The LEGEND experimental program and HPGe detector development in Canada

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IPP Town Hall

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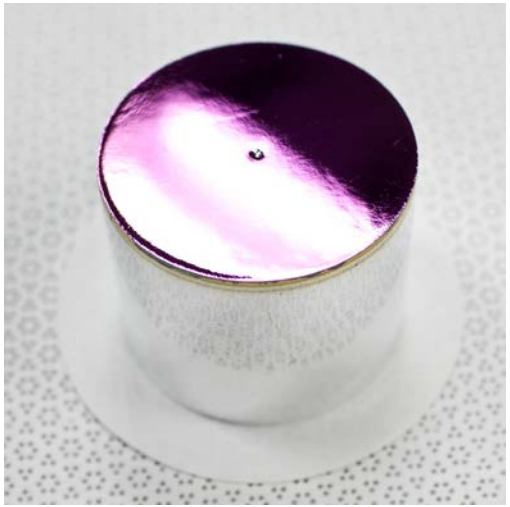


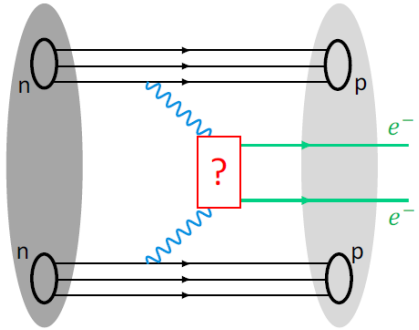
Outline

- Neutrinoless double-beta decay searches in ^{76}Ge
- The LEGEND program
- HPGe detector development
- Current Canadian participation and opportunities

0νββ

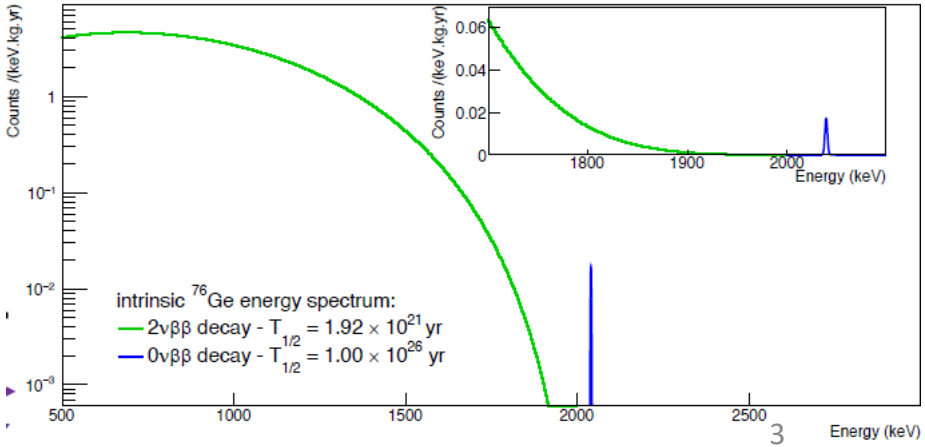
Neutrinoless double-beta decay implies lepton number violation:

- Test for the Majorana nature of neutrinos
- Test mechanisms for matter/anti-matter asymmetry
- Can shed light on neutrino mass scale

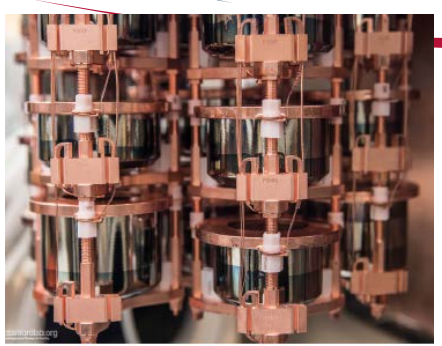


Experimental signature is a peak at Qββ, enhanced by:

- Good energy resolution
- Low backgrounds
- High detection efficiency
- High isotopic abundance



