In Search of Majorana Neutrinos

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THE UNIVERSITY OF TENNESSEE KNOXVILLE

LEGEND Large Enriched Germanium Experiment for Neutrinoless ββ Decay

International Conference on High Energy Particle & Astroparticle Physics (ICHEPAP2023)
Saha Institute of Nuclear Physics
Dec 11-15, 2023

Abstract

- It is yet unknown whether neutrinos are Dirac ($\nu \neq \bar{\nu}$) or Majorana ($\nu = \bar{\nu}$) particles.
- Neutrinoless double-beta (0νββ) decay is an extremely rare nuclear phenomenon, which if observed could prove neutrinos are Majorana fermions and provide an estimation of effective Majorana neutrino mass.
- The 0νββ decay reaction, (A,Z) → (A,Z+2) + 2e−, violates lepton number conservation by two units, hence the decay is forbidden in the Standard Model.
- Observation of neutrino oscillations tells us that neutrinos are massive particles, but such observations cannot measure absolute neutrino mass so other methods are needed.
- Detection of 0νββ is extremely challenging since it requires quasi background free experiments.
- The KamLAND-Zen experiment sets the most stringent limit on the half-life of 0νββ decay: $T_{1/2}^{0\nu} > 2.3\cdot10^{26}$ yr.
- Recently the new experiment LEGEND-200 started collecting data.
- New large-scale upcoming experiments, e.g., LEGEND-1000, nEXO, SNO+, KamLAND-Zen 800, CUPID, are planned.

Are neutrinos their own antiparticles?

Dirac : $\nu \neq \bar{\nu}$, $\Delta L = 0$, Standard Model

Majorana : $\nu = \bar{\nu}$, $\Delta L \neq 0$, Beyond Standard Model

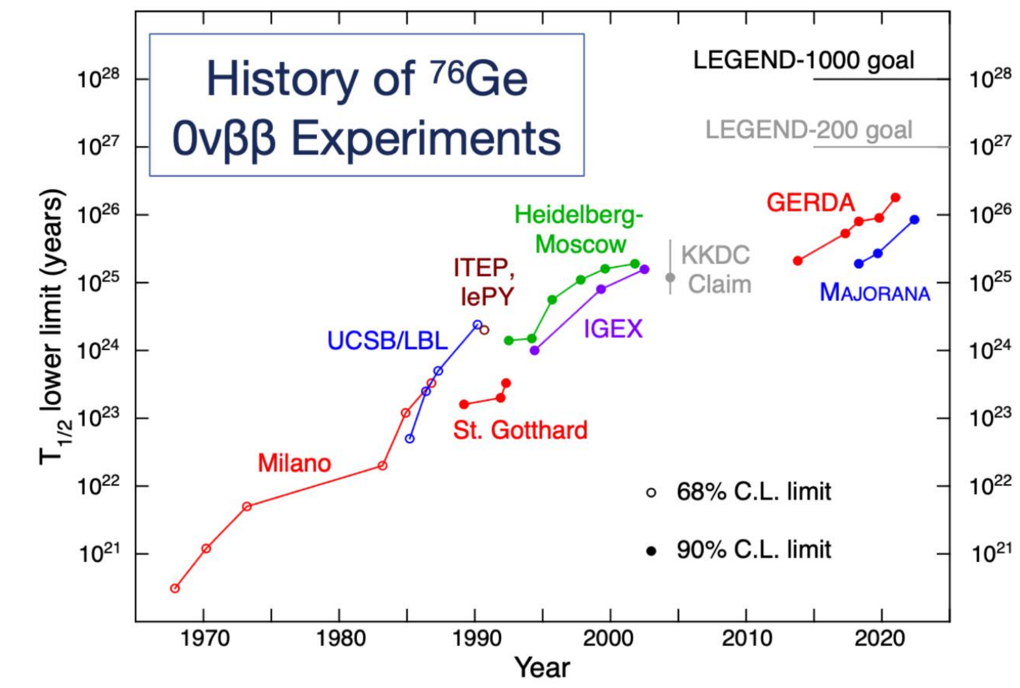
⇓

Motivation for : Leptogenesis : Matter-antimatter Asymmetry

$0\nu\beta\beta$ decay — Neutrino oscillation ($m_\nu \neq 0$)

