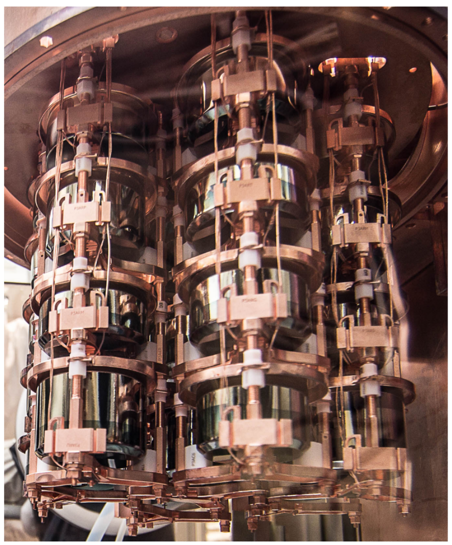
Double-Beta Decay Experiments with ^{76}Ge

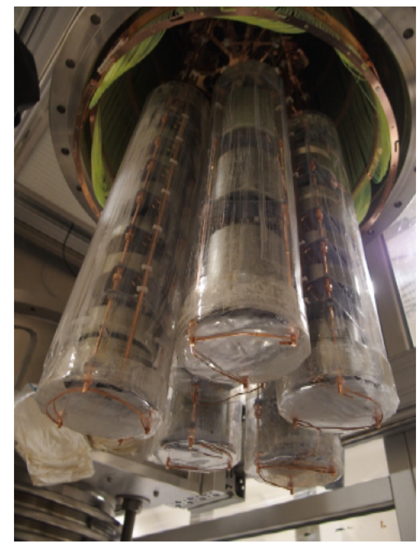
Jason Detwiler, UW/CENPA

INT Workshop 17-2a on

Neutrinoless Double-beta Decay

Seattle, WA, June 12, 2017





Celebrating 50 Years of ^{76}Ge 0νββ Searches!

Volume 25B, number 10 PHYSICS LETTERS 27 November 1967

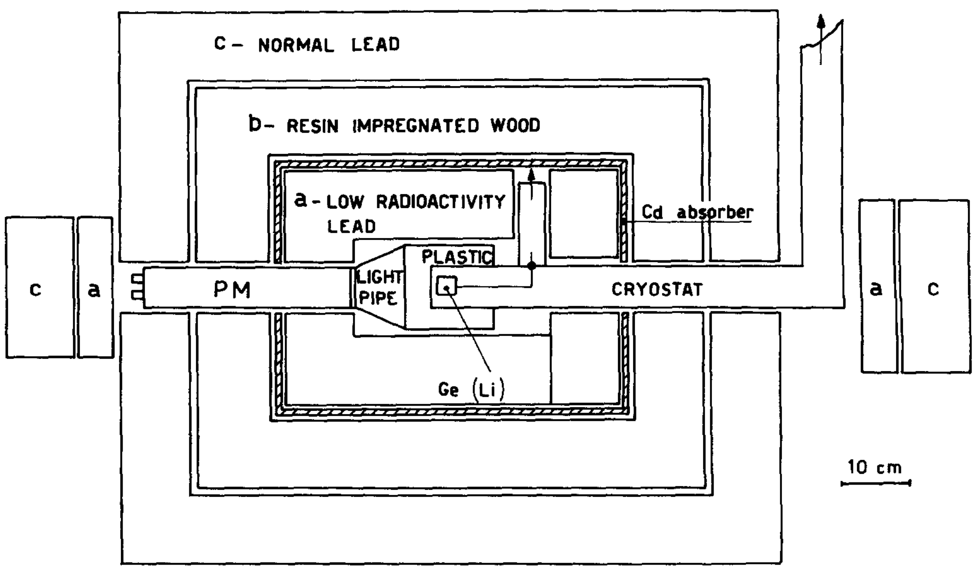
A SEARCH FOR LEPTON NON-CONSERVATION IN DOUBLE BETA DECAY WITH A GERMANIUM DETECTOR

E. FIORINI and A. PULLIA
Istituto di Fisica dell'Università and INFN, Milano, Italy

G. BERTOLINI, F. CAPPELLANI and G. RESTELLI
Euratom, CCR, Ispra, Italy

Received 30 October 1967

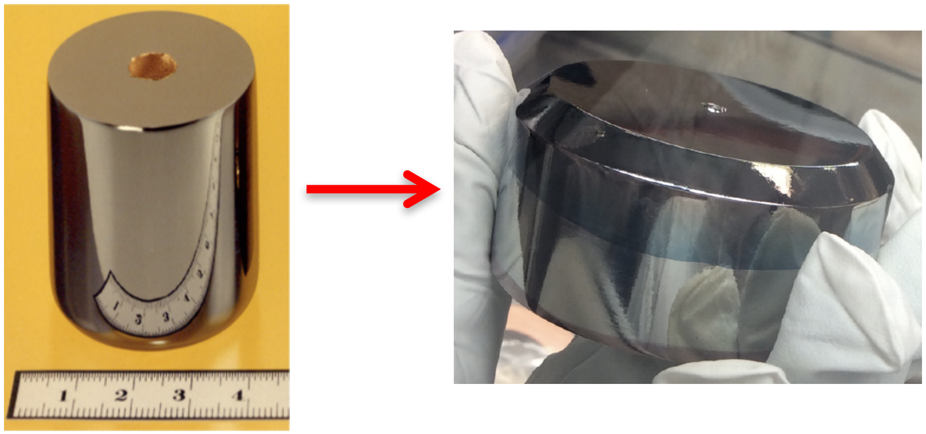
A new technique is applied to the search for neutrinoless double β decay. A Ge(Li) crystal is used both as source and as detector of the ^{76}Ge → ^{76}Se transition. Our negative result ($\tau_{\frac{1}{2}} > 3 \times 10^{20}$ y) is consistent with the lepton conservation law.

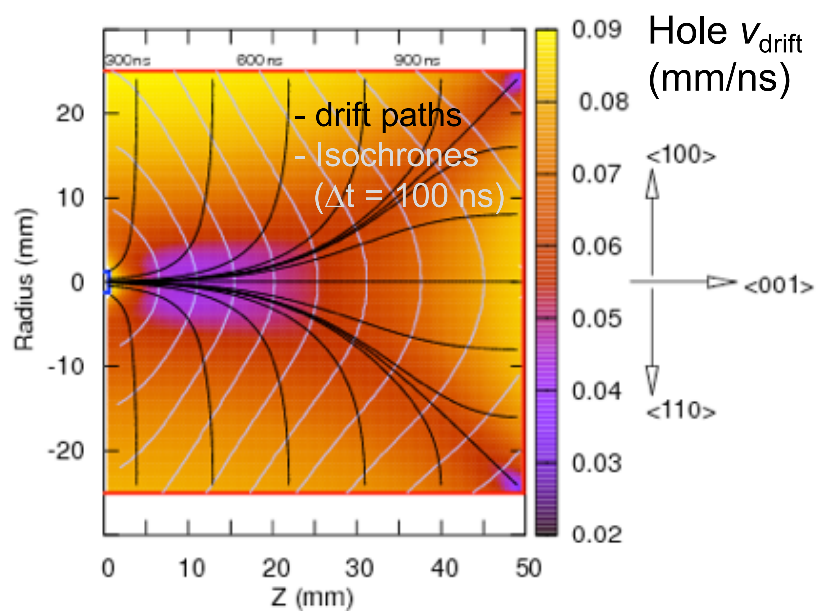


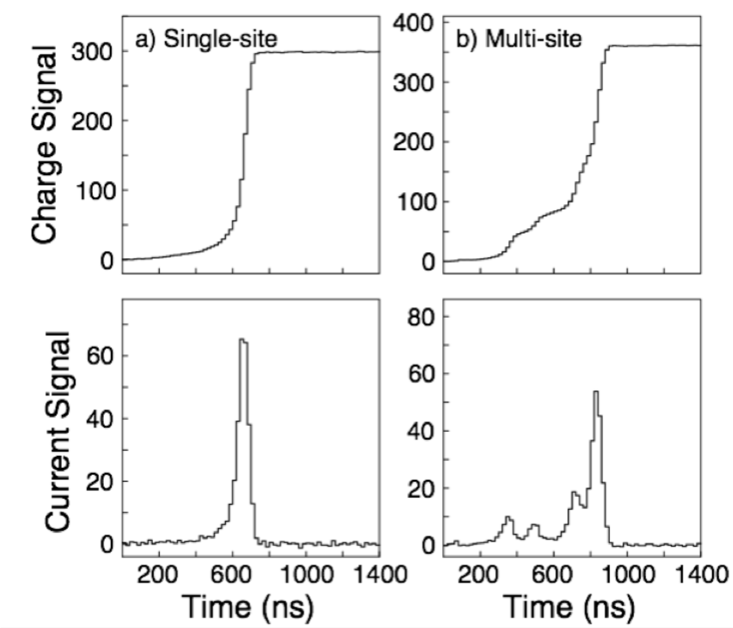
Advantages of ^{76}Ge

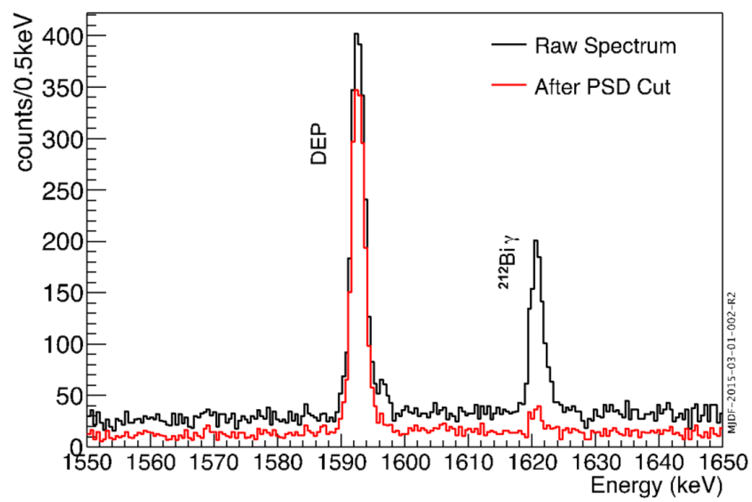
- Intrinsic high-purity Ge detectors = source
- Excellent energy resolution: approaching 0.1% at 2039 keV (~2.4 keV ROI)
- Demonstrated ability to enrich from 7.44% to ≥87%
- Powerful background rejection: multiplicity, timing, pulse-shape discrimination