0νββ in ^{76}Ge

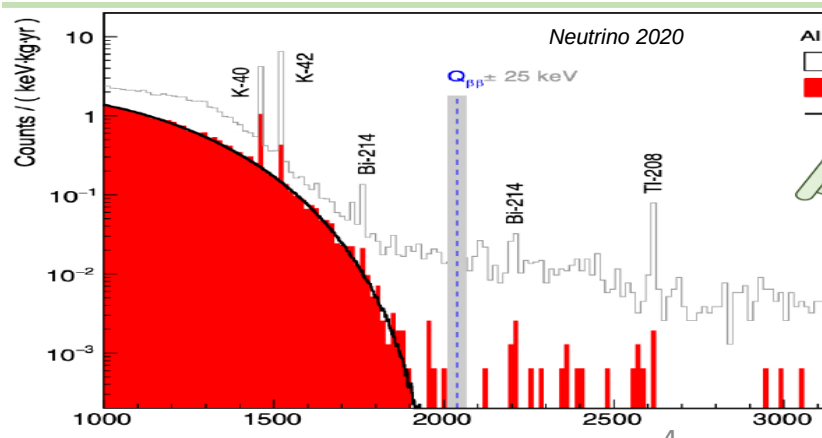


Neutrinoless double-beta decay implies lepton number violation:

- Test for the Majorana nature of neutrinos
- Test mechanisms for matter/anti-matter asymmetry
- Can shed light on neutrino mass scale

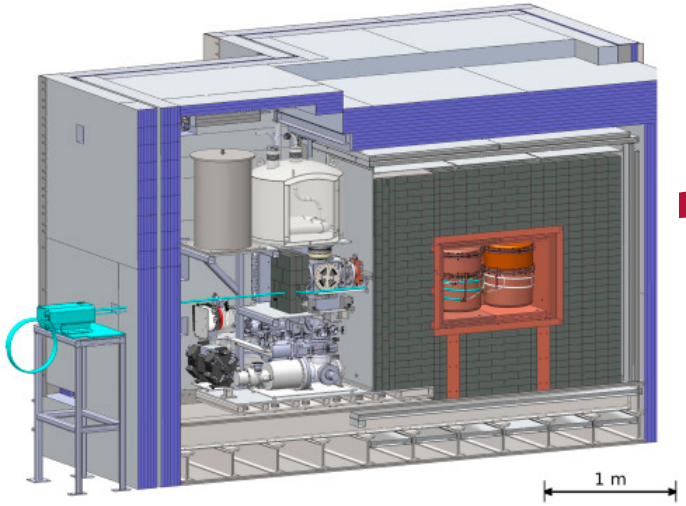
Experimental signature is a peak at 2039keV, enhanced by:

- Good energy resolution [0.13% FWHM Qββ]
- Low backgrounds [$5 \times 10^{-4} \frac{cts}{keV \cdot kg \cdot yr}$]
- High detection efficiency [~ 90%]
- High isotopic abundance [from ~8% to ~90%]

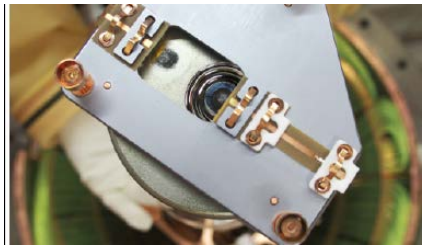


0νββ in ^{76}Ge

- MAJORANA DEMONSTRATOR
  - Primarily US, located at SURF
  - Diodes in vacuum cryostat
  - Use of electroformed copper
  - Low mass front-end electronics, low noise
  - 30kg enriched Ge (PPC)
  - 50kg yr exposure targeted summer 2020



- GERDA
  - Primarily European, located at LNGS
  - Bare diodes in LAr cryostat
  - Water shield around LAr cryostat
  - Electronics in LAr
  - 44kg of enriched Ge (BEGe+ICPC+Coax)
  - 104kg yr exposure attained

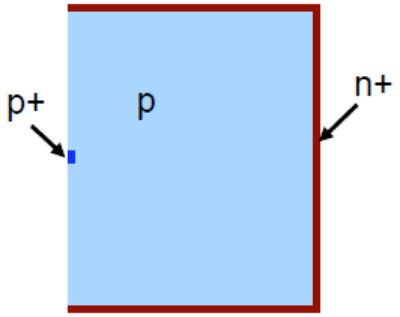


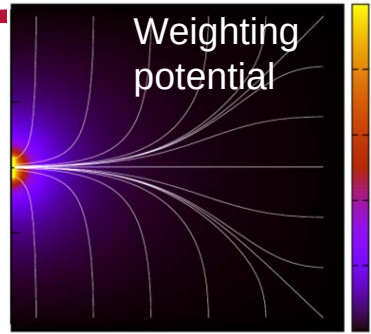
P-type Point Contact Detectors

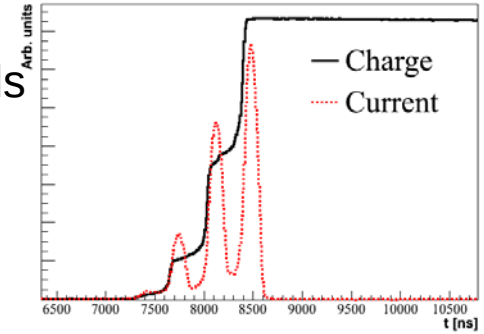
P-type Point Contact detectors made from HPGe, developed in 2008 (Collar and Barbeau):

