The neutrinoless double beta decay experiment LEGEND

R&D on wavelength-shifting materials for the liquid argon instrumentation

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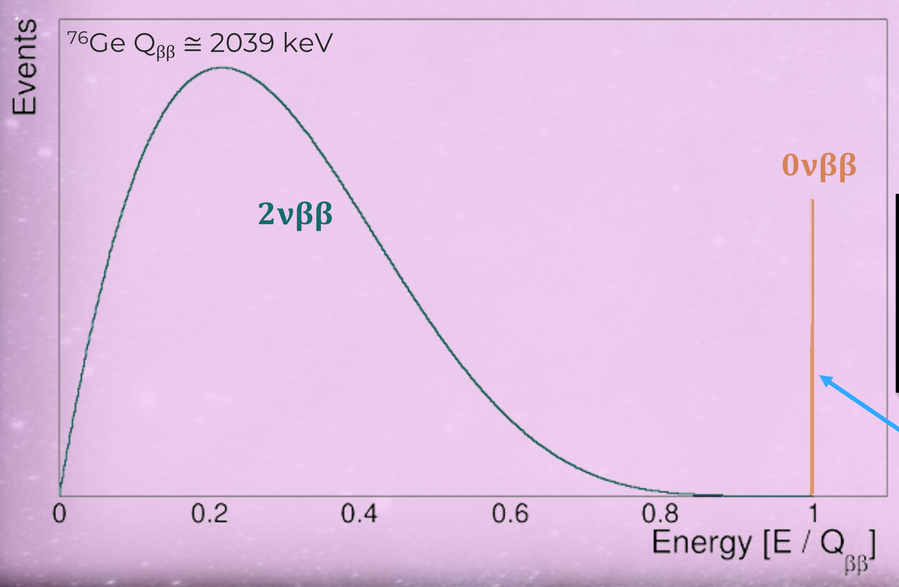
LEGEND — Large Enriched Germanium Experiment for Neutrinoless ββ Decay

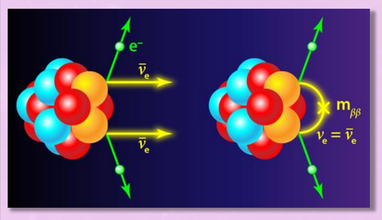
Why does matter dominate over antimatter in the Universe? Despite particle creation and annihilation occur in a balanced manner, the Universe is made almost entirely of matter. Studying neutrinos might lead to the solution of this problem. These elusive particles could be their own antiparticles, violating lepton-number conservation. Built at Laboratori Nazionali del Gran Sasso, Italy, the LEGEND experiment explores the Majorana nature of neutrinos by searching for the rare **neutrinoless double beta decay**.

Physics Goal: Probing the Majorana nature of neutrinos by observing the neutrinoless double beta decay in high-purity germanium (HPGe) crystals enriched in ^{76}Ge.

- Double beta decay (**2νββ**), expected in the SM and observed: two neutrinos emitted **^{76}Ge → ^{76}Se + 2e$^-$ + 2$\overline{\nu_e}$** ($\Delta L = 0$)
- Neutrinoless double beta decay (**0νββ**), beyond SM and not observed so far: no neutrinos emitted **^{76}Ge → ^{76}Se + 2e$^-$** ($\Delta L = +2$)



Lepton-number violating process!



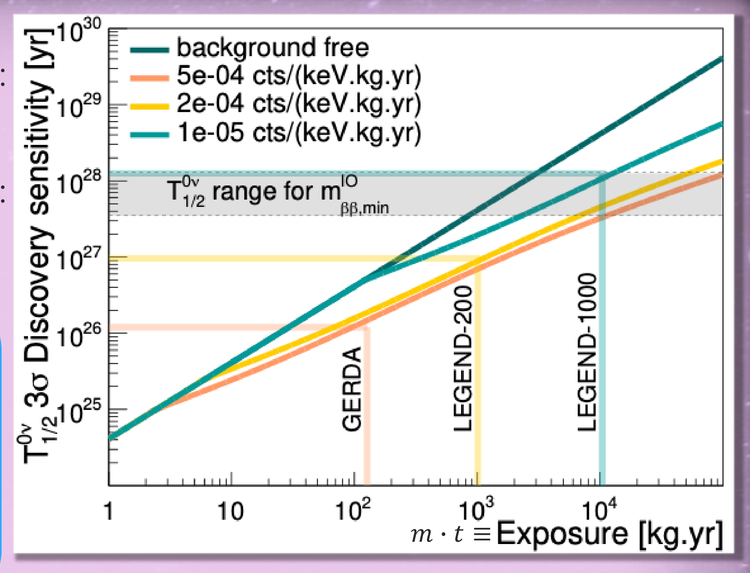
Sensitivity aim:

- LEGEND-200 (5 yr data-taking): decay half life of $T_{1/2} > 10^{27}$ yr
- LEGEND-1000 (10 yr data-taking): decay half life of $T_{1/2} > 10^{28}$ yr

