Duke University
TUNL Triangle Universities Nuclear Laboratory

LEGEND-1000 Overview

LEGEND
Large Enriched Germanium Experiment for Neutrinoless ββ Decay

NEUTRINO 2024

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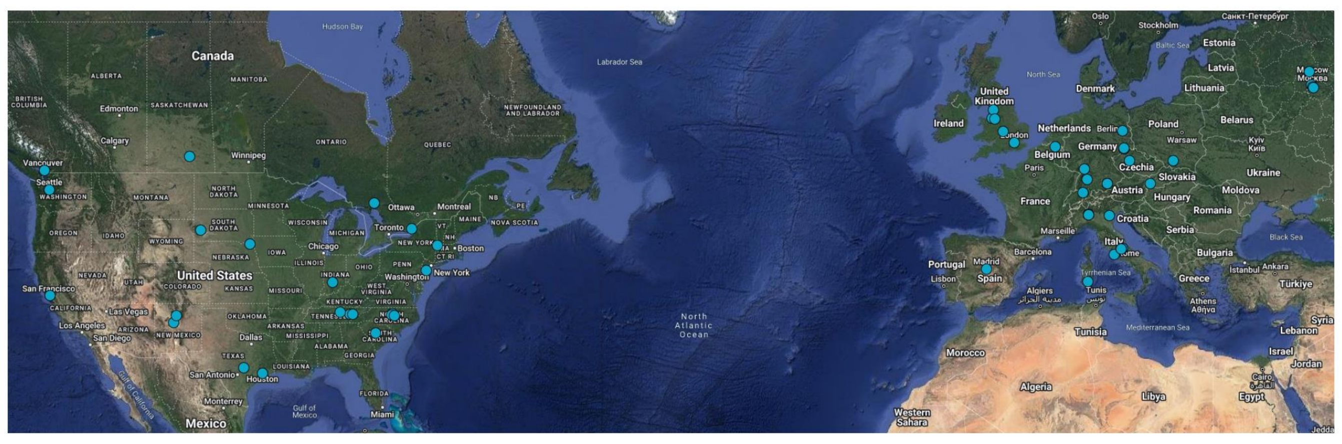

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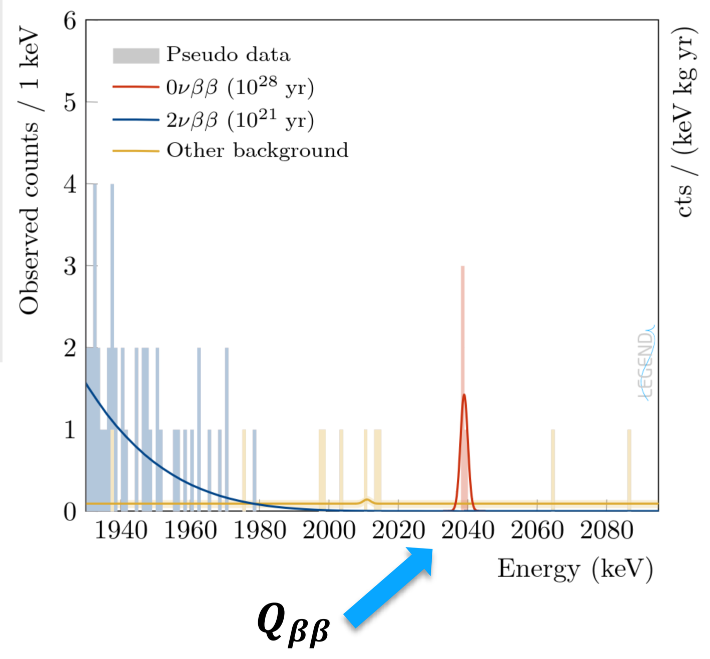
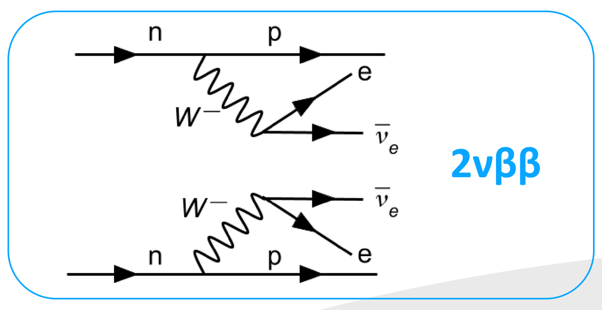
Neutrinoless Double Beta Decay (0νββ)

