The Large Enriched Germanium Experiment for Neutrinoless $\beta\beta$ Decay (LEGEND)

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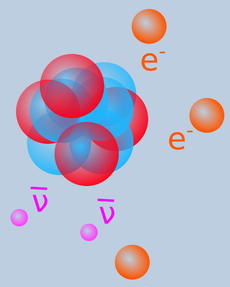
$2\nu\beta\beta$ and $0\nu\beta\beta$ decay

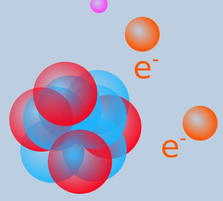
$(A, Z) \rightarrow (A, Z-2) + 2\,e^- + 2\,\bar{\nu}_e$

Two-neutrino double beta ($2\nu\beta\beta$) decay is a second order weak decay allowed in the Standard Model of particle physics (SM) and has been measured in about 10 isotopes.



$(A, Z) \rightarrow (A, Z-2) + 2\,e^-$

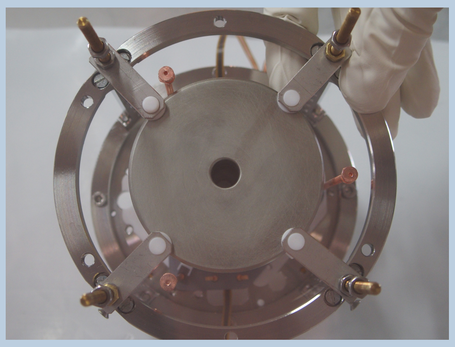
Neutrinoless double beta ($0\nu\beta\beta$) decay is a lepton number violating process with $\Delta L = 2$ and, hence, forbidden in the SM.

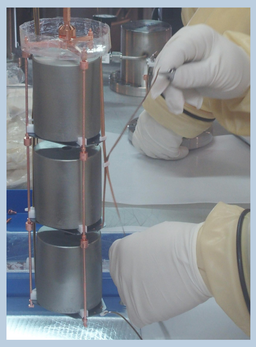


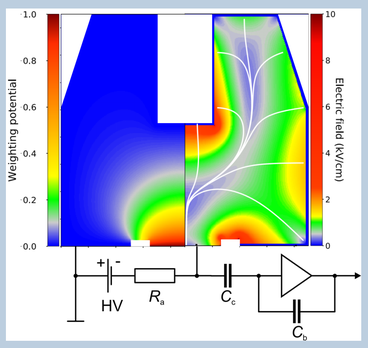
Finding $0\nu\beta\beta$ decay implies new physics beyond the SM and the Majorana nature of neutrinos ($\nu = \bar{\nu}$). This can be an explanation for the smallness of neutrino mass via the see-saw mechanism.

Isotopically enriched IC-HPGe detectors

The detectors which are being produced for LEGEND-200 minimize surface to volume ratio in a configuration that allows for effective Pulse Shape Discrimination (PSD). The Inverted-Coaxial High-Purity Germanium (IC-HPGe) detectors are isotopically enriched to about 88% in the $0\nu\beta\beta$ candidate ^{76}Ge. They are operated as source and detector at the same time which maximizes signal efficiency.