Observation of $2\nu\beta\beta$ decay

Search for $0\nu\beta\beta$ decay ⇒ Neutrinos are Majorana in nature



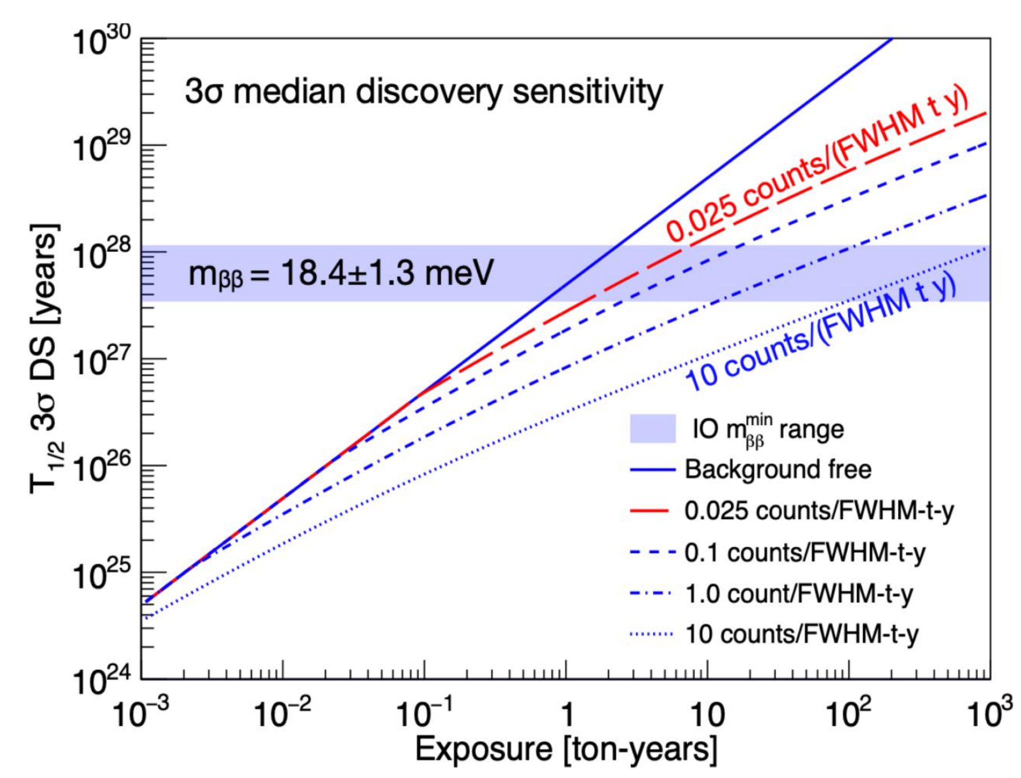
^{76}Ge Experiments, and LEGEND goal, [2].

$$0\nu\beta\beta : (A,Z) \rightarrow (A,Z+2) + e^- + e^-$$

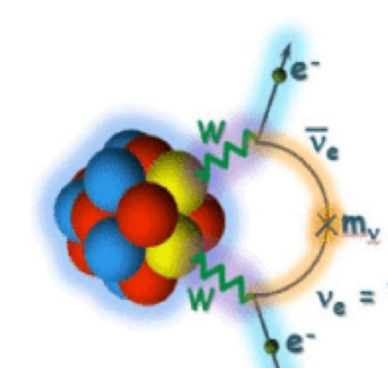
Theory: $$(T_{1/2}^{0\nu})^{-1} = G^{0\nu}\, g_A^4\, |M^{0\nu}|^2\, m_{\beta\beta}^2/m_e^2$$

Experiment: $$T_{1/2}^{0\nu} \propto a\,\epsilon\,\sqrt{\mathcal{E}/(B.\Delta E)}$$

Measurement of half-life leads to neutrino mass.