0νββ with Point Contact Detectors





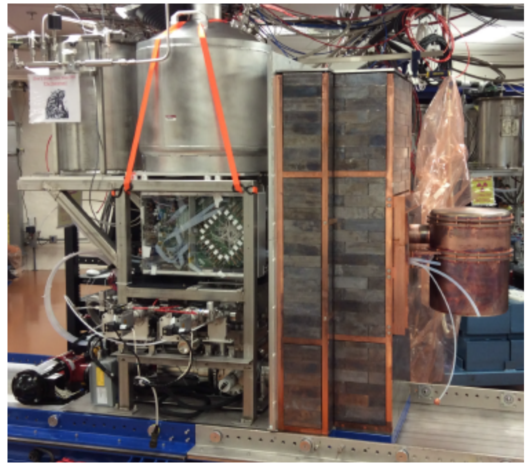


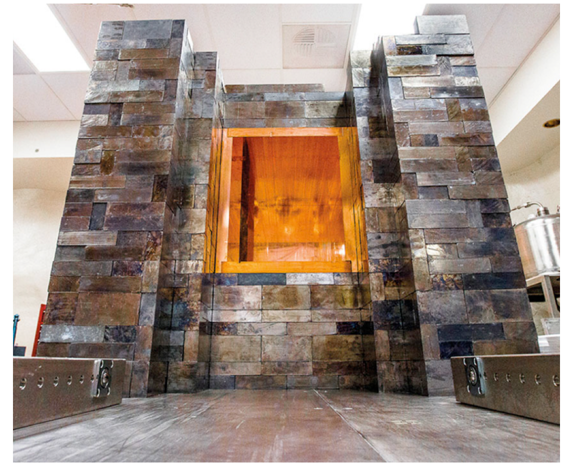


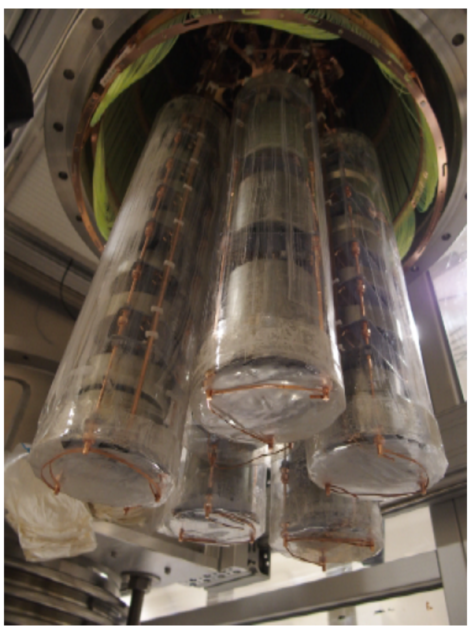
Luke et al., IEEE trans. Nucl. Sci. 36 , 926 (1989)
Barbeau, Collar, and Tench, J. Cosm. Astro. Phys. 0709 (2007).

MAJORANA and GERDA

MAJORANA
“Traditional” configuration:
Vacuum cryostats in a
passive graded shield
with ultraclean materials







GERDA
“Novel” configuration:
Direct immersion
in active LAr shield

The MAJORANA Collaboration

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Duke University, Durham, North Carolina, and TUNL
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Yuri Efremenko, Andrew Lopez

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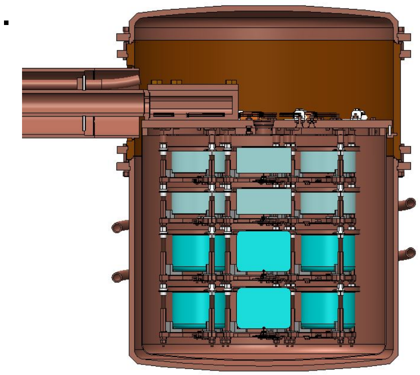
The MAJORANA DEMONSTRATOR

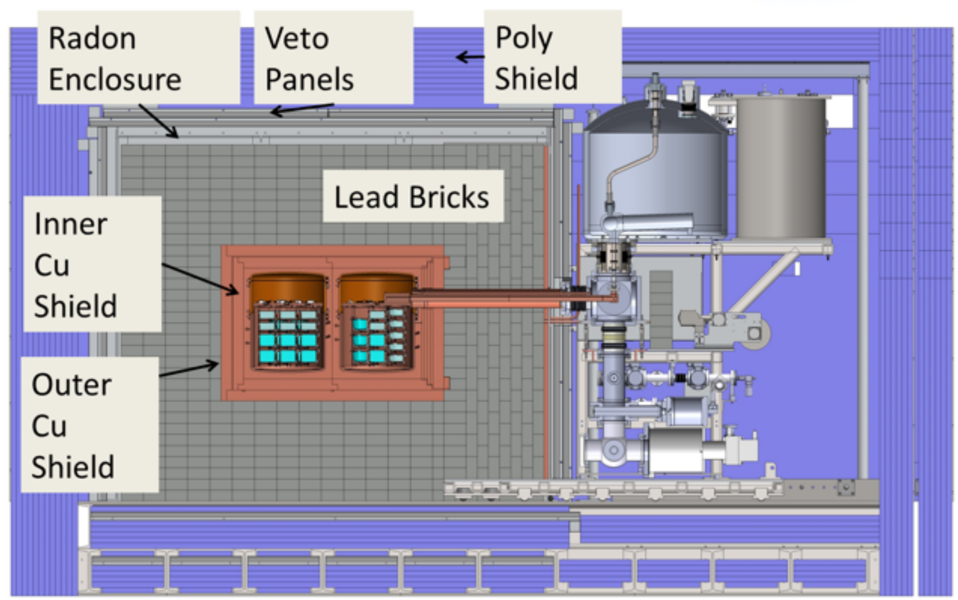
Funded by DOE Office of Nuclear Physics, NSF Particle Astrophysics, NSF Nuclear Physics
with additional contributions from international collaborators.

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.



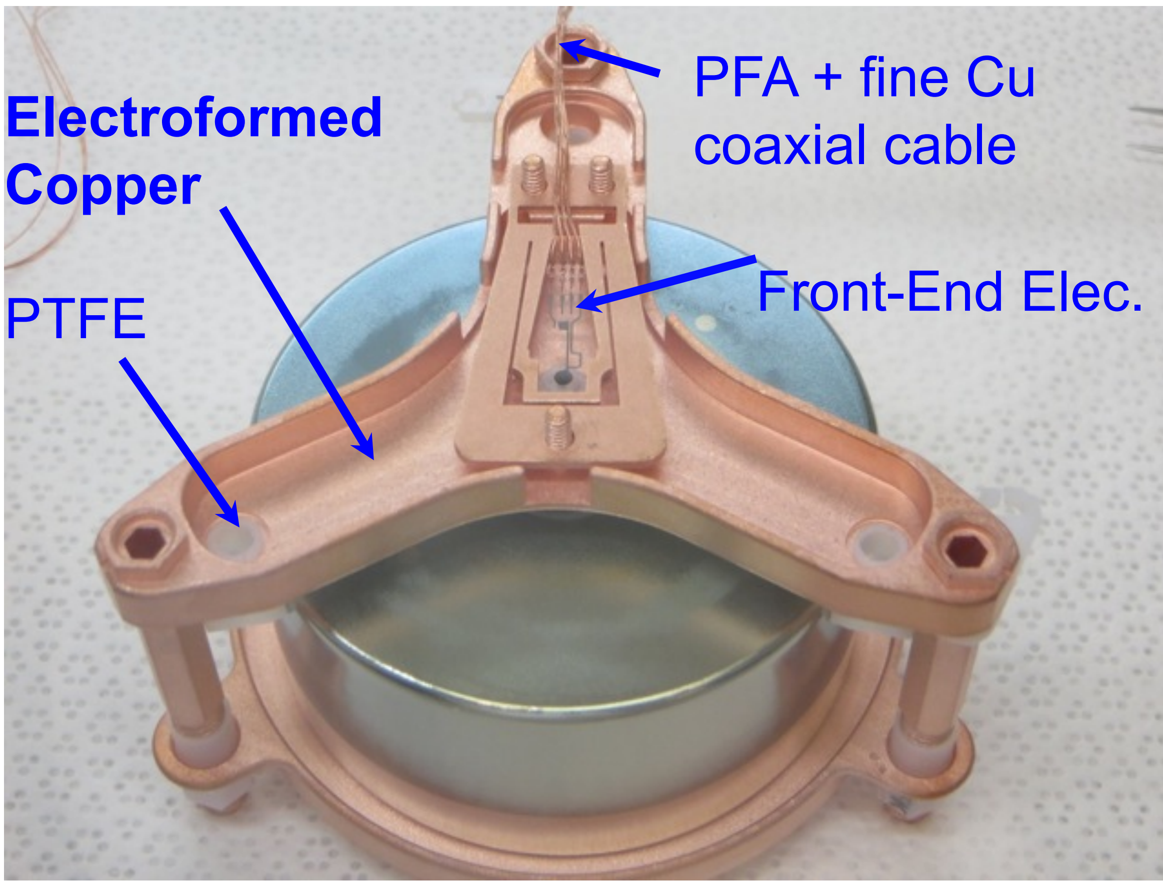
- Operating underground at 4850' Sanford Underground Research Facility
- Background Goal in the $0\nu\beta\beta$ peak region of interest (4 keV at 2039 keV)
  3 counts/ROI/t/y (after analysis cuts) Assay U.L. currently ≤ 3.5