- ✓ Small point contact to readout charge, low capacitance → low electronic noise
- ✓ Thick n+ outer contact attenuates backgrounds (e.g. alpha/beta)
- ✓ Large variation in drift time across volume leads to multi-site event rejection

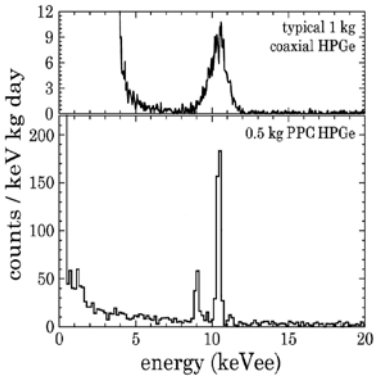
→ Used to search for neutrinoless double-beta decay, dark matter, coherent neutrino-nucleus elastic scattering







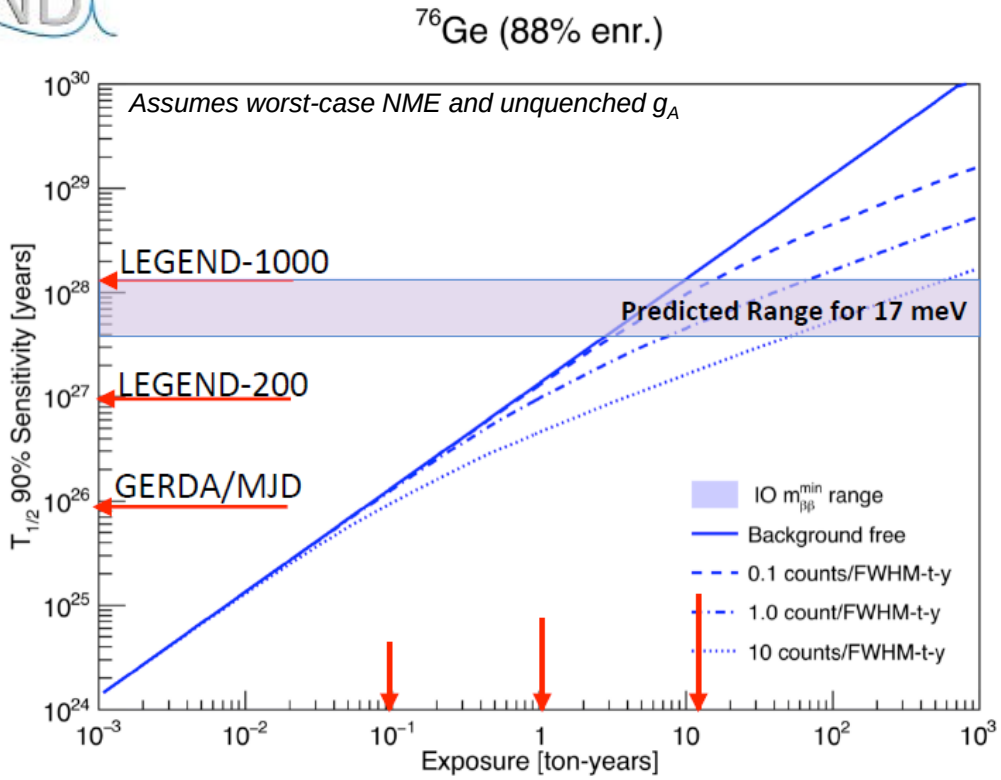
A multi-site event is easily rejected



A lower energy threshold, and better energy resolution compared to a coax

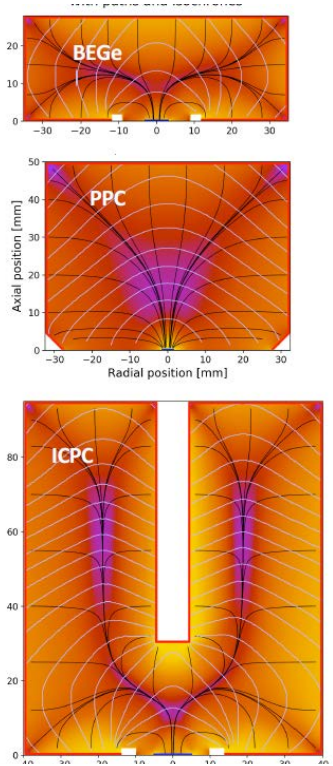
The LEGEND experimental program

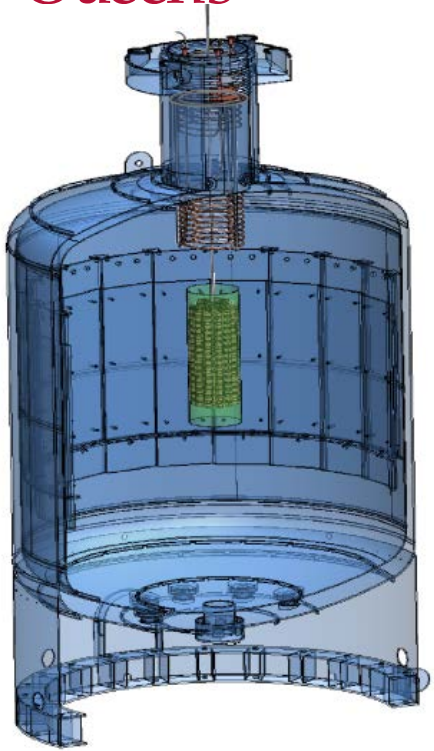
- Large Enriched Germanium Experiment for Neutrinoless ββ Decay
- 54 institutions, ~250 collaborators worldwide (Europe, US, China, Canada)
- In order to probe larger half-lives, need larger exposures while continuing to reduce backgrounds
- ~200kg scale experiment, LEGEND-200, will extend half-life sensitivity to 10^{27} yr