LEGEND-1000 Sensitivity, [2].



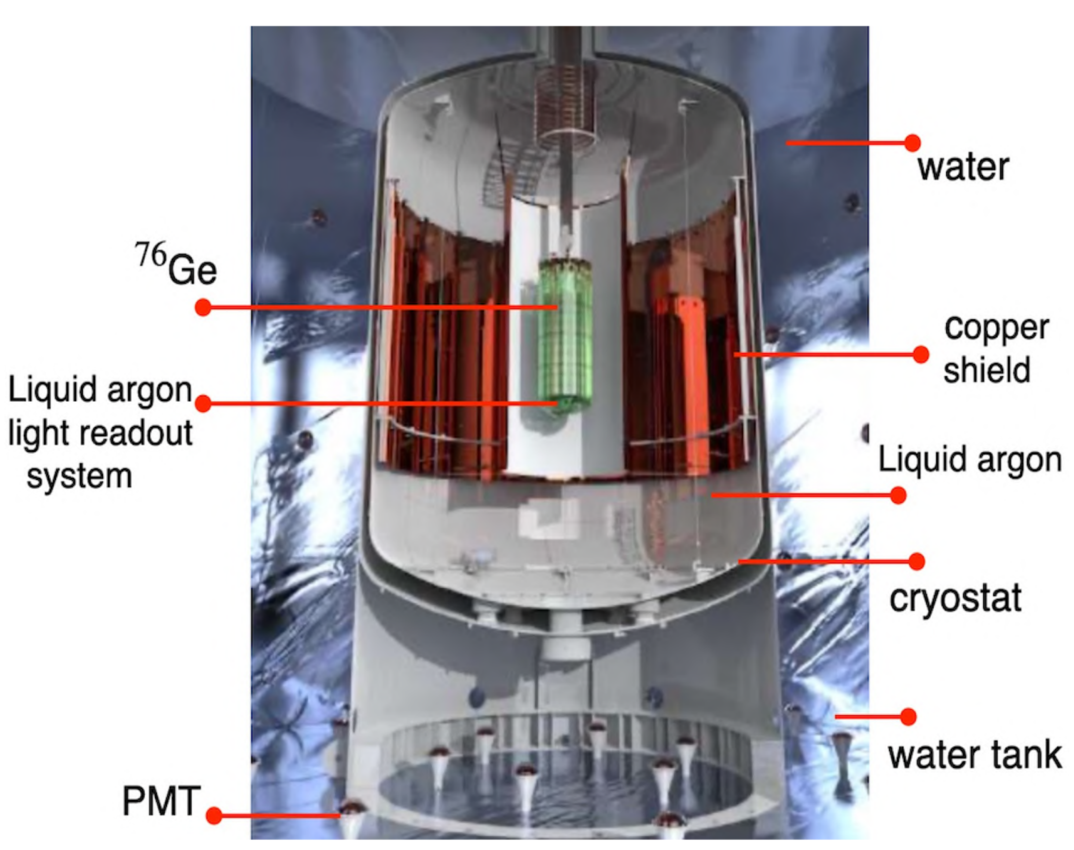
0νββ decay, Credit : CANDLES.