Very rare event!

$$T_{1/2} \propto \begin{cases} m \cdot t & \text{if } BI = 0 \\ \sqrt{\frac{m \cdot t}{BI \cdot \Delta E}} & \text{if } BI \neq 0 \end{cases}$$

with m = detector mass
t = run-time
BI = background index
ΔE = energy range considered



Results of the first year of LEGEND-200 data-taking [1]:
Decay half life of $T_{1/2} > 1.9 \cdot 10^{26}$ yr
BI (90% C.L.) = (5.3 ± 2.2) 10^{-4} counts/(keV kg yr)

Excellent energy resolution (FWHM ~0.1% @ $Q_{\beta\beta}$) + Lower background → Higher chance of discovery

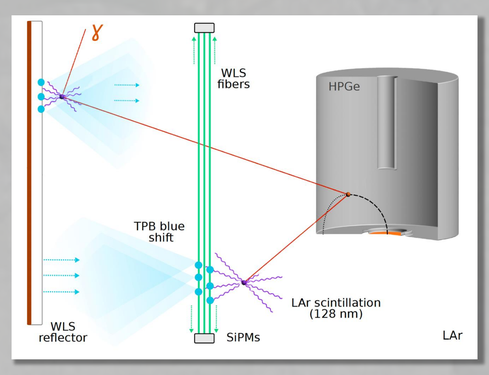
Gran Sasso Mountain overburden (1.4 km) provides shielding from atmospheric muons

LEGEND-200
Currently taking data with ~140 kg of ^{76}Ge detectors immersed in 63 m^3 of liquid argon

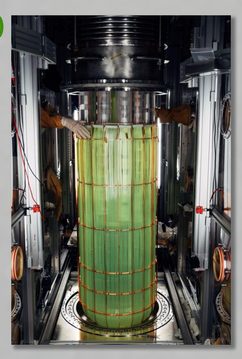
LEGEND-1000
Planned to employ 1000 kg of ^{76}Ge in underground liquid argon. Phased commissioning expected to start in 2030

Liquid argon instrumentation:
Liquid argon (LAr) cools the detectors to 87 K, & serves as both passive shield & active veto:

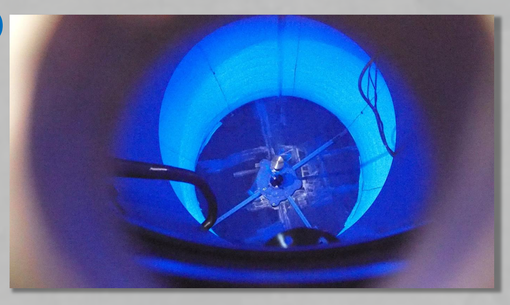
- When energy is deposited by background events in LAr, LAr scintillates in the **Vacuum Ultra Violet** (VUV) range
- The detectors are surrounded by wavelength-shifting **fibers**[(a)] coupled to photodetectors, to shift light to green
- A cylindrical wavelength-shifting Tetratex **reflector**[(b)] surrounds the fibers to enanche light collection, ensuring that light emitted in all direction is captured
- Additionally, detector holders[(c)], made of polyethylene naphthalate, act as wavelength-shifters as well



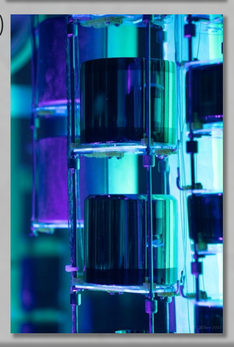
(a)



(b)



(c)



R&D on wavelength shifting reflector (WLSR) materials:
My research is exploring and studying alternative materials to those used in LEGEND-200, offering better performances in light collection efficiency, radiopurity and scalable feasibility, in view of the next phase, LEGEND-1000.

Candidate WLSR materials:

- Polyethylene naphthalate (PEN)
- Thin reflective films based on extruded Polytetrafluoroethylene (PTFE) or High-density polyethylene (HDPE)
- White reflective paints

Properties investigated:

- VUV light reflectivity in LAr (previous important result: [2]. Cryogenic setup @ UZH: [3])
- Radiopurity (assayed by ICP-MS and γ-spectrometer)
- Gas emanation
- Resistance to mechanical stresses & shrinkage level in LAr

[1] LEGEND Collab, *The first year of LEGEND-200 physics data in the quest for 0νββ decay* [Conference presentation], XXXI International Conference on Neutrino Physics and Astrophysics, Milan, Italy, June 18th 2024.
[2] G.R. Araujo et al., *R&D of wavelength-shifting reflectors and characterization of the quantum efficiency of tetraphenyl butadiene and polyethylene naphtalate in liquid argon*, In: The European Physical Journal C 82.5, May 2022.
[3] L. Baudis et al., *Enhancement of light yield and stability of radio-pure tetraphenyl-butadiene based coatings for VUV light detection in cryogenic environments*, In: Journal of Instrumentation 10.09, September 2015.

The LEGEND Collaboration — 56 Institutions, 12 countries, ~300 members