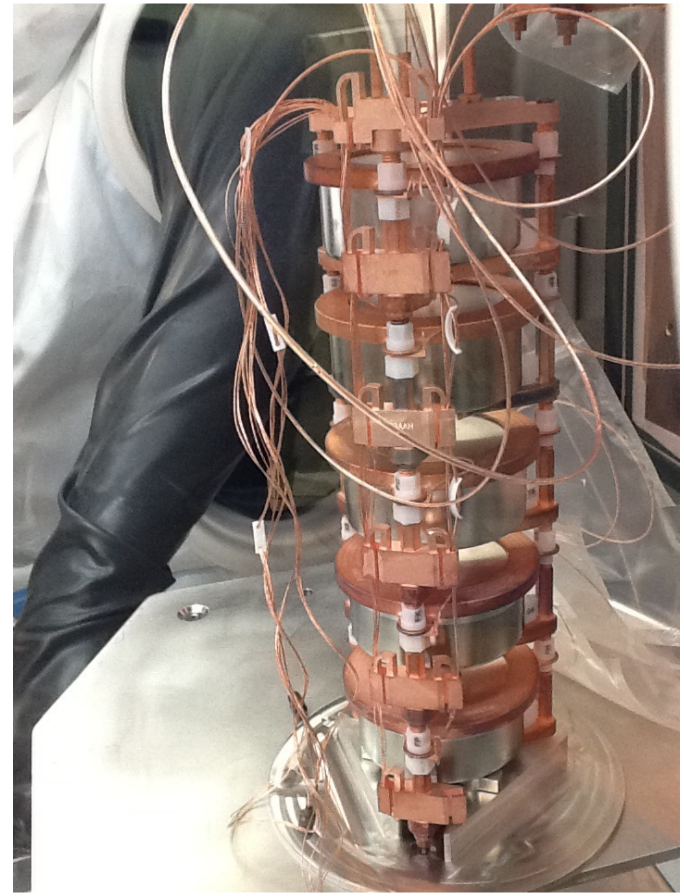
- 44.1-kg of Ge detectors
  - 29.7 kg of 87% enriched ^{76}Ge crystals
  - 14.4 kg of ^{nat}Ge
  - Detector Technology: P-type, point-contact.
- 2 independent cryostats
  - ultra-clean, electroformed Cu
  - 22 kg of detectors per cryostat
  - naturally scalable
- Compact Shield
  - low-background passive Cu and Pb shield with active muon veto



Assembled Detector Unit and String

AMETEK (ORTEC) fabricated enriched detectors.
35 Enriched detectors at SURF 29.7 kg, 88% ^{76}Ge.
20 kg of modified natural-Ge BEGe (Canberra) detectors in hand (33 detectors UG).



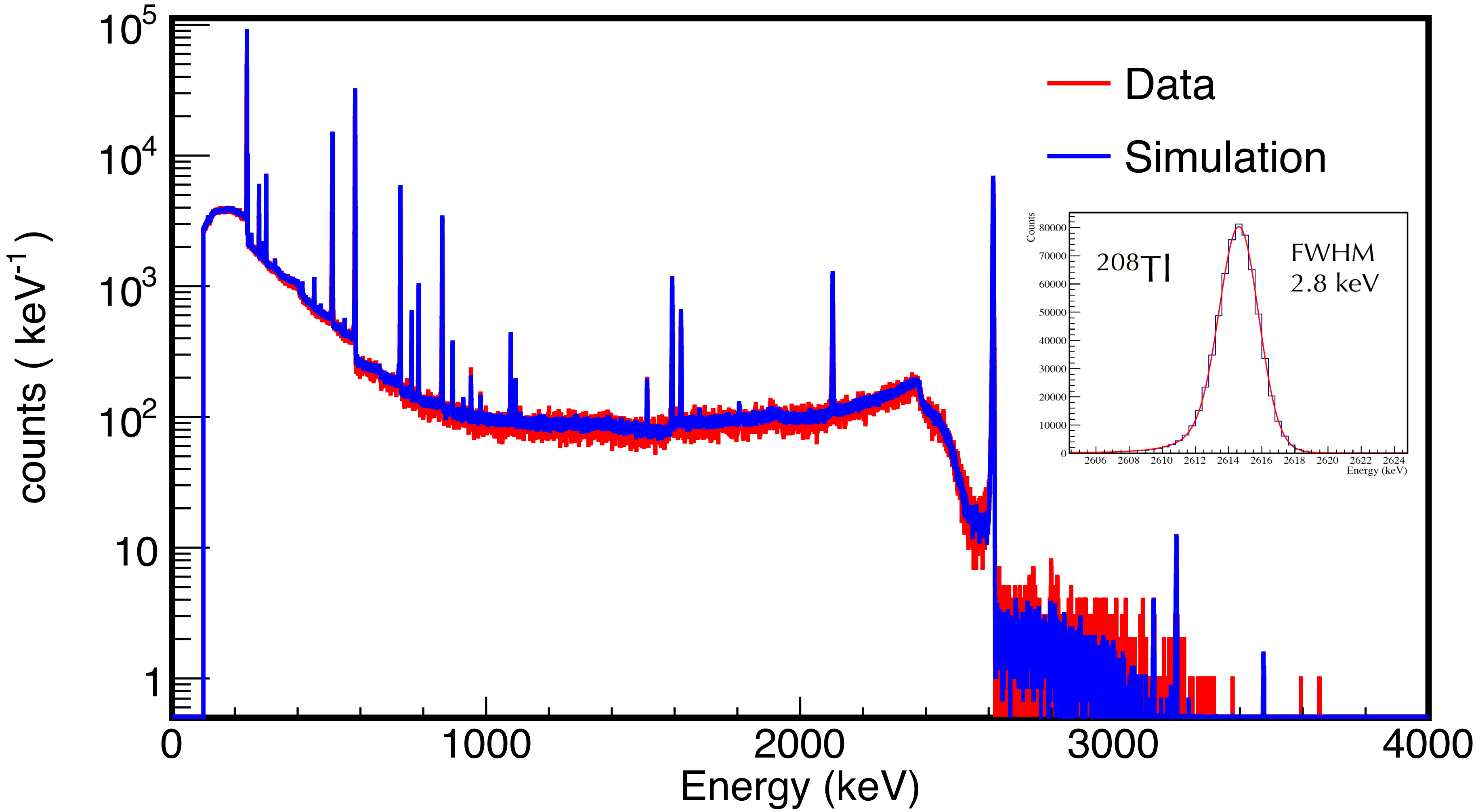


All detector assembly performed in N_2 purged gloveboxes.
All detectors' dimensions recorded by optical reader.

Assay Program: NIMA **828** (2016) 22.

^{228}Th Calibration Spectrum

Full detector hit spectrum in Module 1. FWHM = 2.4 keV at $Q_{\beta\beta}$: best resolution of any $\beta\beta$ experiment to date.



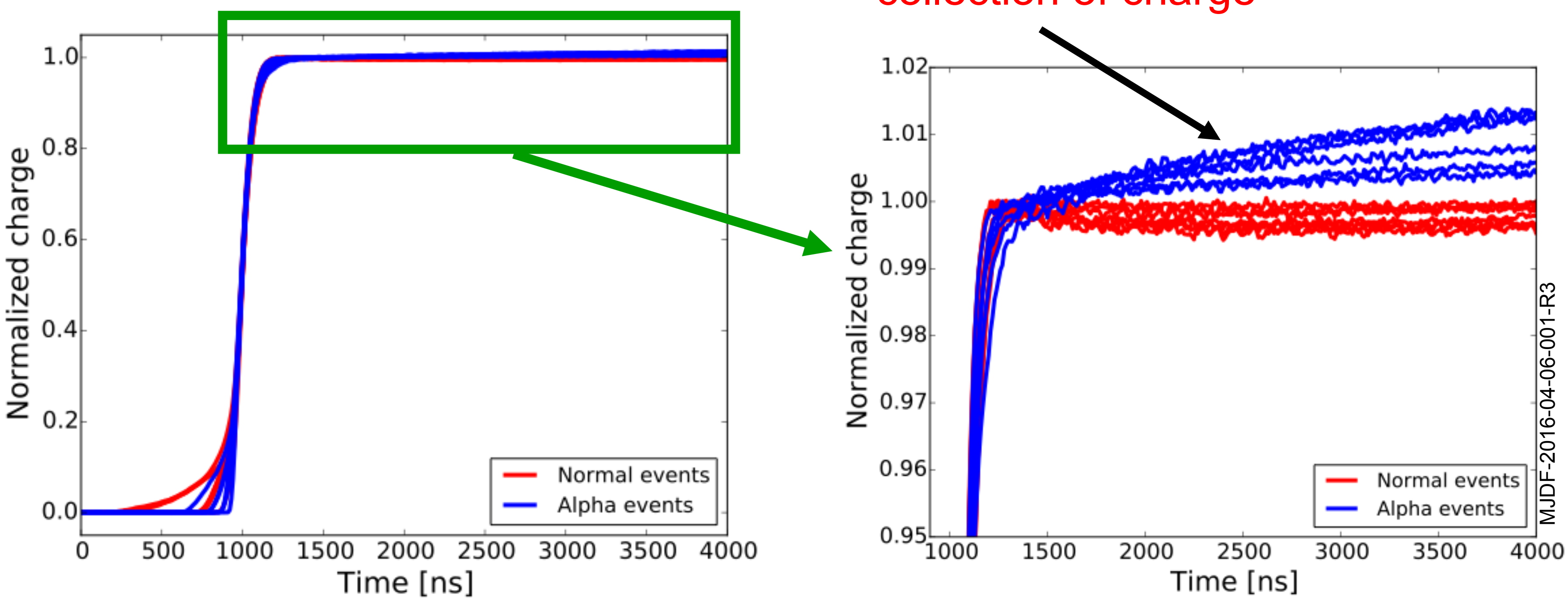
arXiv:1702:02466

The Delayed Charge Recovery Cut for α's

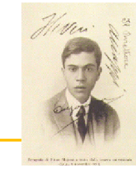
- Alpha background response observed in Module 1 commissioning (DS0)
- Identified as arising from alpha particles impinging on passivated surface.
- Results in prompt collection of some energy, plus very slow collection of remainder.
- Produces a distinctive waveform allowing a high efficiency cut.