LEGEND-200 Experiment

Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay

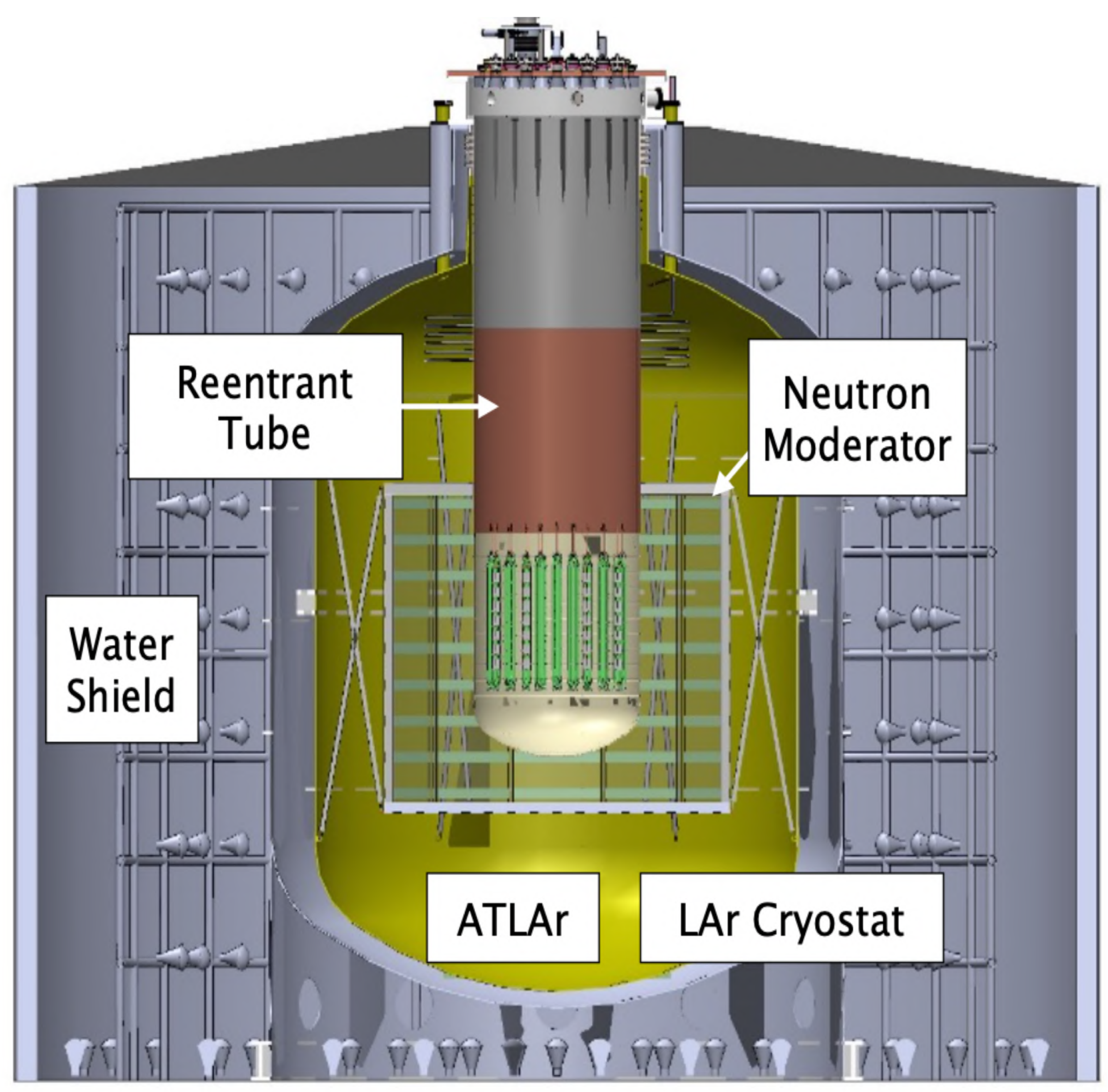
Goal: $^{76}Ge \rightarrow {}^{76}Se + e^- + e^-$