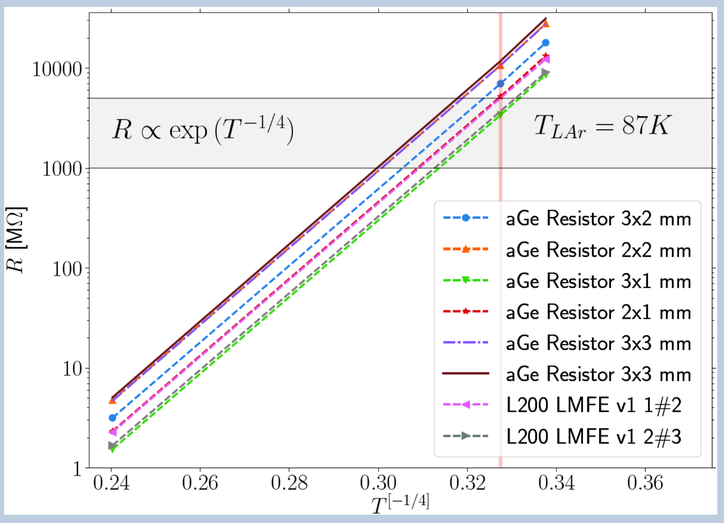


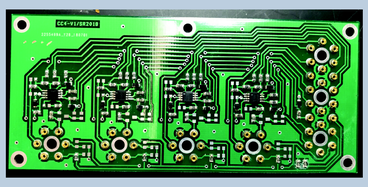




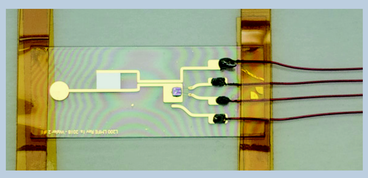
Low-mass front-end electronics

A combination of the Liquid Argon (LAr) operated preamplifier of GERDA with the ultra-clean Low-Mass Front-End Electronics (LMFE) of the MAJORANA DEMONSTRATOR is under development. The LMFE couples an amorphous germanium (aGe) feedback resistor ($1 - 5\,\mathrm{G}\Omega$) to a bare die junction gate field-effect transistor (JFET).





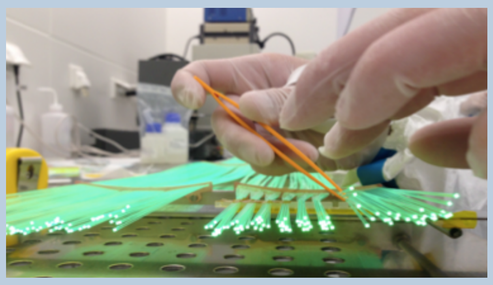
preamplifier operated in LAr

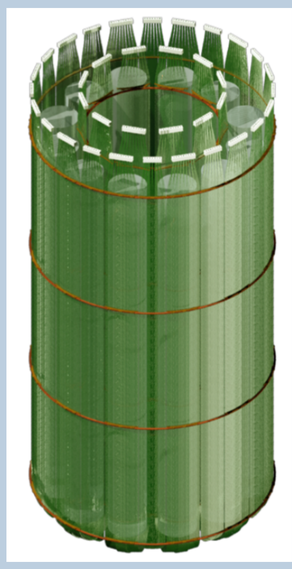


aGe + bare die JFET LMFE

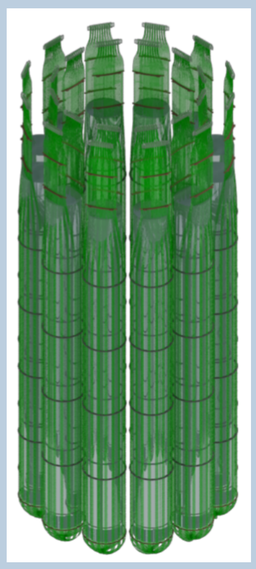
The Liquid Argon (LAr) veto

A LAr veto scintillation light read out via light-guiding fibers coupled to SiPMs has proven successful in GERDA and will be implemented in LEGEND-200. Possible designs are a two-barrel or a string-individual geometry.





two-barrel



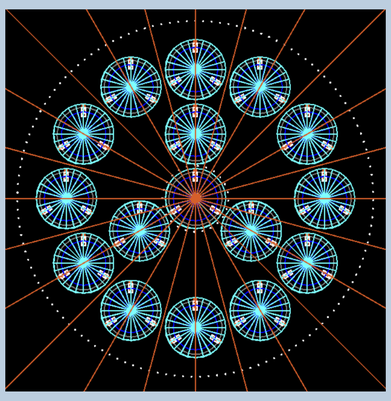
string-ind.

LEGEND-200 setup and time line

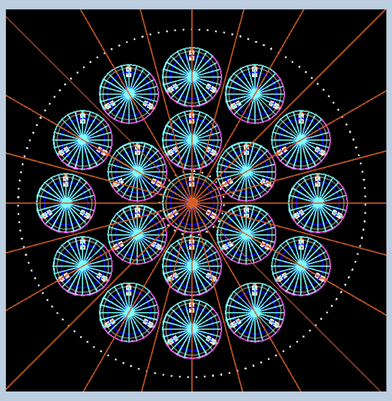
The LEGEND [1] experiment will search for $0\nu\beta\beta$ decay in the candidate isotope ^{76}Ge and most funding for a first stage is already secured. The GERDA [2] and the MAJORANA DEMONSTRATOR (MJD) [3] experiment close data taking beginning of 2020. The existing GERDA facility at Laboratori Nazionali del Gran Sasso (LNGS) will then be modified to host up to 200 kg of HPGe detectors. Start of data taking with LEGEND-200 is foreseen for 2021.