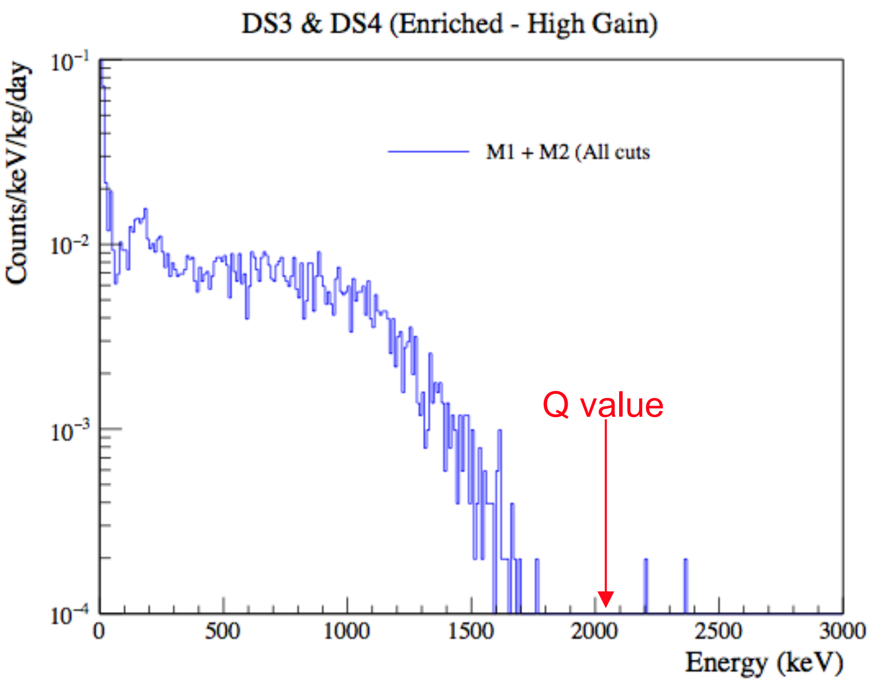
Example pole-zero corrected waveforms

Slow signal component associated with delayed collection of charge



Initial Results from the DEMONSTRATOR





First results from Modules 1 and 2 in-shield

- Exposure: 1.39 kg y
- After cuts, 1 count in 400 keV window centered at 2039 keV (0νββ peak)
- Projected background rate is
  $5.1\ ^{+8.9}_{-3.2}$ c /(ROI t y)
  for a 2.9 keV (Modue 1- DS3) and 2.6 keV (Module 2 - DS4) ROI, (68% CL).
- Background index of 1.8 x 10^{-3} c/(keV kg y)
- Analysis cuts are still being optimized.
- Through mid-May, have 10x more exposure in hand. Analysis is in progress.

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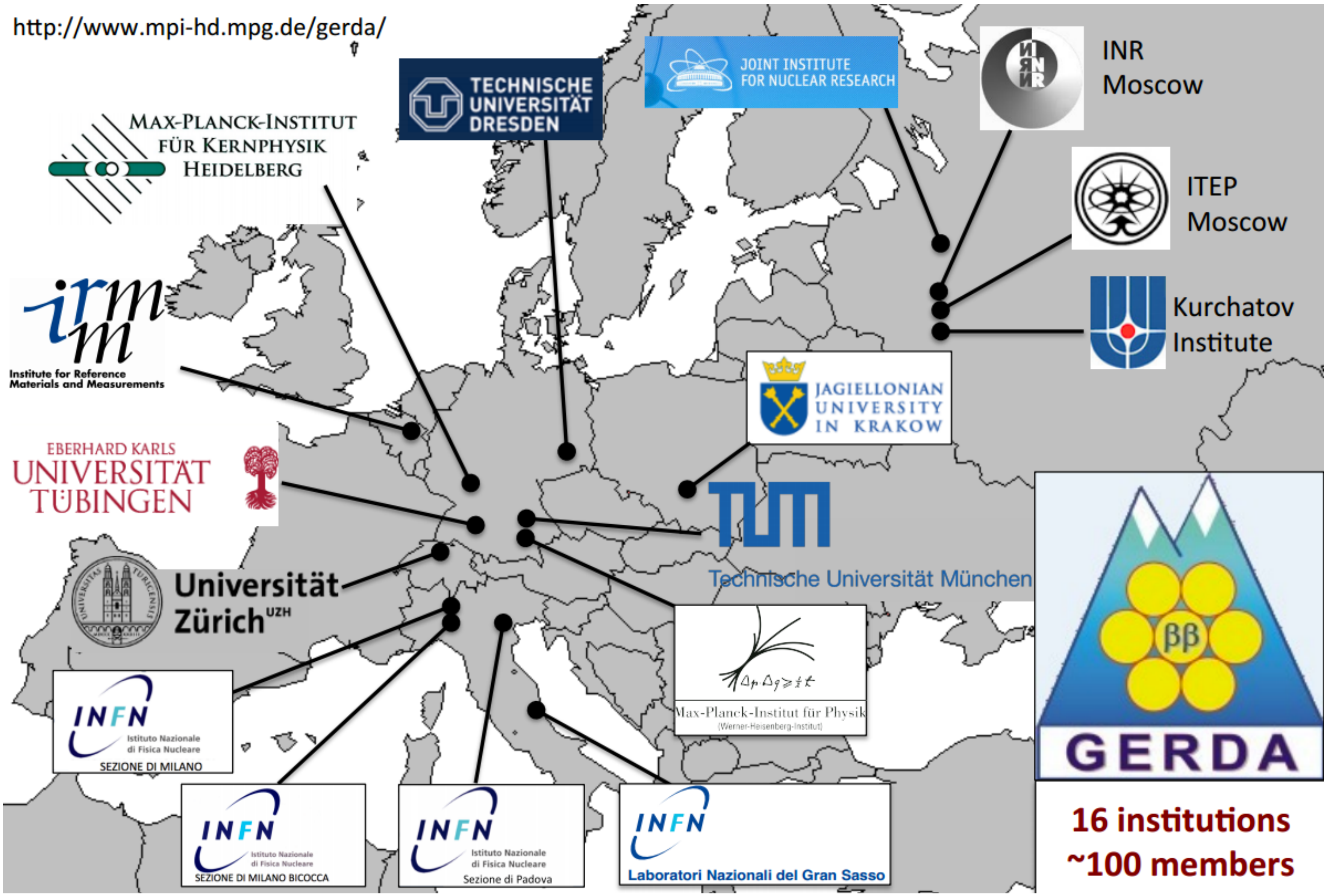
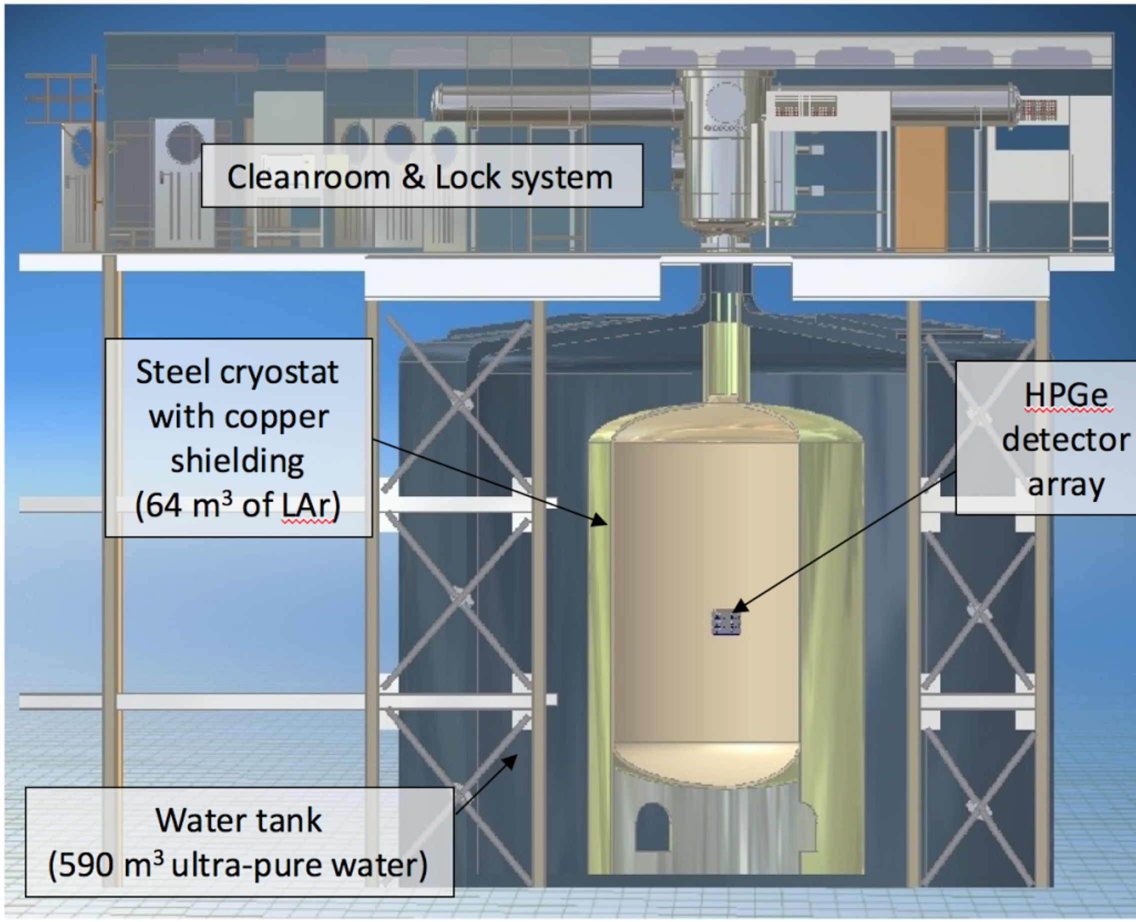
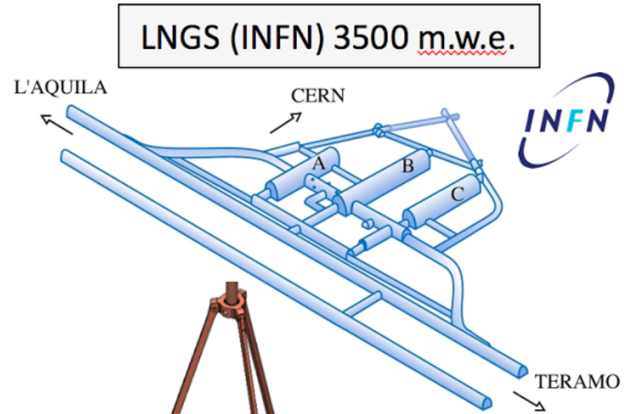
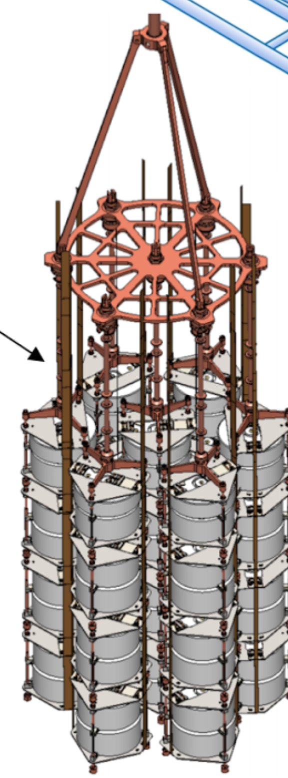
The GERDA Collaboration