Merger of GERDA and MAJORANA

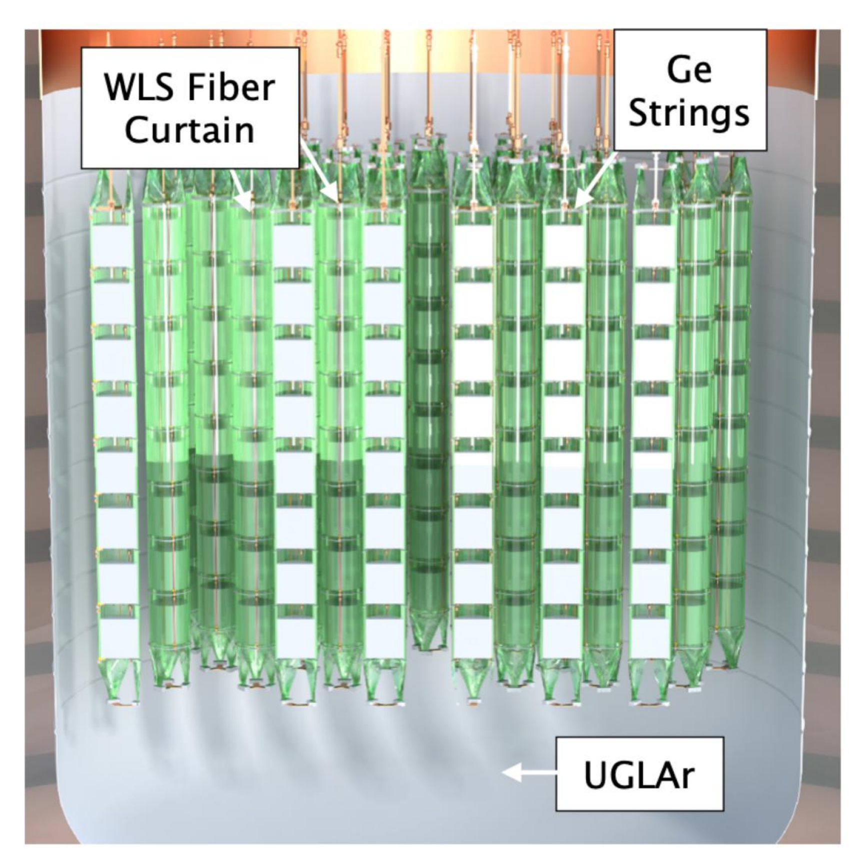


LEGEND-200 Detector at LNGS, [1].

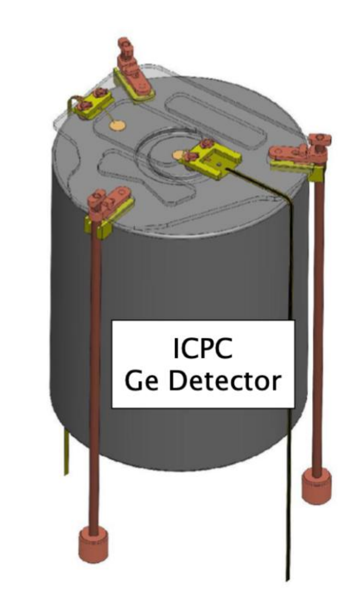
LEGEND-1000 Experiment



LEGEND-1000 Experimental Design, [2].

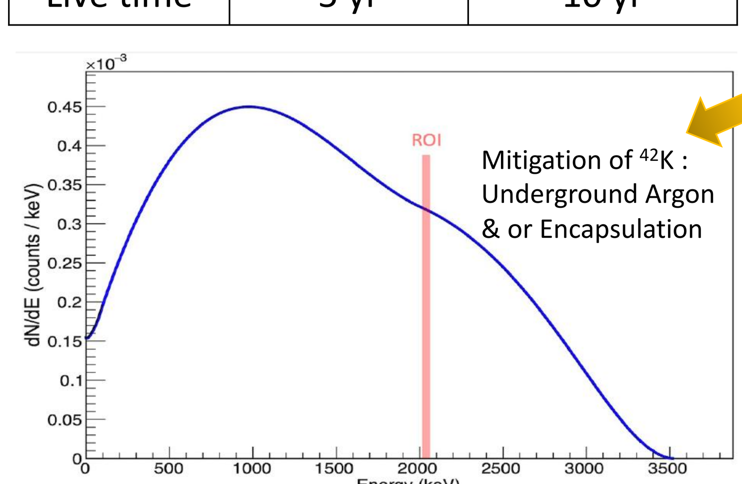


^{76}Ge detector strings will be installed separately in cryostat, [2].