- ~1000kg scale experiment, LEGEND 1000 to extend to 10^{28} yr → Probe the bottom of the inverted hierarchy



LEGEND-200

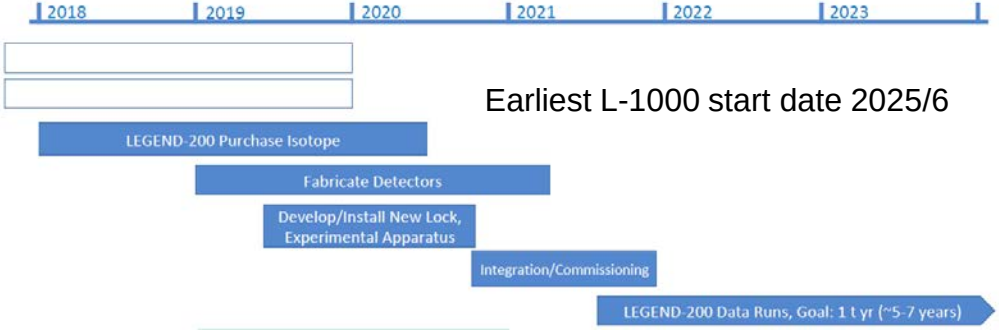
- Re-using existing GERDA infrastructure at LNGS
- Target 14-17 strings of detectors for a max diameter of 550mm (800mm neck)
- Started testing, 9 detectors, new DAQ, new head electronics, first calibrations March 2020
- Changes:
  - Large increase in number of readout channels
  - New electronics and cables, lower noise
  - Higher purity LAr, better readout
  - New detector types, larger masses, thicker n+ contacts
  - Expect 5x background reduction compared to MJD/GERDA



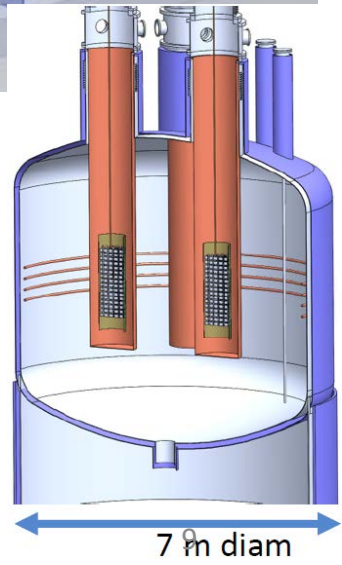


LEGEND-1000

- Preliminary design stage, targets a phased approach to reach 1000kg, with 4 x 250kg modules. One module approximately the same as L-200.
- Project imbricated in US downselect
- SNOLAB used for baseline design. Timeline: 2025-2040
- Each payload surrounded by depleted LAr (42-K background), 100 tons total depleted LAr