LEGEND-200 detector array

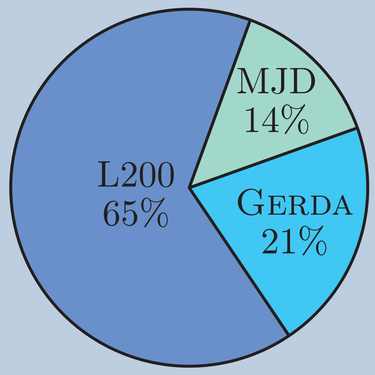
The detectors which are operated in GERDA and MJD at the moment will be incorporated in LEGEND. Detector production in order to complete the 200 kg array of LEGEND-200 will start in spring 2019. All detectors will be characterized prior installation in an extensive characterization campaign.



possible 16-string configuration



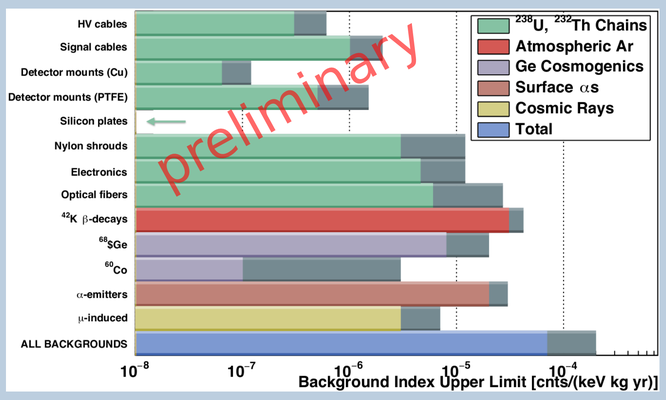
possible 19-string configuration



detector mass fractions L200: prod. start 2019

Background expectation

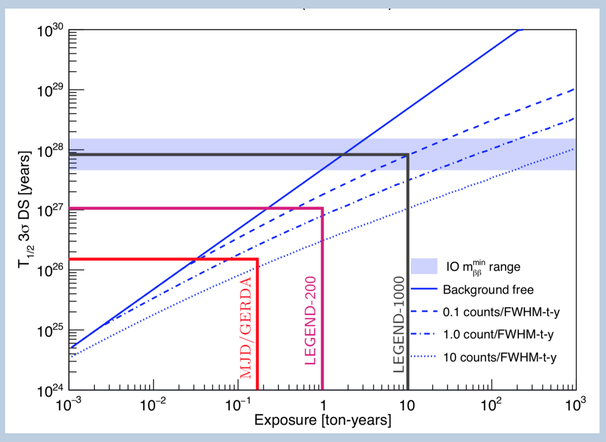
The background contributions due to a variety of structural components in the setup is estimated in Monte Carlo (MC) simulations. Impurity estimates are based on currently implemented material in GERDA and the MAJORANA DEMONSTRATOR.



The total predicted background index is about 10^{-4} cts/(kg keV yr). With FWHM@$Q_{\beta\beta}$ = 3 keV this is equivalent to 0.3 cts/(ton FWHM yr).

Discovery Sensitivity Projection

The LEGEND-200 goal is to reach a half-life discovery sensitivity of $> 10^{27}$ yr (3σ). The ultimate goal is to reach the parameter space of inverted ordering (IO) of neutrino masses which will be achieved with LEGEND-1000. Germanium is particularly adapt for signal discovery thanks to the exceptional energy resolution achievable.



References

[1] The LEGEND Collaboration: *The large enriched germanium experiment for neutrinoless double beta decay (LEGEND)*, AIP Conference Proceedings (2017) 1894:020027

[2] The GERDA Collaboration: *Upgrade for Phase II of the GERDA Experiment*, Eur. Phys. J. C (2018) 78:388

[3] The MAJORANA Collaboration: *Search for Neutrinoless Double-β Decay in ^{76}Ge with the MAJORANA DEMONSTRATOR*, Phys. Rev. Letters (2018) 120:132502