# Muon Veto of the LEGEND Experiment

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Bundesministerium für Bildung und Forschung

LEGEND
Large Enriched Germanium Experiment for Neutrinoless ββ Decay

TAUP VIENNA 2023

**Gina Grünauer** on behalf of the **LEGEND collaboration**
*University of Tübingen*
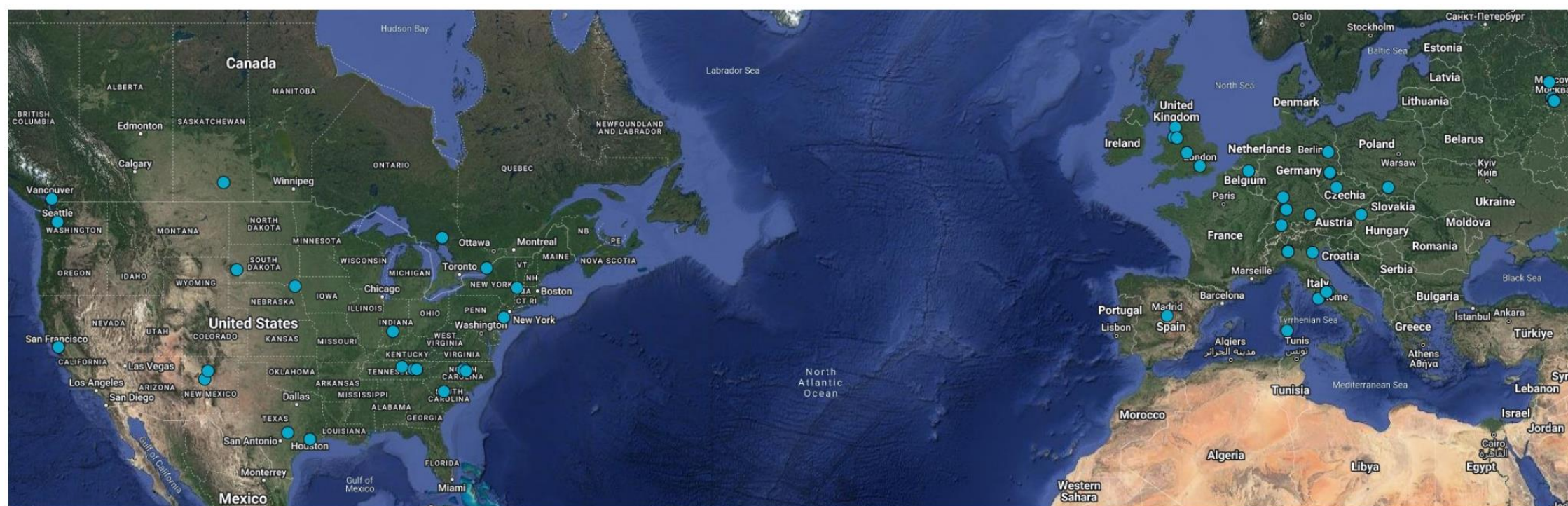