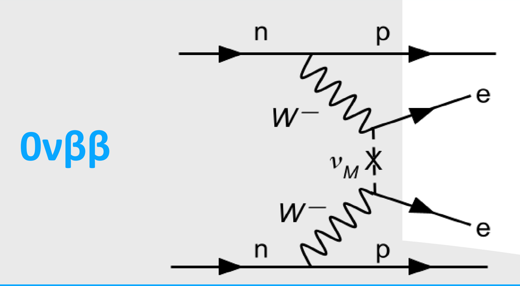
Why search for 0νββ? Discovery would:

- Indicate the Majorana nature of the neutrino
- Demonstrate lepton number violation
- Enable Leptogenesis as an explanation to the matter-antimatter asymmetry
- Give insight into the origin of the neutrino's mass mechanism



0νββ for ^{76}Ge has a clear detection signature: a peak at $Q_{\beta\beta}$ = 2039 keV



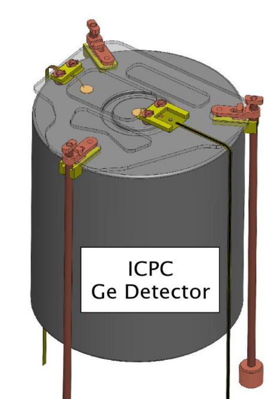


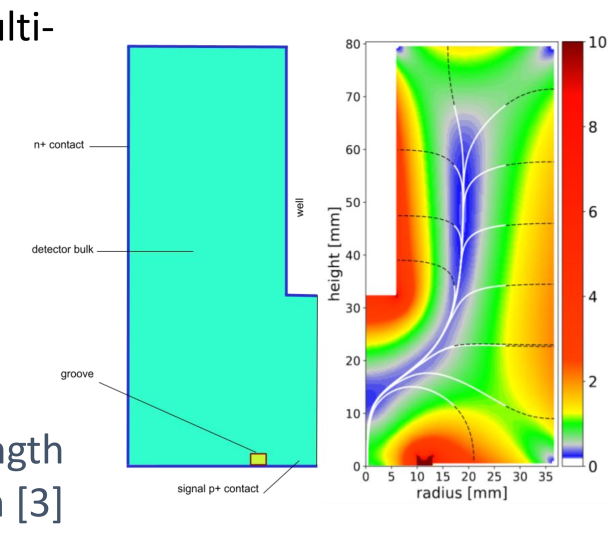
Majorana neutrino is own antiparticle and annihilates

Detector Characterization

The studies needed to measure Inverted Coaxial Point-contact (ICPC) detector performance and background rejection capabilities are [1][2]:

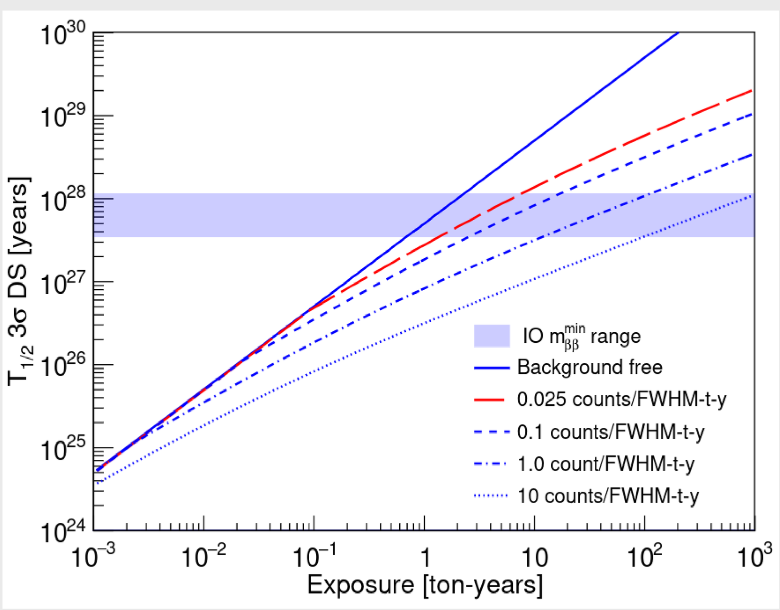
- **Dead layer/Active Volume Determination**
  - Li+ doped detectors have an external "dead layer," which inhibits full charge collection for near-surface events
- **Pulse shape discrimination**
  - Distinction between single-site and multi-site events is crucial for background rejection
- **Diode charge collection/uniformity**
  - Large-size (>3 kg) ICPC detectors are checked for spatially uniform charge collection