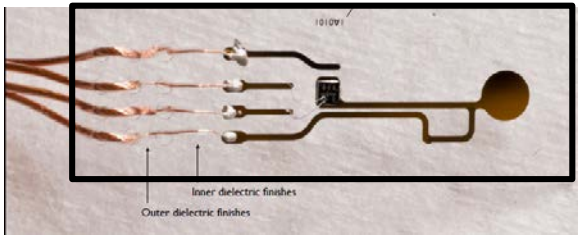


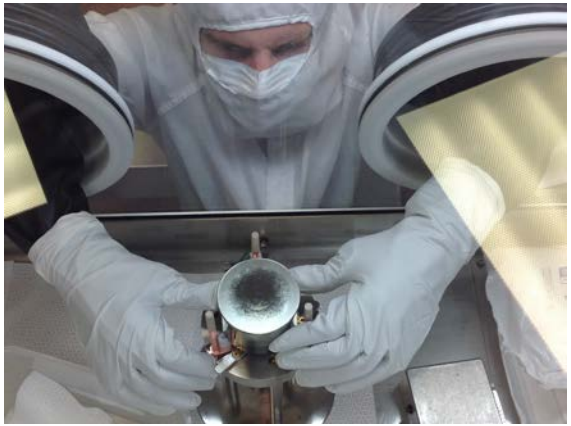
Earliest L-1000 start date 2025/6



LEGEND in Canada

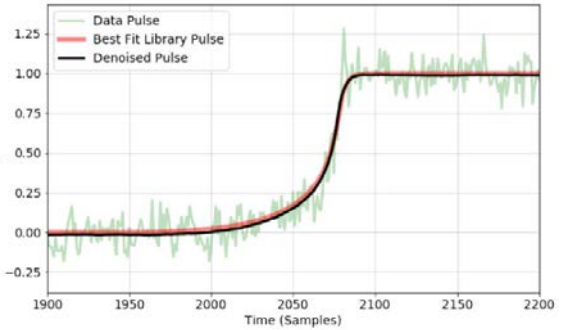
- Only 1 group in Canada: PI: Ryan Martin (Queen's)
- Background and interests:
  - Characterization and development of PPC detectors, mounts, and electronics for MJD
  - Assembly of detectors for MJD
  - Software and analysis
- Currently "ramping up" on LEGEND with hire of PDF in March 2020, work with detector characterization group

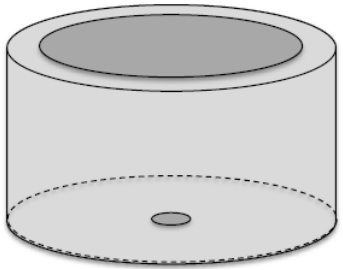


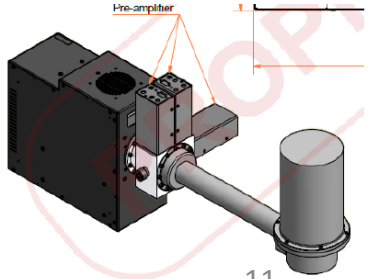


PPC Detector lab at Queen's

- PPC detector characterization facility:
  - Understand surface events in PPC detectors (1kg OPPC, 2.4kg LPPC)
  - Understand charge transport in large PPC detectors
  - Develop better models of signal formation
  - Develop machine learning tools for analysis
  - Develop capacity to establish L-1000 characterization facility in Canada
  - Develop LAr detector test stand







Opportunities for LEGEND in Canada

- LEGEND-1000 may be one of few next generation $0\nu\beta\beta$ experiments. If sited at SNOLAB, it will be a **large effort in Canada**, and a good opportunity for Canadian particle physicists to take leadership.
- We have a lot of relevant experience in Canada, and there are many synergies between LEGEND and other projects.
- Canadians could take leadership for a subsystem in LEGEND, for example
  - LAr purification facilities and systems
  - Detector characterization facility
  - Large scale assaying
- Need 3-4 PIs to join LEGEND for Canadian contribution to be substantive

Opportunities for LEGEND in Canada

- R&D efforts in LEGEND that have synergy with Canadian groups:
  - Developing **efficient light sensors** for the LAr LEGEND veto, and generally developing technology around low background application of LAr.
  - Developing **low background ASIC electronics** that can be deployed close to the HPGe detectors.
  - Developing **low background cable systems** that can be used to readout signals with high fidelity in a cryogenic environment.
  - Developing **LAr purification systems** to reduce backgrounds and provide depleted LAr.
  - Developing **assaying capabilities** to measure radioactive contaminants, for example on surfaces.
  - Developing **copper electroforming facilities** for large scale production of electroformed copper.
  - Developing **software** to collect, store, and analyze data.