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Comenius Univ.
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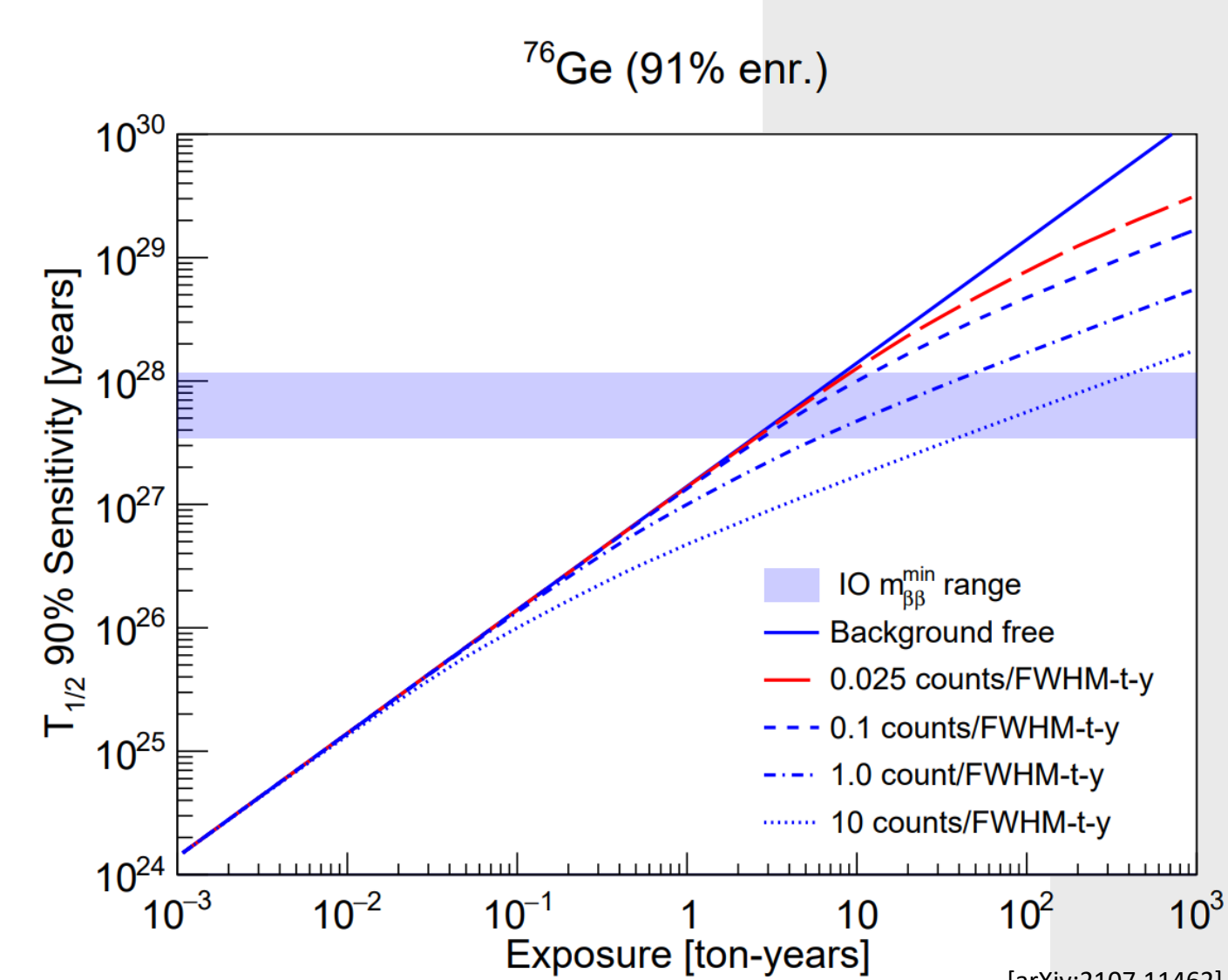Lancaster Univ.
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Univ. of Tuebingen
Univ. of Warwick
Univ. of Washington and CENPA
Univ. of Zurich
Williams College