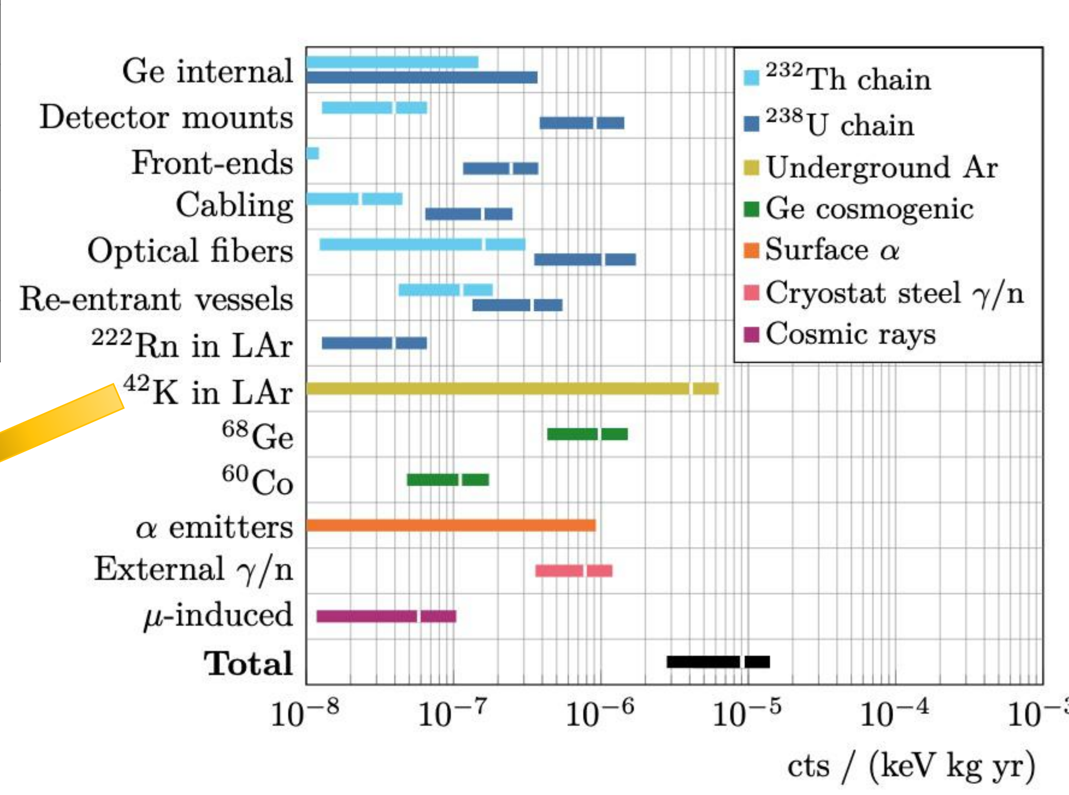


336 Detectors,
3 kg average mass, [2].

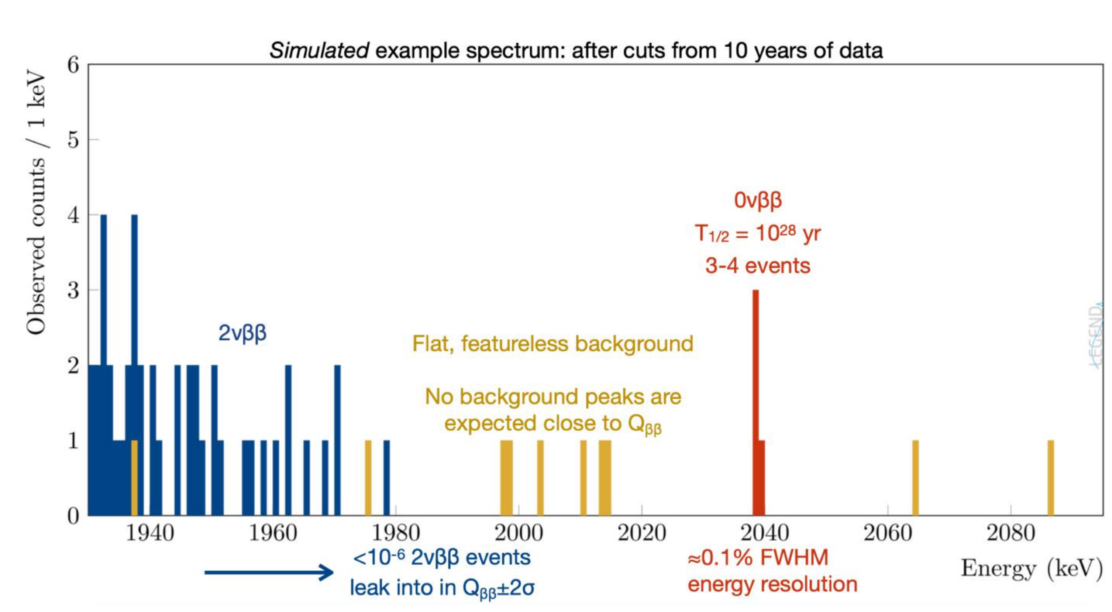
Experiment	LEGEND-200	LEGEND-1000
Status	Data taking	Planned
Location	LNGS	LNGS/SNOLAB
Isotope	^{76}Ge	^{76}Ge
Active mass	200 kg	1000 kg
Discovery sensitivity	10^{27} yr	10^{28} yr
Live time	5 yr	10 yr



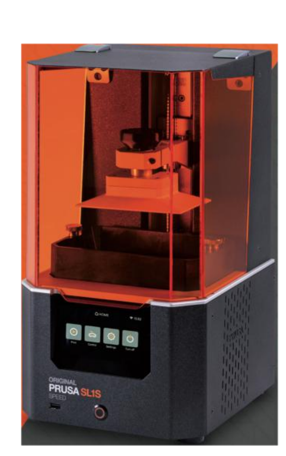
^{42}K beta spectrum overlaps the $0\nu\beta\beta$ decay ROI (2039 keV for ^{76}Ge). Data is taken from [3].



Total Background for LEGEND-1000, [1].



LEGEND-1000 simulated data,[2].



3D printer at ORNL for the development of ultra-pure encapsulation materials for LEGEND-1000.

Experiment	Isotope	Half-life $T_{1/2}^{0\nu}$ (10^{26} yr) [90% C.L.]	Effective Majorana Neutrino mass $m_{\beta\beta}$ (meV)
KamLAND-Zen	^{136}Xe	> 2.3	< 36 - 156
GERDA	^{76}Ge	> 1.8	< 80 - 180
MAJORANA	^{76}Ge	> 0.83	< 113 - 269
EXO-200	^{136}Xe	> 0.35	< 90 - 290
CUORE	^{130}Te	> 0.22	< 90 - 310

Current limits on $0\nu\beta\beta$ decay half-life and effective Majorana neutrino mass.

References:

[1] N. Abgrall et al. (LEGEND), arXiv: 2107.11462 (2021)
[2] V. Guiseppe, (LEGEND), TAUP 2023.
[3] https://www-nds.iaea.org/

Acknowledge:
ORNL LEGEND group, ORNL Physics Division

OAK RIDGE National Laboratory