GERDA Configuration

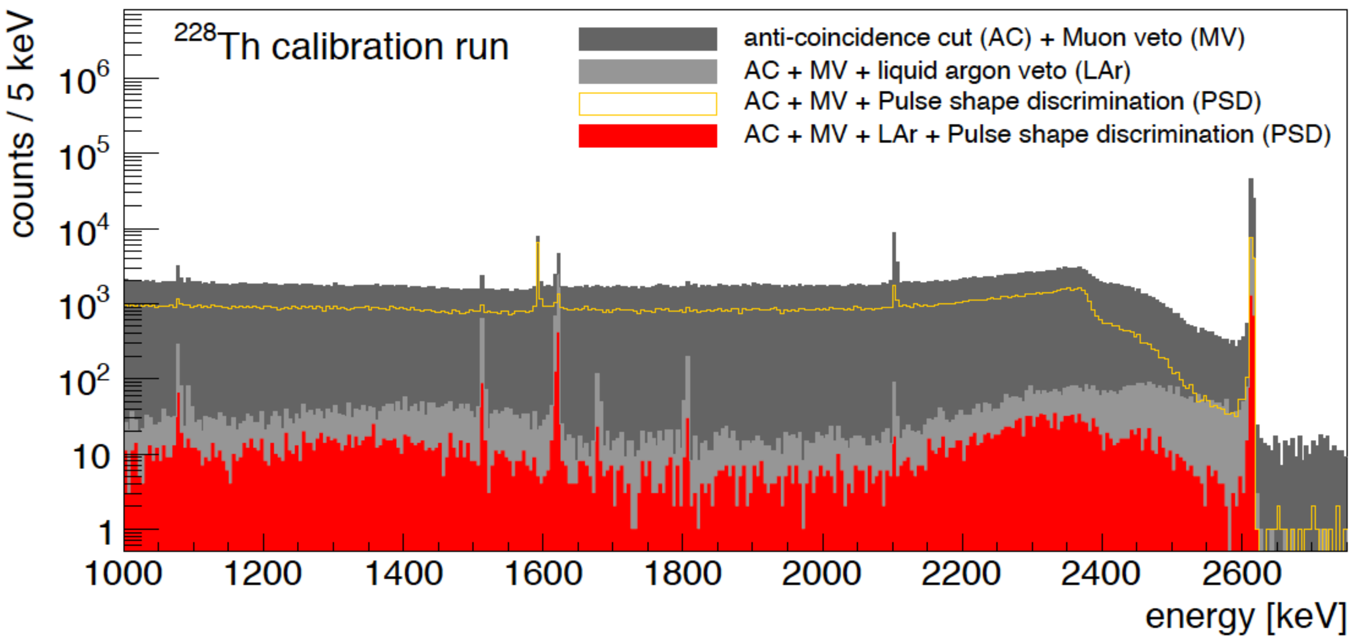


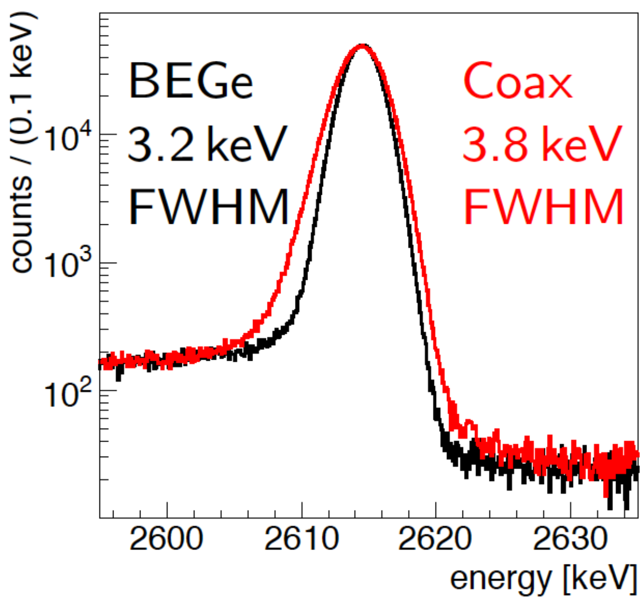


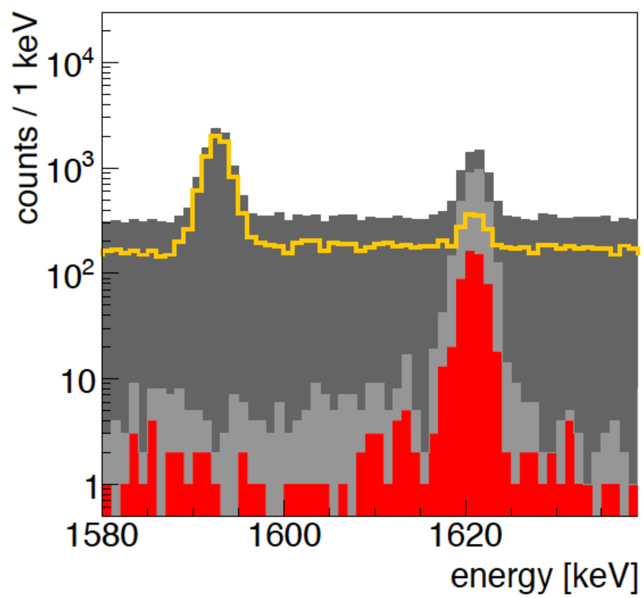


30 BEGe (20 kg) and
7 Coax (15.6 kg) (Phase II)

Detector Performance







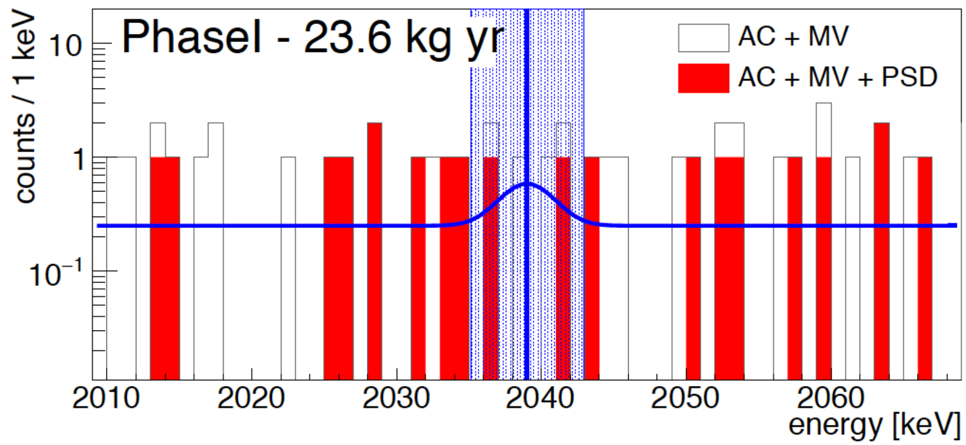
Direct immersion and active rejection work beautifully!

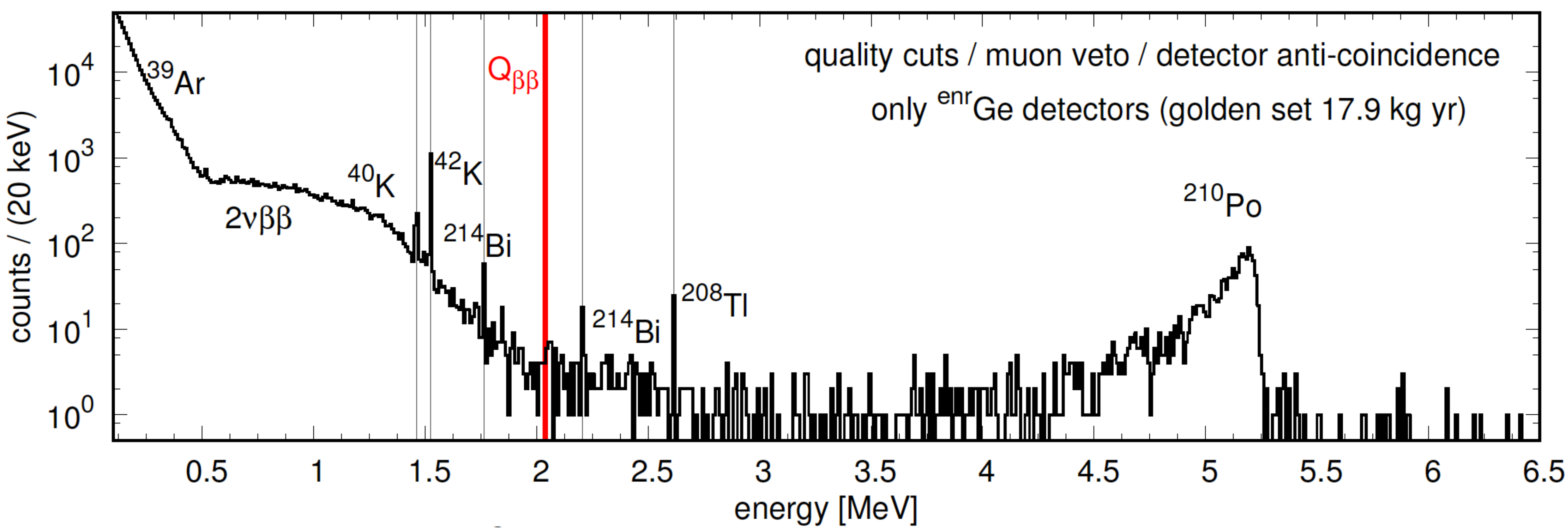
GERDA Phase I

Mostly refurbished coaxial detectors from previous-generation experiments, no LAr active veto

Analysis cuts:

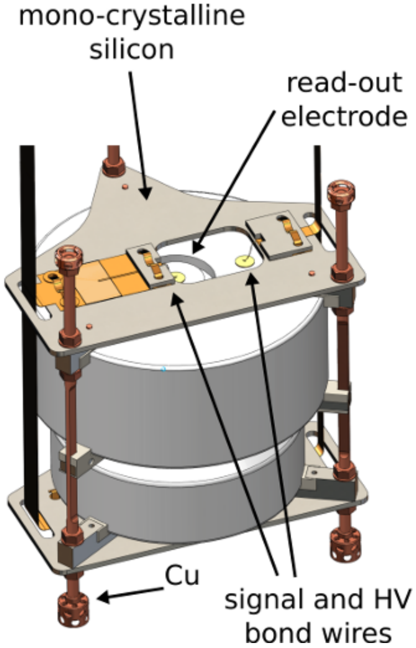
- Anti-coincidence (AC)
- Muon veto (MV)
- Pulse-shape discrimination (PSD)



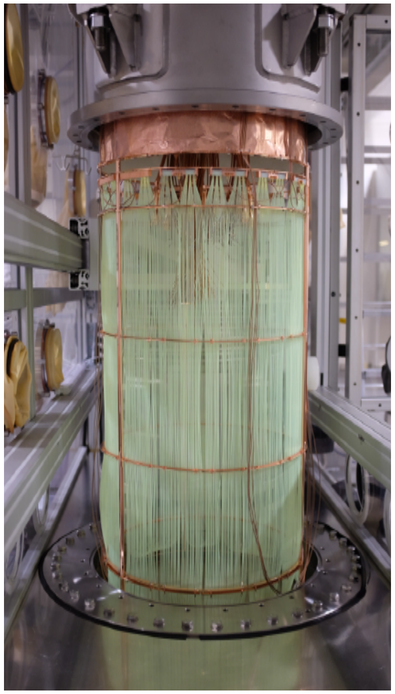


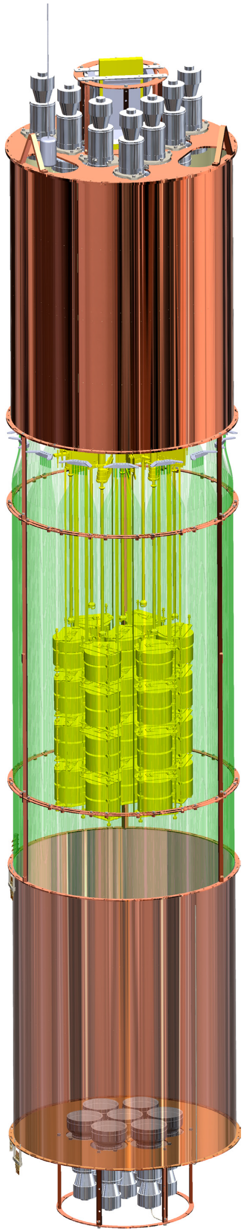
Phase II Upgrades

Double the mass with BEGe's (PPCs), lower-BG mounts

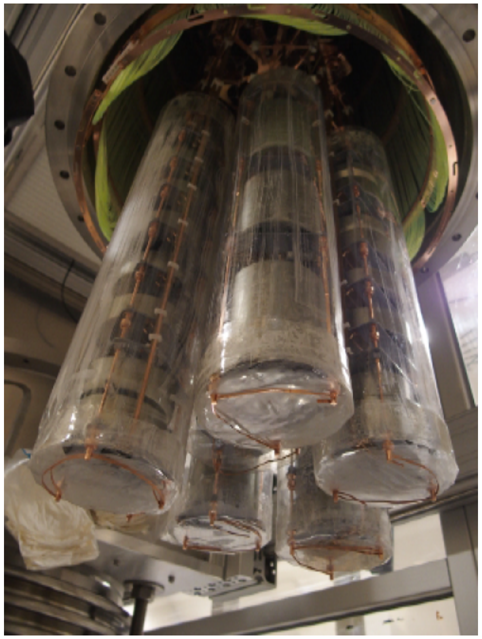


Instrument the LAr veto with SiPM's plus WLS fibers

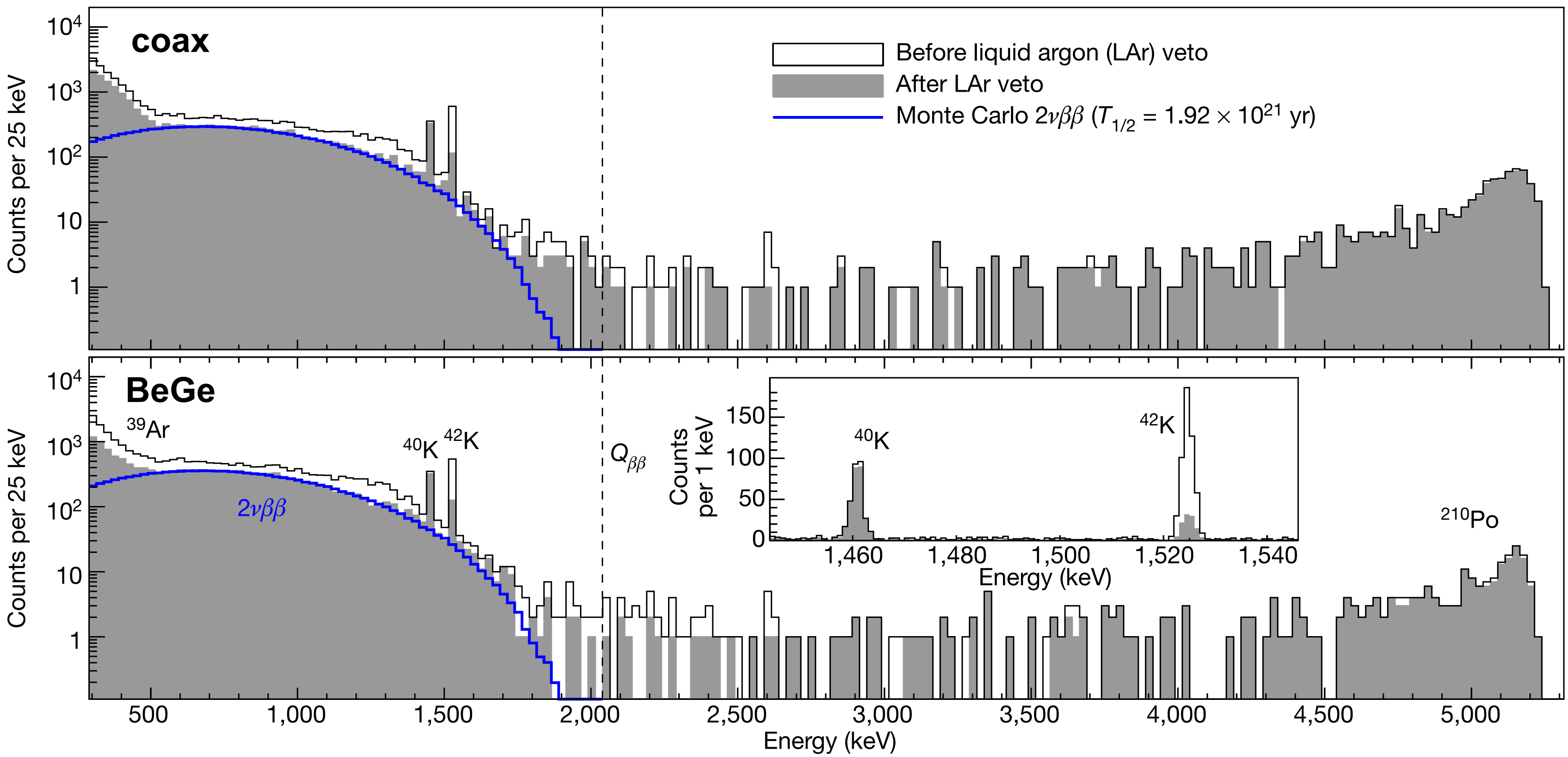




Enshroud strings in WLS nylon



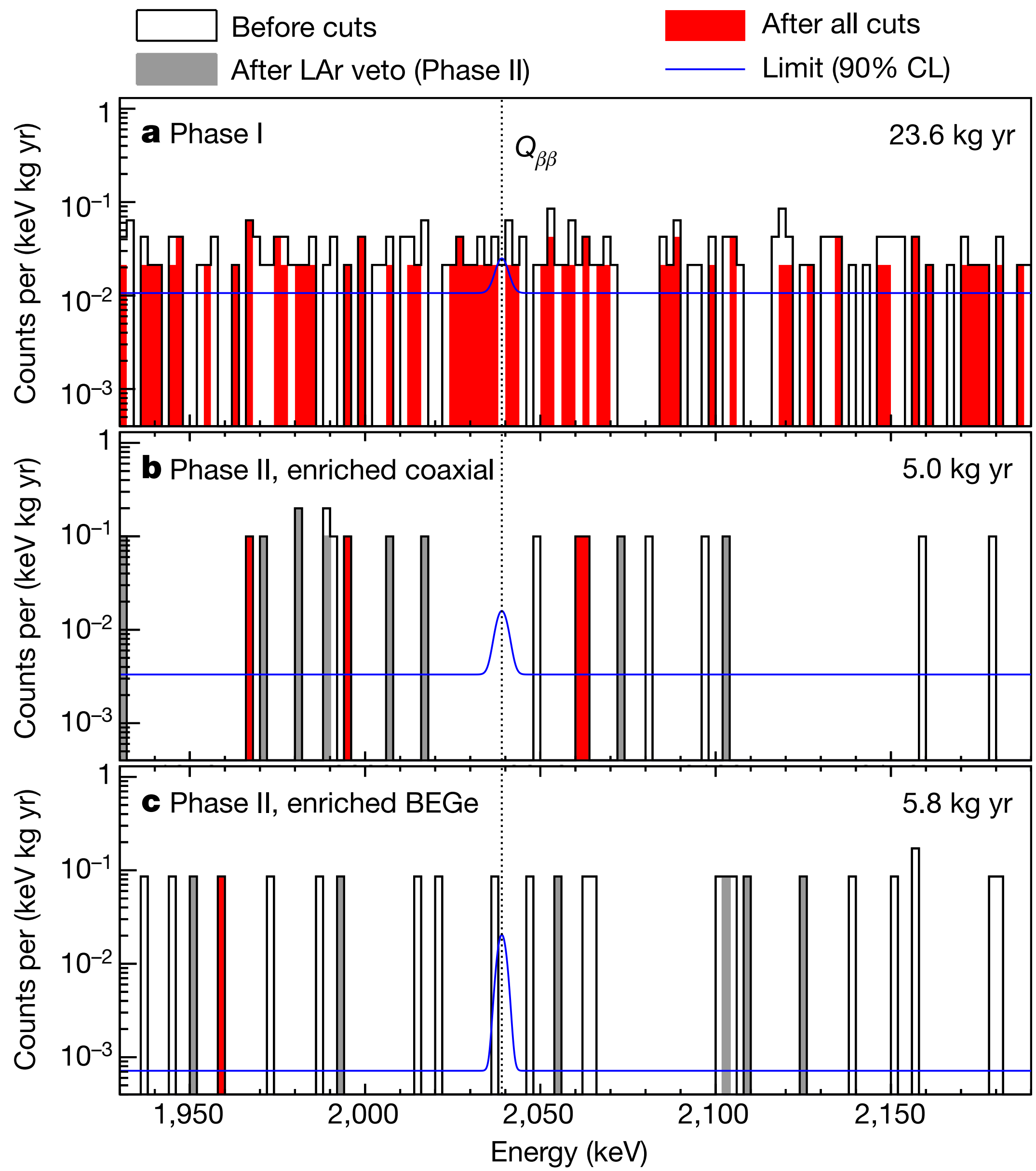
Phase II Background Performance



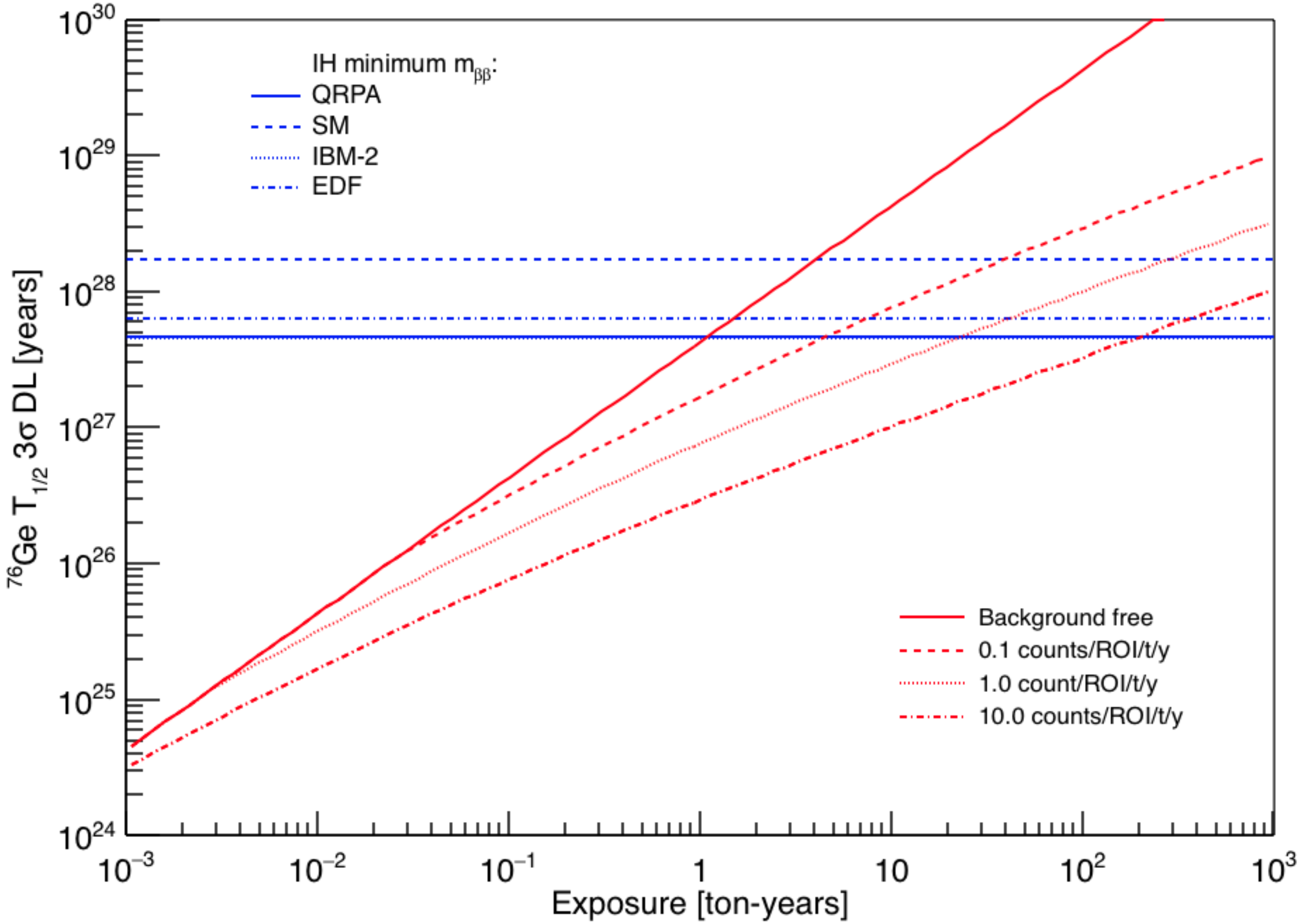
Nature 544, 47–52 (2017).

Phase I + II Results

- Phase I and II Exposure: 34.4 kg y
- Projected background from 1930 to 2190 keV window excludes 2104 ± 5 keV and 2119 ± 5 keV. Window of ±20 keV around $Q_{\beta\beta}$ blinded.
- For Phase II BEGes, have achieved "background free" measurement with background index of 1.8 c/(FWHM-t-y) or $(0.6\ ^{+0.6}_{-0.4}) \times 10^{-3}$ c/kky)
- $T_{1/2}$ $(0\nu\beta\beta) \geq 5.3 \times 10^{25}$ years (90%CL)



^{76}Ge Discovery Sensitivity



arXiv:1705:02996

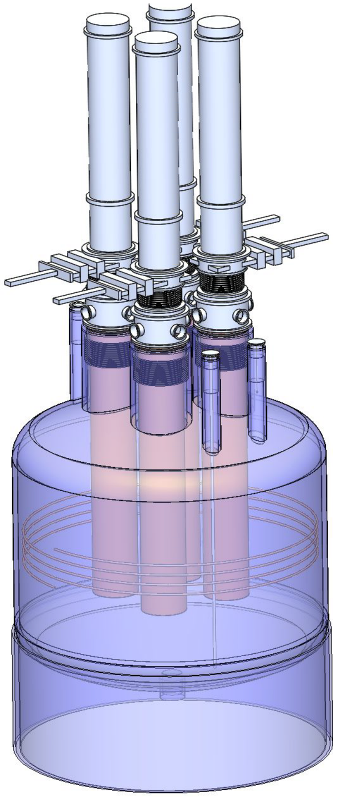
LEGEND: Large Enriched Germanium Experiment for Neutrinoless ββ Decay

Mission: The collaboration aims to develop a phased, ^{76}Ge-based double-beta decay experimental program with discovery potential at a half-life significantly longer than 10^{27} years, using existing resources as appropriate to expedite physics results.