## LEGEND Experiment

The **L**arge **E**nriched **G**ermanium **E**xperiment for **N**eutrinoless ββ **D**ecay (LEGEND) is an experiment dedicated to the search for the neutrinoless ββ decay of the $^{76}$Ge isotope. The current experimental phase LEGEND-200 is upgraded to 200 kg of High Purity Germanium (HPGe) detectors, surrounded by a Liquid Argon (LAr) Instrumentation and a Muon Veto as active background rejection. It will take data for about 5 years and achieve a sensitivity of $T_{1/2} > 10^{27}$ yr.

The planned experimental phase LEGEND-1000 will deploy 1000 kg of HPGe detectors and achieve an even lower background of around 0.025 cts/(FWHM·t·yr).

The goal is to reach a sensitivity of $T_{1/2} > 10^{28}$ yr.



$^{76}$Ge (91% enr.)

IO $m_{\beta\beta}^{min}$ range
— Background free
— 0.025 counts/FWHM-t-y
— 0.1 counts/FWHM-t-y
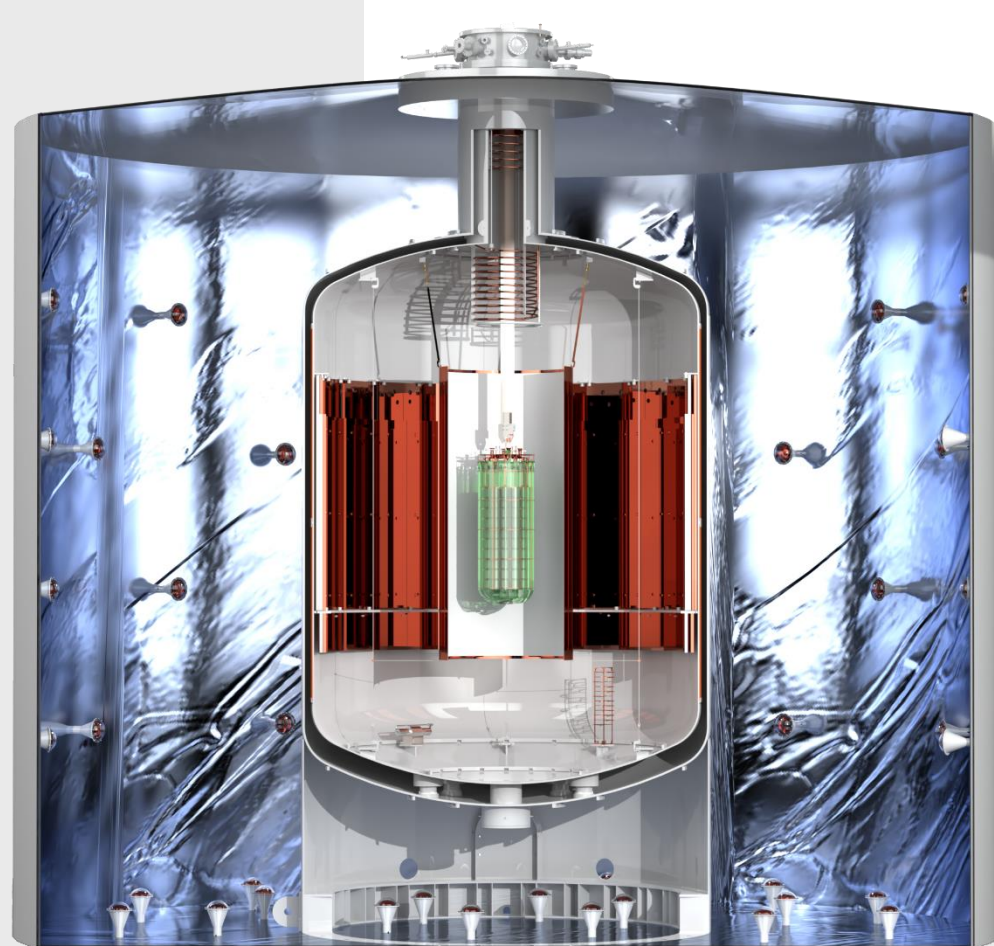— 1.0 count/FWHM-t-y
— 10 counts/FWHM-t-y

[arXiv:2107.11462]

LEGEND-200 (picture on the right) consists of:
**HPGe detectors:** inverted coaxial point contact (ICPC) with an active mass up to 3 kg
**LAr Instrumentation:** background rejection using scintillation light from energy depositions in LAr
**Muon Veto:** Water-Cherenkov-Veto with photomultiplier tubes (PMTs) as light detector

## LEGEND-200 Muon Veto

A Water-Cherenkov-Veto system acts as active background rejection for LEGEND-200. It uses PMTs as light detectors in a water-tank covered with a reflective foil to increase the light yield inside the water. The Muon Veto is reused from GERDA[1]. Some PMT positions were changed to ensure the detection of muons going through the neck of the tank and therefore through the HPGe detectors and the LAr Instrumentation.

