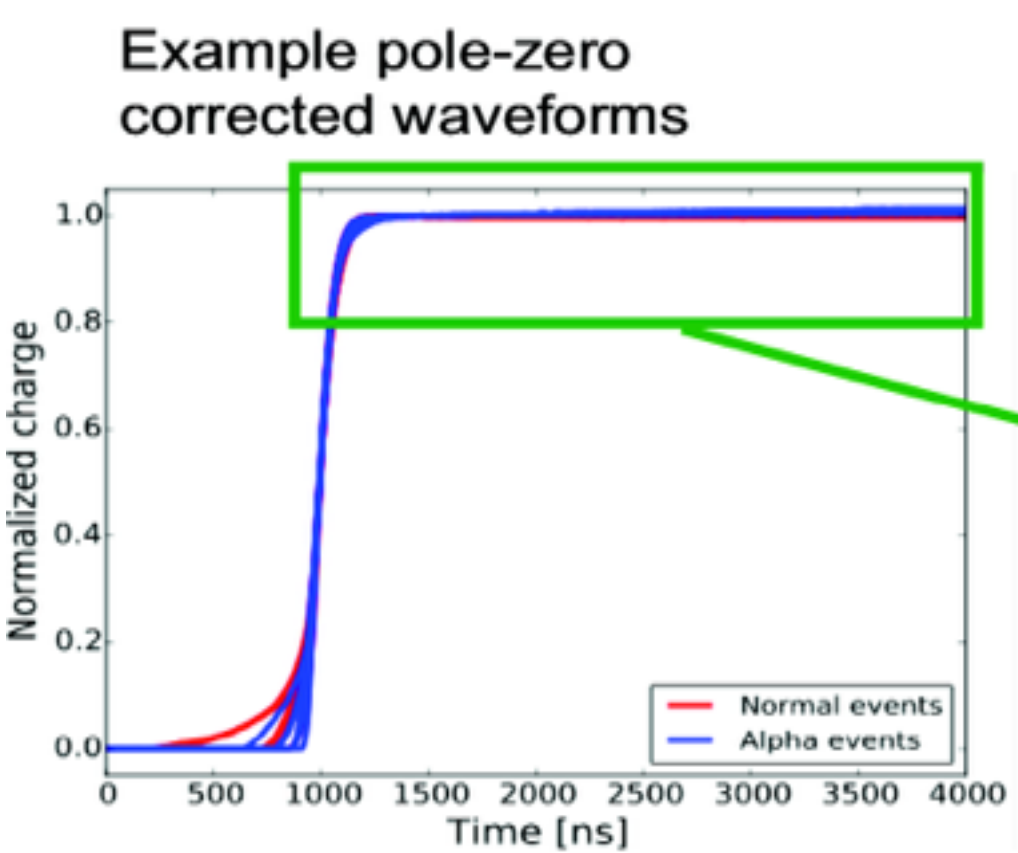


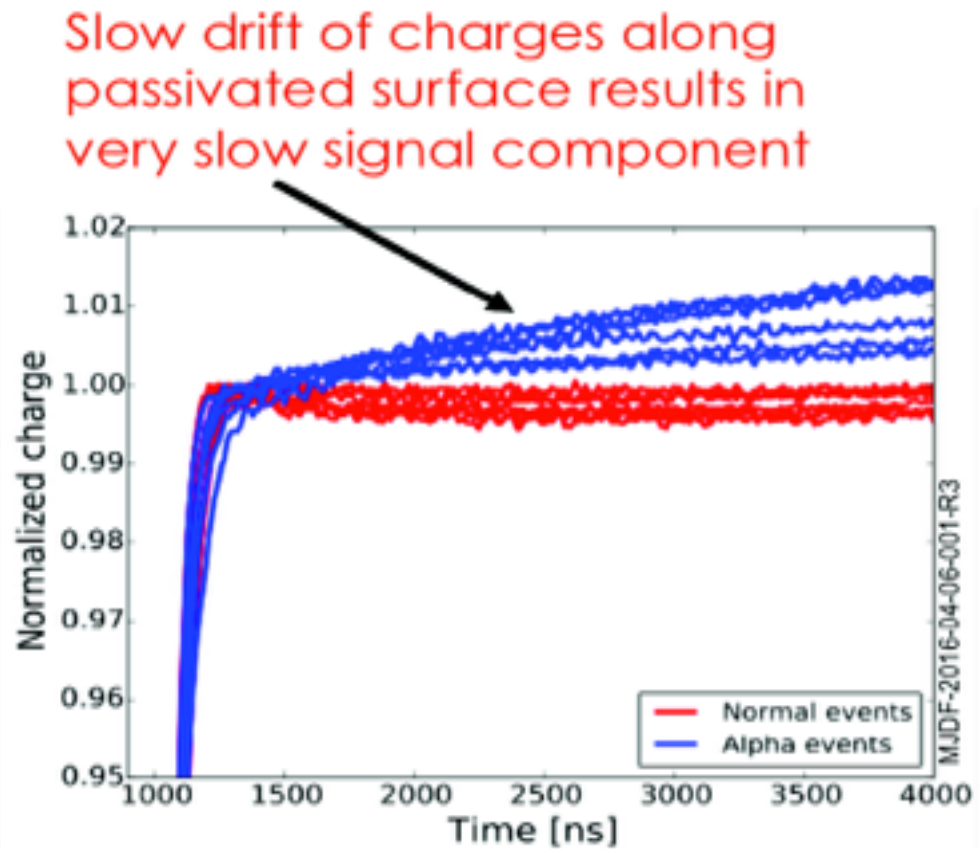
208Tl DEP (single site events) fixed to 90%

208Tl SEP (multiple site events) reduced to 6%

Alpha Backgrounds

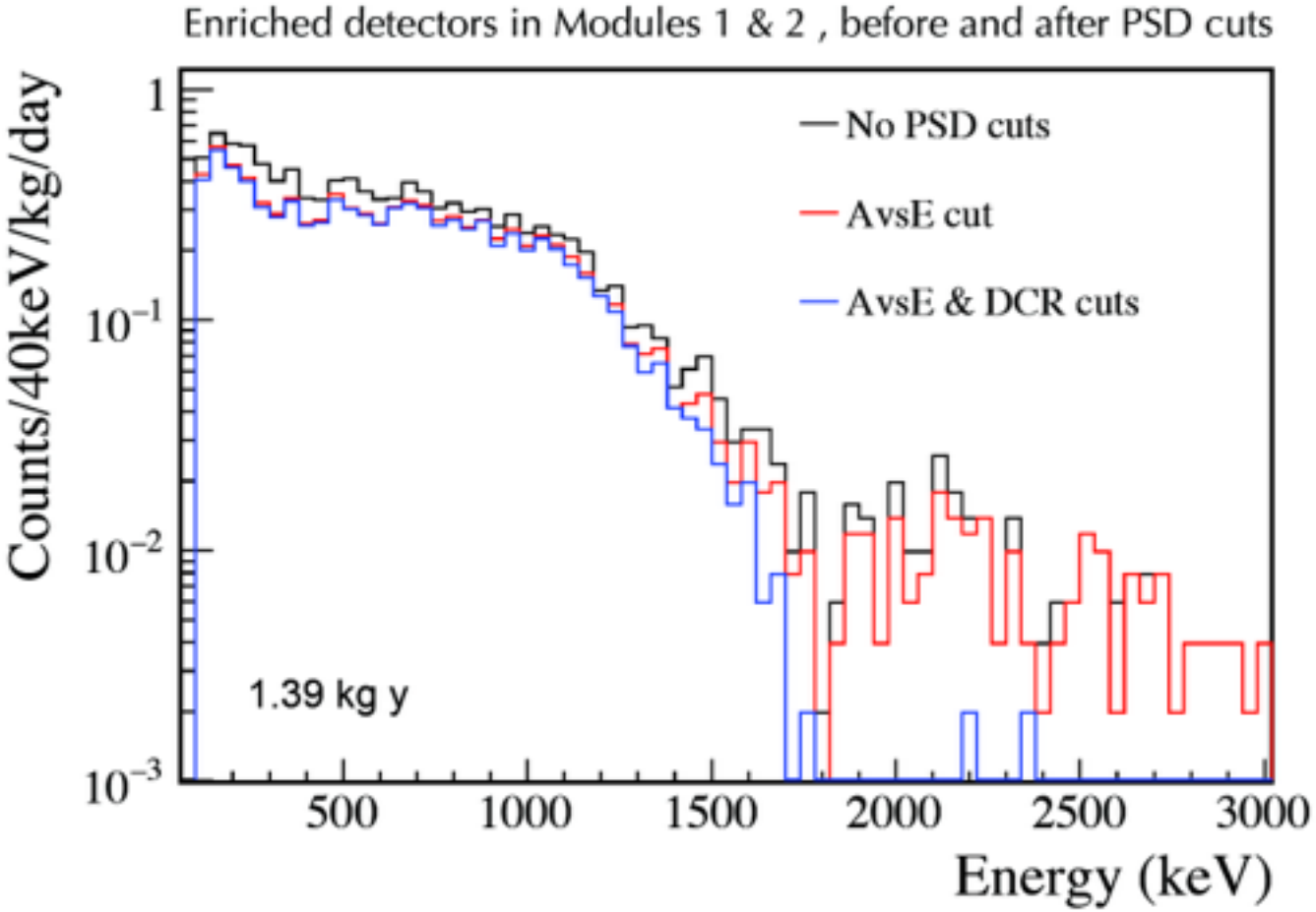
- Energy degraded alpha background observed in early data sets
- Charge from these events drifts along the surface rather than through the bulk
- Results in a distinctive delayed charge recovery (DCR) signal which is used to efficiently cut alpha events based on the slope past the rising edge
- Measurements taken and being analyzed from a DEMONSTRATOR detector in the TUBE alpha scanner at Technical University of Munich to better understand the source and response of surface alphas