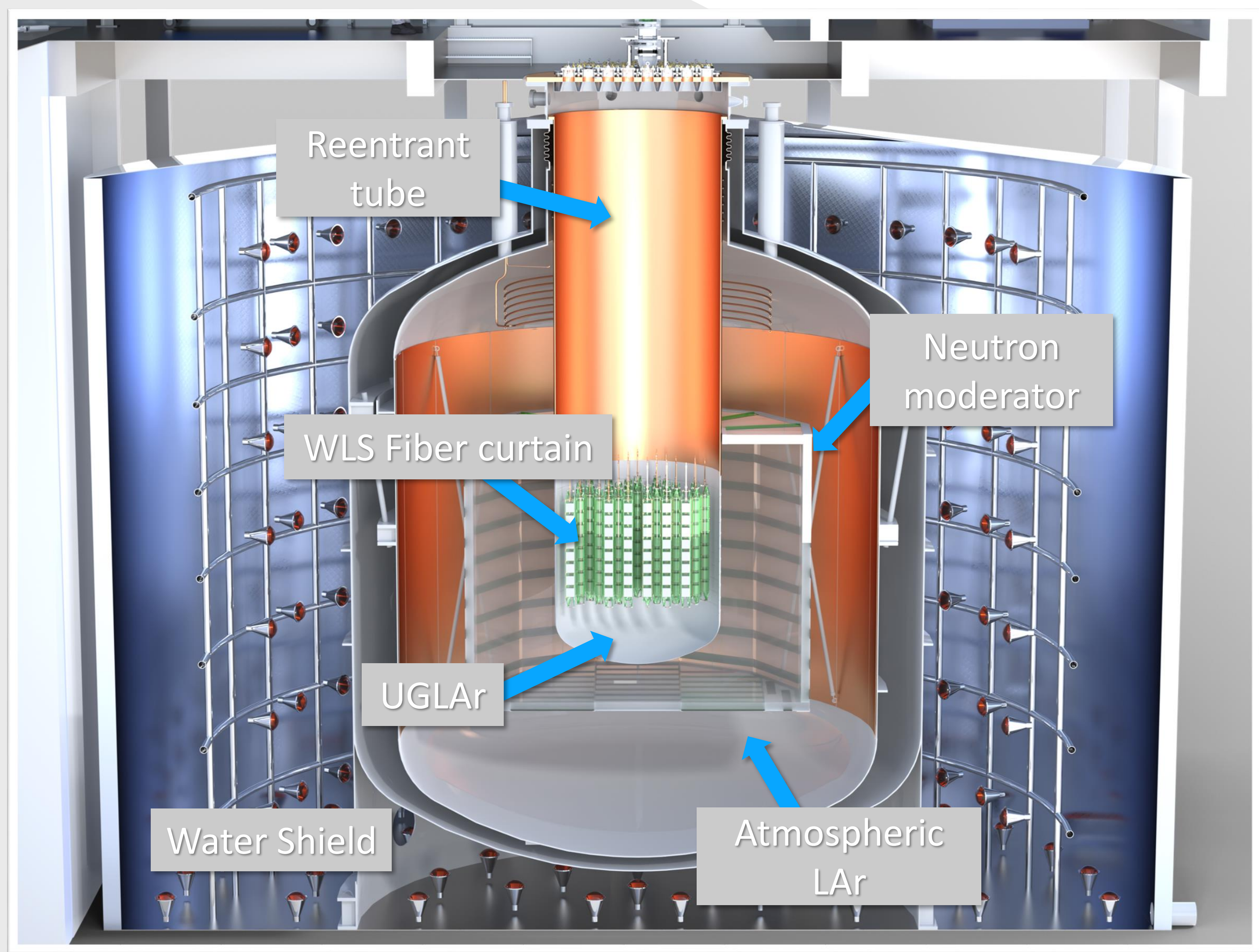


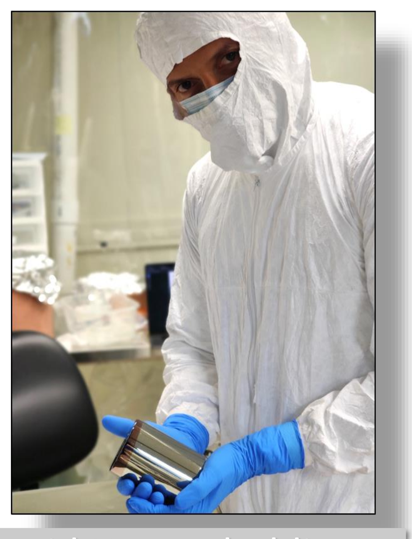
ICPC features (left) and electric field strength (right, kV/cm). Adapted from [3]

LEGEND-1000 Goals



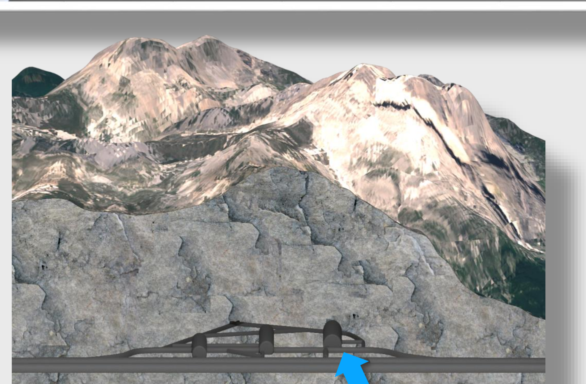
- Deploy **1000 kg of high-purity, ICPC-type germanium detectors**, with > 90% ^{76}Ge enrichment
- Probe ^{76}Ge **0νββ decay half-lives beyond 10^{28} yr** with a 99.7% confidence level discovery sensitivity, defined to be a 50% chance of measuring a signal of at least **3σ significance**, corresponding to a mββ upper limit in the range **of 9 – 21 meV** within 10 yr of live time





David Hervas holding a recently-decryostated ICPC detector

Mariia Redchuk operating an automated scanning stand at HADES (Belgium) [6].



LNGS: L-1000 to be located in Hall C

L-1000 will re-deploy 130 kg of L-200 ICPC detectors and **fabricate 870 kg of new detectors.**

The Ge detector procurement process involves Ge-76 enrichment, Ge metal production & purification, then crystal pulling and ICPC fabrication.

Materials Screening and Assay

L-1000 has stringent radiopurity requirements, so all candidate materials are surveyed for ^{238}U, ^{232}Th, ^{222}Rn (and their daughters). Assay methods include:

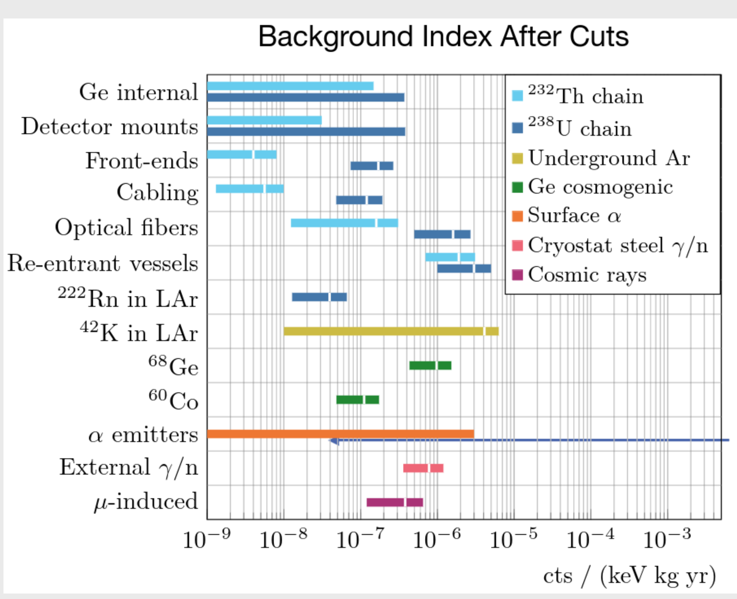
- **Mass spectroscopy**
- **Gamma-Ray Counting**
- **Neutron Activation Analysis**
- **Radon Emanation Analysis**
- **Surface Assays**

Expected throughput: **> 200 samples/yr**

L-1000 Backgrounds

A 3σ discovery potential after 10 ton-years exposure requires a **20x reduction in backgrounds** from L-200. In the 2.5 keV FWHM signal peak, the background index goal is **< 0.025 cts/(FWHM t yr).** To reach this goal:

- Underground LAr
- Only ICPC Ge detectors
- Lower background materials (ASIC front end electronics, lower packing density)
- Improved material handling



Underground Liquid Argon

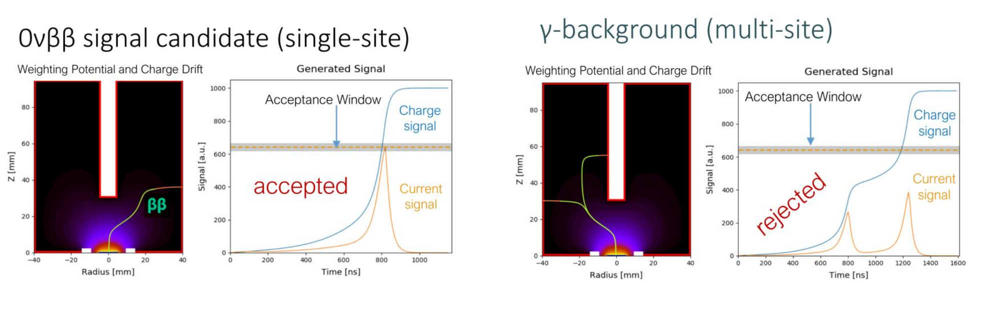
The jump from L-200 to L-1000 will include Underground Liquid Argon (UGAr) in addition to atmospheric LAr, instrumented like before as an active veto with WLS and SiPMs, and used as Ge semiconductor cooling.

^{40}K (from ^{42}Ar) and ^{39}Ar are expected backgrounds from LAr. UGAr has a **1400x reduction in ^{39}Ar** [5].

UGAr is sourced from deep underground CO_2 wells. Following Darkside, L-1000 will commission **30t of UGAr** from the Argon Extraction Facility in Cortez, CO.

Background Rejection

To help separate signal from background, we will utilize **pulse shape analysis, timing coincidences** (LAr scintillation, water-based Cherenkov muon veto), and **inter-detector coincidences.**



Two examples of detector response for 0vBB signal (left) and a potential background event (right).

REFERENCES
[1] E Andreotti et al., JINST 8 P06012 (2013)
[2] M. Agostini et al., *Eur. Phys. J. C* **75**, 39 (2015)
[3] M. Agostini et al. (GERDA Collaboration), Eur. Phys. J. C 81, 505 (2021)
[4] N. Abgrall, et al. (LEGEND Collaboration), arXiv:2107.11462 (2021)
[5] P. Agnes *et al.* (DarkSide Collaboration), Phys. Rev. D **98**, 102006 (2018)
[6] Courtesy of Carmen Romo Luque
[7] Courtesy of I. Guinn

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