GERDA experiment

Therefore, the PMTs of LEGEND-200 have a higher distribution across the Floor and Pillbox (red area on the left) than across the Wall. Their PDE has its maximum at 400 nm.

chimney

6.5m 702
5m 610 609 608 607 606 605 603 602
3.5m 510 509 508 507 504 503 502 501
2m 410 409 404 403 402 401

305 306 305 704
308 307 104 70B 703
309 206 105 102 202
310 207 707 101 203
311 208 201 302
301

PMT map of the Muon Veto at the start of LEGEND-200 (Wall, Floor and Pillbox)

Capsuled PMT inside the water tank which is covered with "VM2000"

[1]https://www.mpi-hd.mpg.de/gerda/public/2008/c08_ndip08_MuonVeto_mk.pdf

## Muon Veto Calibration



Channel 20 (PMT 303)

pedestal

single p.e. peak

double p.e. peak

During the calibration of the Muon Veto, 5 LED diffuser balls are pulsed to measure the single photoelectron (p.e.) peak of the PMTs. The calibration goal is a gain which corresponds to 30 ADC channels for 1 p.e. This allows peaks of up to 100 p.e. to be measured by a 12-bit ADC. The voltage supplied to the PMTs is changed according to:

$$V_{target} = V \left(\frac{g_{target}}{g}\right)^{\frac{1}{kn}}$$

with $n = 12$ Dynodes, $g_{target} = 30$ ADCs, the gain $g = \frac{Q}{e}$, the supplied voltage $V$, constant $k$

## Muon Veto Events

Muon induced events seen by the Muon Veto are selected by two cuts (see plot on the right):
- The so called "low multiplicity bump" caused by scintillation of the reflective foil is cut out by $multiplicity \leq 12$ and a $p.e. \leq 30$.
- Nonphysical data is cut out by $\frac{p.e.}{multiplicity} \leq 0.4$.

Integral light p.e. vs. multiplicity of period p03-p04

LEGEND Preliminary

— cuts for not physical data
— cuts for low multiplicity bump

Muon rates per day for all PMTs of period p03-p04

LEGEND Preliminary

period p03    period p04

The corresponding muon rates of the PMTs are shown per day of data taking.

The peak on the 4th of April 2023 is caused by a broken PMT on the Wall, which was flashing while it was breaking.

Otherwise, the rates are stable and lead to a total muon rate of around 35 mHz.

## Muon Veto Pillbox Efficiency

The rates of the muon events detected by the LAr/HPGe detector system and the Muon Veto are stable during the runs. They increased once due to the enabled LAr trigger since period 04. The rates show the importance of the Pillbox (PB), which consists of 10 PMTs placed directly below the cryostat and detects around 70.8% of the muons measured by the Muon Veto and the LAr/HPGe detector system.

Muon event rates of LAr/HPGe and MV compared with muon event rates of LAr/HPGe and MV PB

— muons of LAr/HPGe&MV
— muons of LAr/HPGe&MV PB

period p03    period p04

## Plans for the Muon Veto of LEGEND-1000



Schematic representation of outer Muon Veto and inner Neutron Tagger around the Cryostat of LEGEND-1000

The Muon Veto of LEGEND-1000 will be built in a larger tank due to the 5 times higher detector mass. This will bring changes compared to the current Muon Veto from LEGEND-200. Furthermore, there is the consideration to install an additional Neutron Tagger directly around the cryostat to reduce the background from cosmogenic neutrons.

Current plans for the Muon Veto of LEGEND-1000:
- larger tank → more PMTs
- PMTs placed only on Floor and Pillbox
- new reflective foil to avoid low multiplicity bump
- discussions about additional Neutron Tagger:
  - PMTs surrounding the LAr instrumentation
  - increase light yield → Gadolinium water

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