Select best technologies, based on what has been learned from GERDA and the MAJORANA DEMONSTRATOR, as well as contributions from other groups and experiments.

First Phase:
- (up to) 200 kg
- modification of existing GERDA infrastructure at LNGS
- BG goal (x5 lower) 0.6 c /(FWMH t y)
- start by 2021

Subsequent Stages:
- 1000 kg (staged)
- timeline connected to U.S. DOE down select process
- BG: goal (x30 lower 0.1 c /(FWHM t y)
- Location: TBD
- Required depth (^{77m}Ge) under investigation



LEGEND Collaboration

Collaboration formed:
- 1st: Munich April 2016
- 2nd: Atlanta October 2016
- 3rd: LNGS May 2017

47 Institutions
219 Scientists

Univ. New Mexico
L'Aquila Univ. and INFN
Gran Sasso Science Inst.
Lab. Naz. Gran Sasso
Univ. Texas
Tsinghua Univ.
Lawrence Berkeley Natl. Lab.
Leibniz Inst. Crystal Growth
Comenius Univ.
Lab. Naz. Sud
Univ. of North Carolina
Sichuan Univ.
Univ. of South Carolina
Jagiellonian Univ.
Banaras Hindu Univ.
Univ. of Dortmund
Tech. Univ. – Dresden
Joint Inst. Nucl. Res. Inst.
Nucl. Res. Russian Acad. Sci.
Joint Res. Centre, Geel
Chalmers Univ. Tech.

Max Planck Inst., Heidelberg
Dokuz Eylul Univ.
Queens Univ.
Univ. Tennessee

Argonne Natl. lab.
Univ. Liverpool
Univ. College London
Los Alamos Natl. Lab.

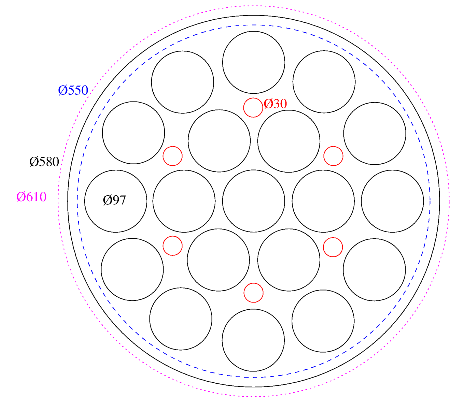
Lund Univ.
INFN Milano Bicocca
Milano Univ. and Milano INFN
Natl. Res. Center Kurchatov Inst.