Background in DS3 and DS4

- 1.39 kg-yr exposure of enriched detectors
- One count after cuts in a 400 keV region around the Q-value of 2039 keV
- Projected background in 2.8 keV wide ROI of $5.1^{+8.9}_{-3.2}$ c/(ROI-t-y)
- Background index of 1.8×10^{-3} c/(keV-kg-y)



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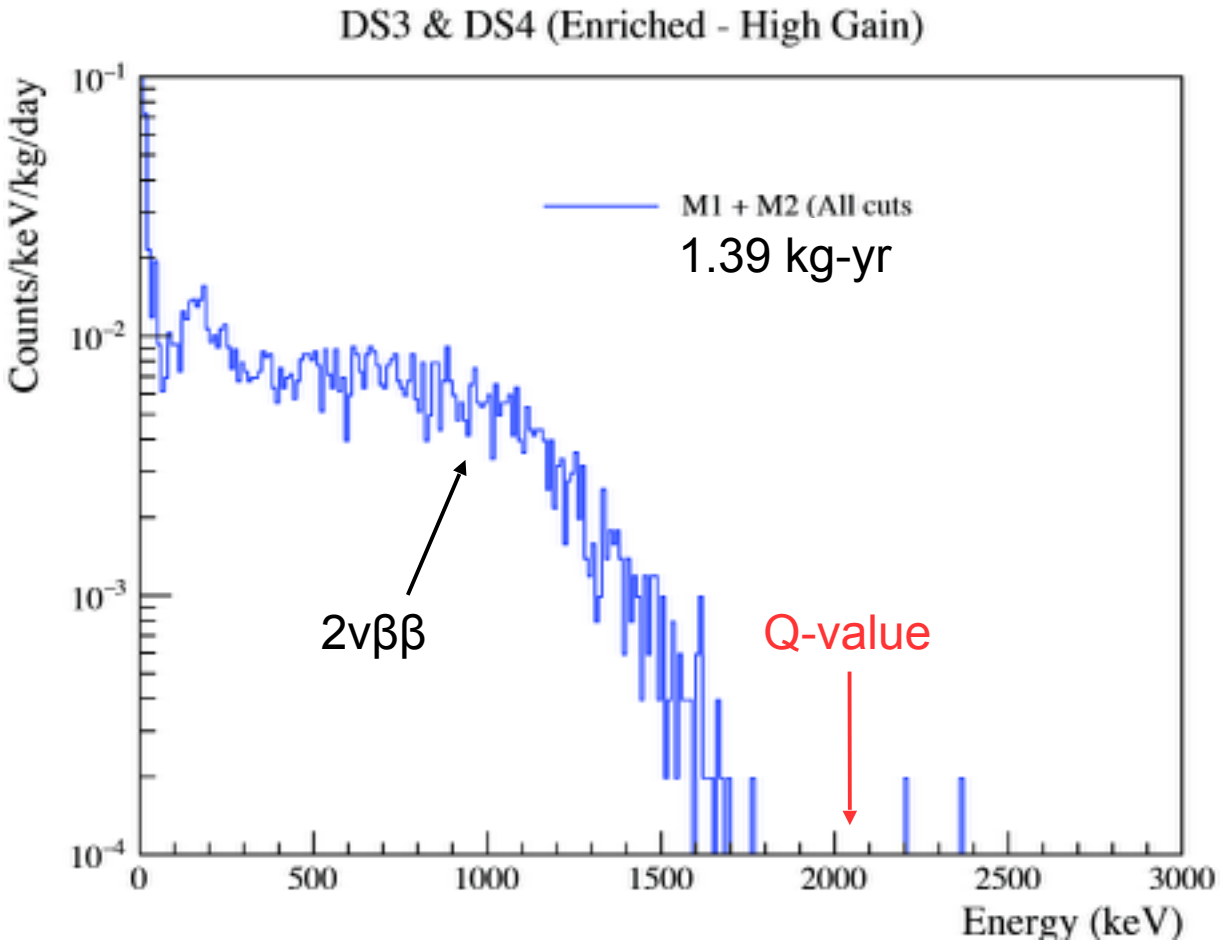
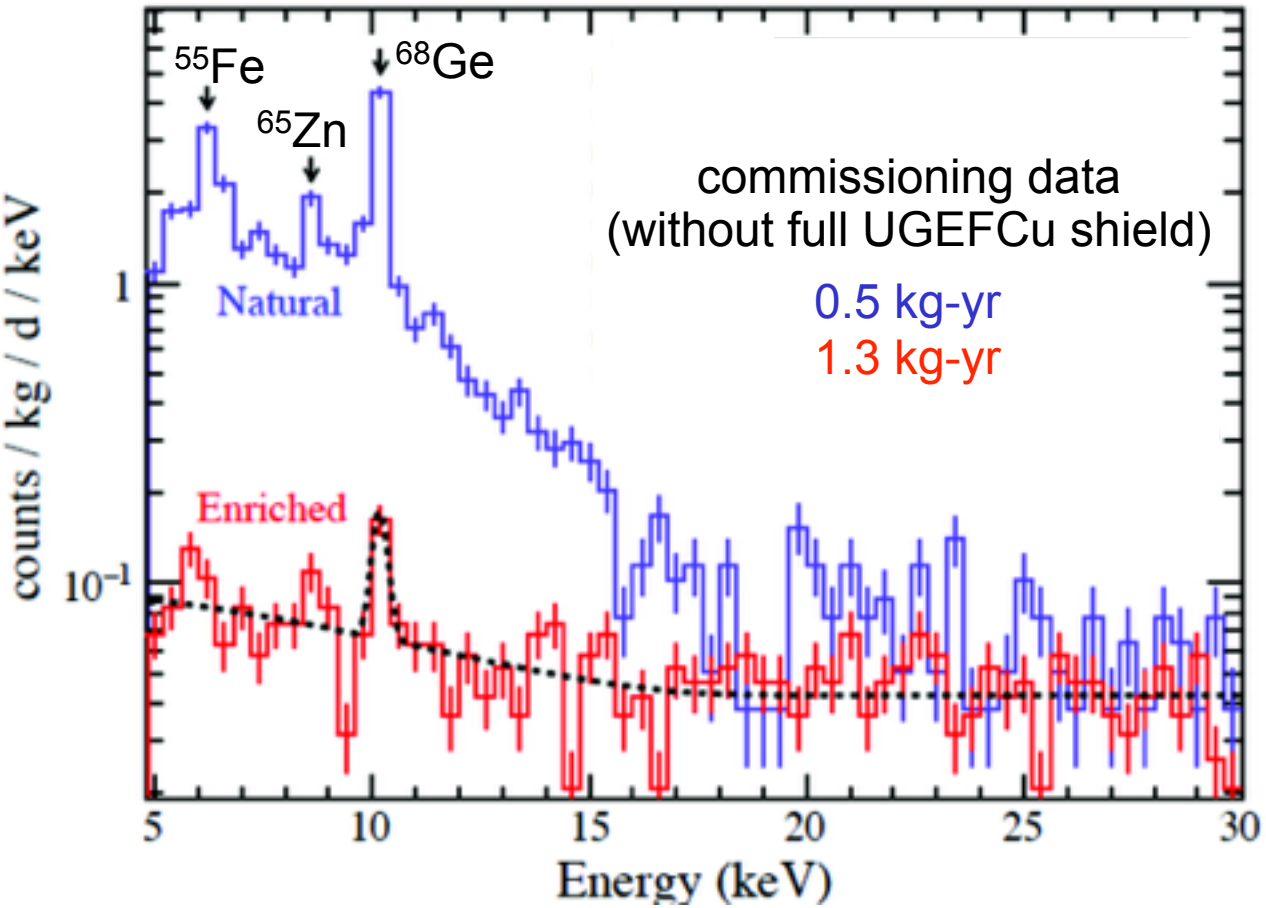


Low-Energy Physics Searches

- Limited exposure of enriched material to cosmic rays
- For the DEMONSTRATOR, the enriched detector ^{68}Ge rate is low enough that an X-ray delayed coincidence cut is not necessary
- Tritium is obvious and dominates in natural detectors below 18.6 keV endpoint
- Hardware thresholds below 1 keV, analysis below 5 keV is ongoing

- Shown below: DS0 commissioning background (without full electroformed Cu shield)
- Factor of several reduction in low-energy background in later datasets



Low-Energy Searches for Physics Beyond SM

- Pseudoscalar dark matter
- Vector dark matter
- 14.4 keV solar axion
- $e^- \rightarrow 3\nu$
- Pauli Exclusion Principle violation

N. Abgrall et. al., Phys. Rev. Lett. 118, 161801 (2017)

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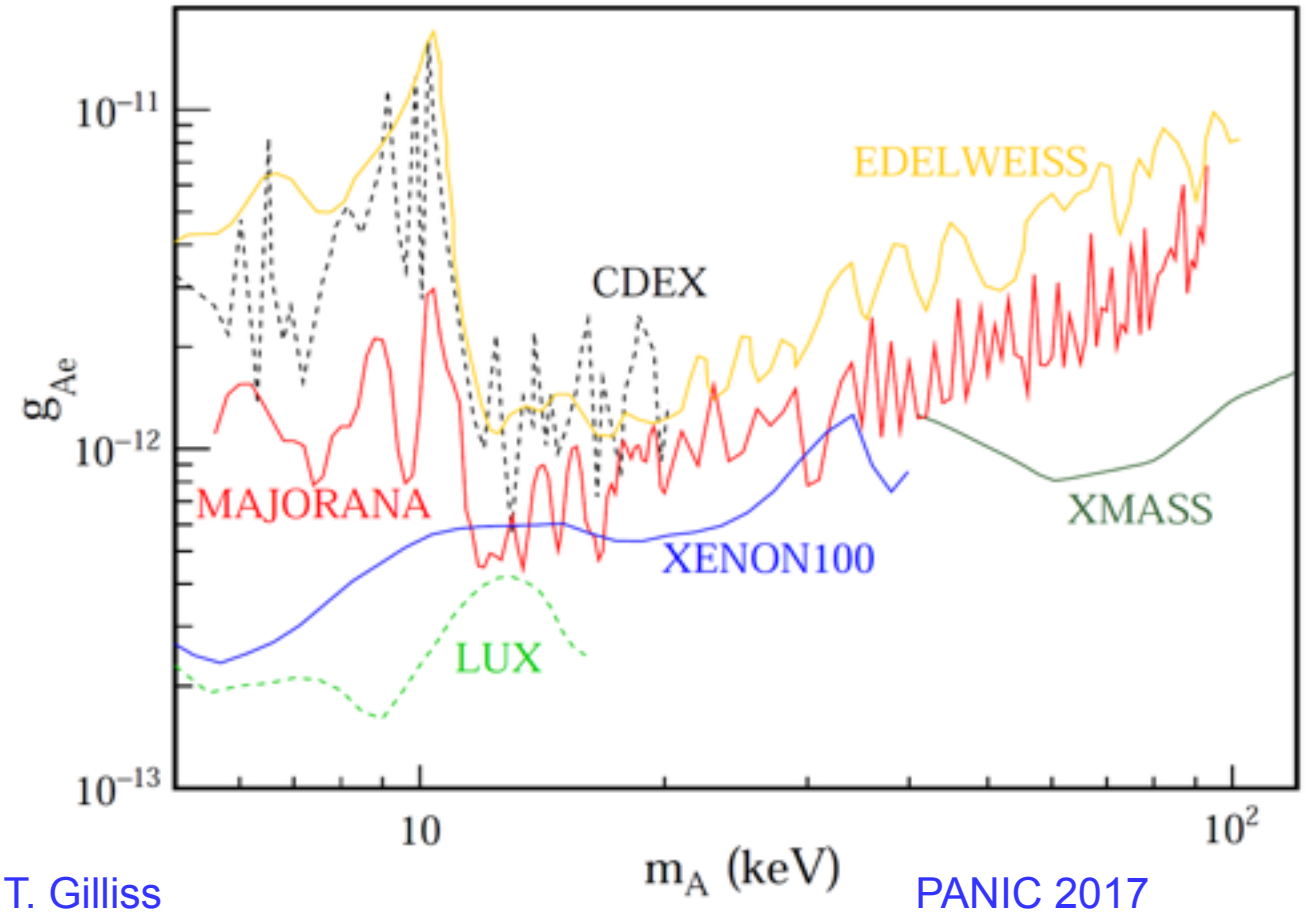
Pseudoscalar ALP Coupling



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MAJORANA and GERDA

To reach the ton-scale (and the necessary backgrounds), LEGEND will combine the strengths of both GERDA and the MAJORANA DEMONSTRATOR

MAJORANA:

- Radiopurity of nearby parts (FETs, cables, Cu mounts, etc.)
- Low noise electronics yields better PSD
- Low energy threshold (cosmogenic and low-E background)

GERDA:

- LAr active veto
- Low-A shield, no Pb

See parallel talk in "Neutrino Physics" Session, Room 301A, 14:20

Both:

- Clean fabrication techniques
- Control of surface exposure
- Development of large point-contact detectors

Summary