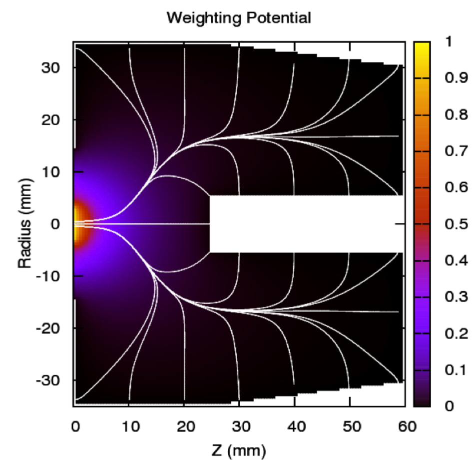
Lab. for Exper. Nucl. Phy. MEPhI
Max Planck Inst., Munich
Tech. Univ. Munich
Oak Ridge Natl. Lab.
Padova Univ. and Padova INFN
Czech Tech. Univ. Prague
Princeton Univ.
North Carolina State Univ.
South Dakota School Mines Tech.
Univ. Washington
Academia Sinica
Univ. Tuebingen
Univ. South Dakota
Univ. Zurich

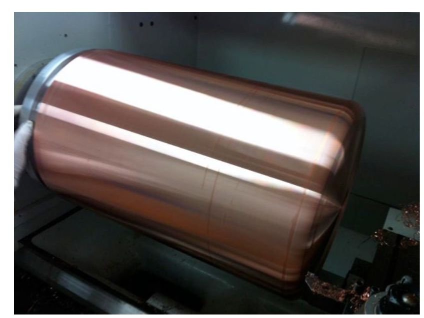

LEGEND collaboration meeting @ LNGS, 15-17.5.2017

LEGEND 200

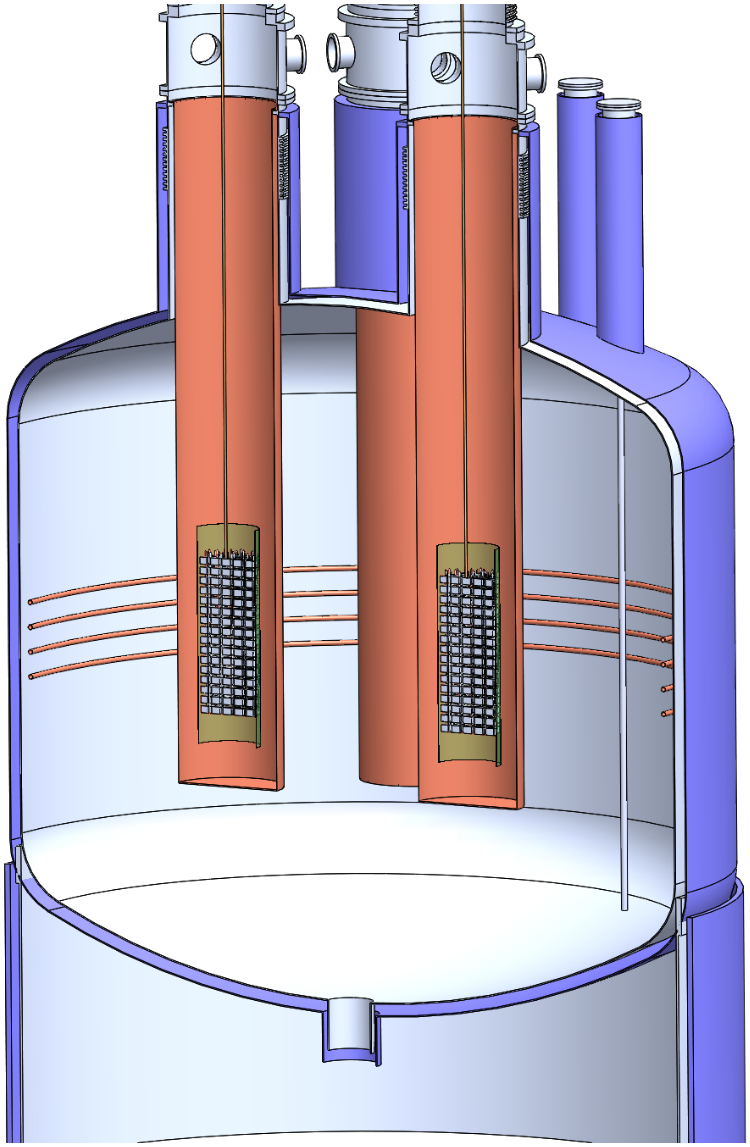
- Reuse existing GERDA infrastructure at LNGS.
- Modifications of internal cryostat piping so can accommodate up to 200 kg of detectors.
- Improvements
  - use some larger Ge detectors (1.5 - 2.0 kg)
  - improve LAr scintillator light collection (2x in test stand)
  - lower mass, cleaner cables
  - lower noise electronics
- Estimate background improvement by ~x5 over GERDA/MAJORANA. Goal: 0.6 cnt/(FWMH t y)
  - intrinsic: including $^{68}Ge/^{60}Co$ all OK
  - external Th/U: cleaner materials based on those used in DEMONSTRATOR
  - surface events: alpha & beta rejection via PSD
  - ^{42}Ar: better suppression & mitigation
  - muon induced: OK
- Contingent upon funding, data taking by 2021







LEGEND 1000: “Baseline Design”

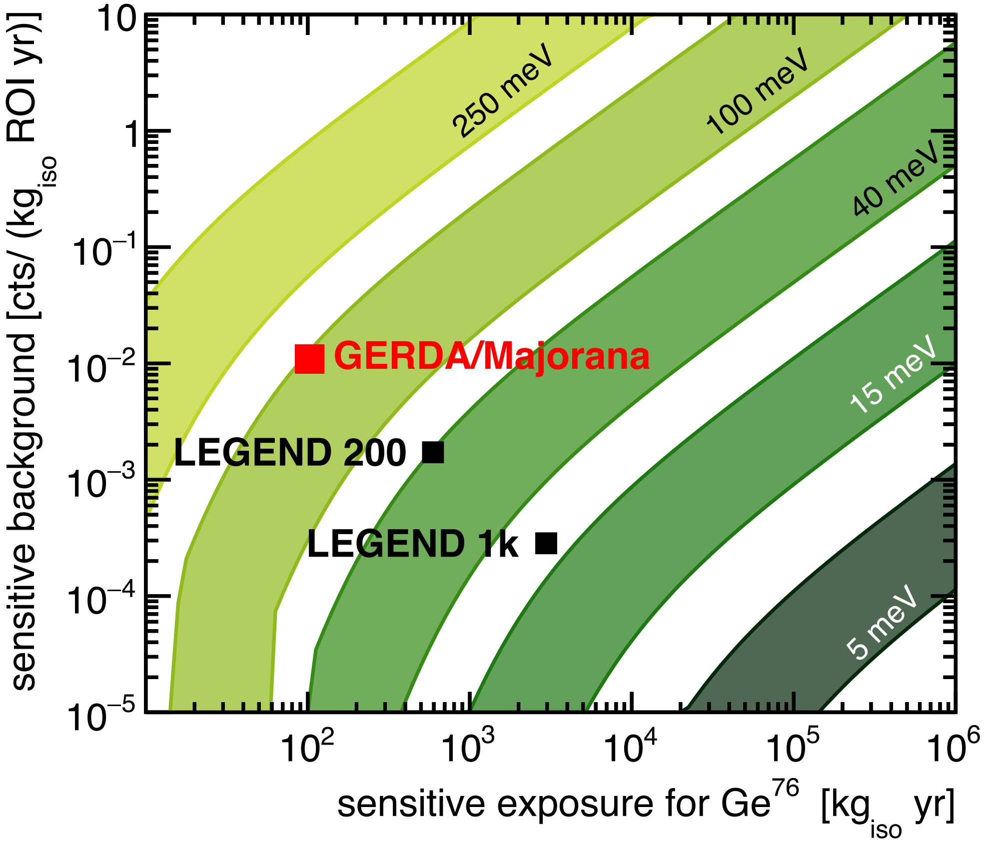


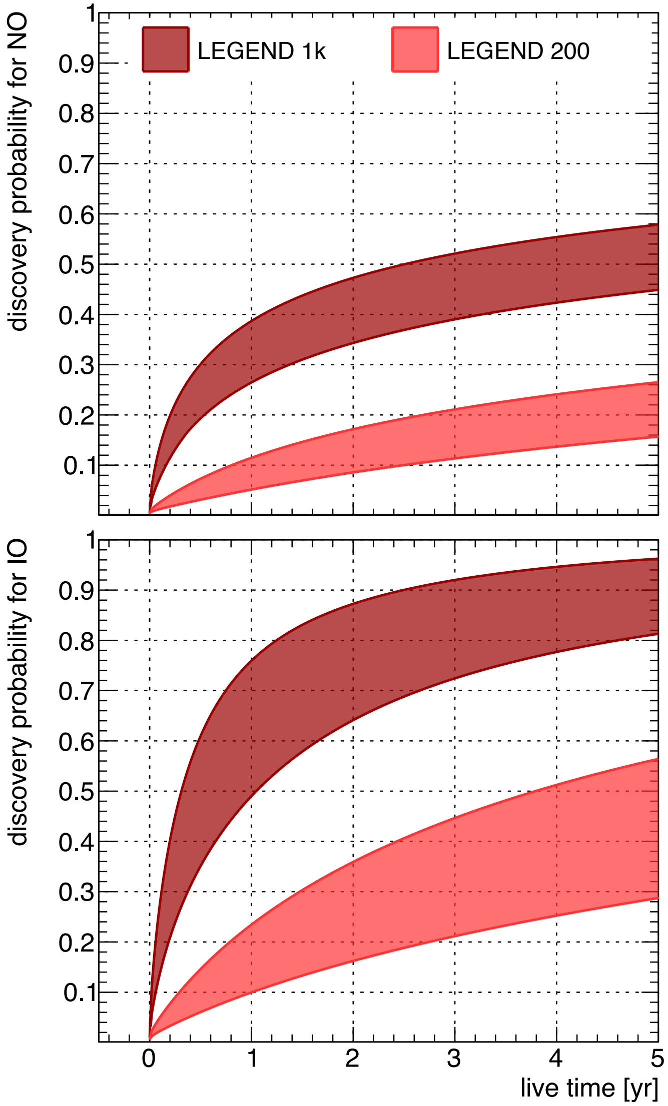
- 1000 kg
- BG goal (x30 lower): 0.1 c/(FWHM t y)
- 4-5 payloads in LAr cryostat in separate 3 m^3 volumes, payload 200-250 kg, with ~100+ detectors.
- Every payload “independent” with individual lock
- LAr detector volume separated by thin (electro-formed) Cu from main cryostat volume.
- Use depleted LAr in inner detector volumes
- Modest sized LAr cryostat in “water tank” (6 m Ø LAr, 2-2.5 m layer of water)

  or

  large LAr cryostat w/o water (9 m Ø) with separate neutron moderator

^{76}Ge Discovery Sensitivity / Probability





arXiv:1705:02996

Summary

- MAJORANA and GERDA are both up and running with their full arrays: combined mass >60 kg ^{enr}Ge, effectively background free
- ^{76}Ge experiments have demonstrated the highest resolution and lowest background of any isotope for $0\nu\beta\beta$ searches
- Covering the inverted hierarchy is in reach for a ton-scale apparatus – planning is underway for LEGEND