- The ^{76}Ge enriched PPC detectors developed by MAJORANA
  - have attained the best energy resolution (2.4 keV FWHM at 2039 keV) of any ββ-decay experiment.
  - provide excellent pulse shape discrimination for reduction of backgrounds.
  - have sub-keV thresholds and excellent energy resolution at low-energy allowing the DEMONSTRATOR to perform sensitive tests in this region for physics beyond the standard model.

- The DEMONSTRATOR's initial backgrounds in the ROI are among the lowest achieved to date (approaching GERDA's recent best value) by development and selection of ultra-low activity materials and low-mass designs.

- Combining the strengths of GERDA and MAJORANA, the LEGEND collaboration is moving forward towards a ton-scale ^{76}Ge based experiment. Based on the successes to date, LEGEND will be able to meet the backgrounds (~0.1 c/(ROI-t-y)) and energy resolution necessary for discovery-level sensitivities in the inverted ordering region.

The MAJORANA Collaboration

Black Hills State University · ITEP · Berkeley Lab · Duke University · The University of North Carolina at Chapel Hill · Oak Ridge National Laboratory · Los Alamos National Laboratory · South Dakota School of Mines & Technology · Tennessee Tech · Technische Universität München · University of South Carolina · The University of Tennessee · NC State University · University of South Dakota · Pacific Northwest National Laboratory · Princeton University · Queen's University

Sanford Underground Research Facility