Germanium detector community

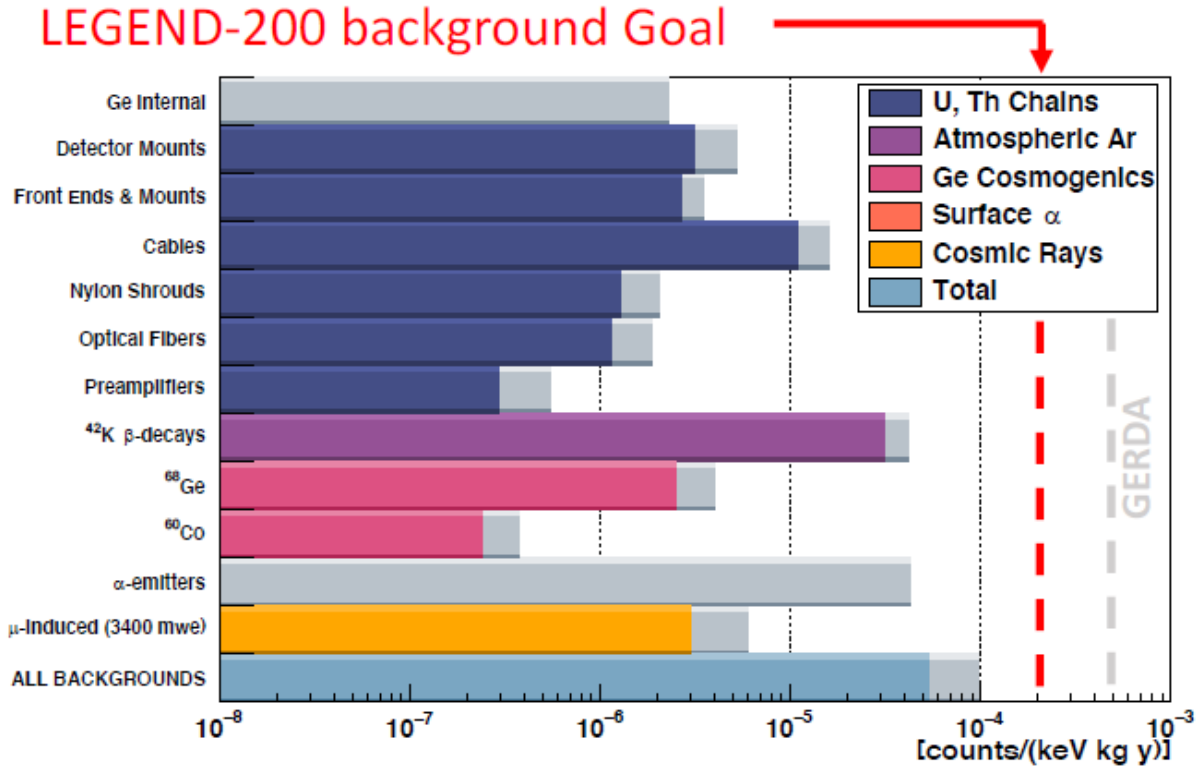
- GEMADARC: Germanium Materials and Detectors Advancement Research Consortium
- NSF-PIRE program to “develop germanium-based technologies to advance knowledge, to advance education in STEM, and to increase international collaboration in these areas”
- Membership from 5 countries and collaborations that use Ge for rare-event searches (e.g. LEGEND, SuperCDMS, TEXONO)
- Queen’s will host collaboration meeting, summer school, mK Ge detector workshop in Summer 2021

Conclusion

- There is a well-developed international effort to search of $0\nu\beta\beta$ in ^{76}Ge.
- The flagship $0\nu\beta\beta$ experiment, LEGEND-1000, is likely to be sited in Canada, and start construction around 2025.
- There are many opportunities for Canadians to contribute to the LEGEND experimental program.
- The Canadian community should discuss strategies for contributing to LEGEND in the context of the US down-select.

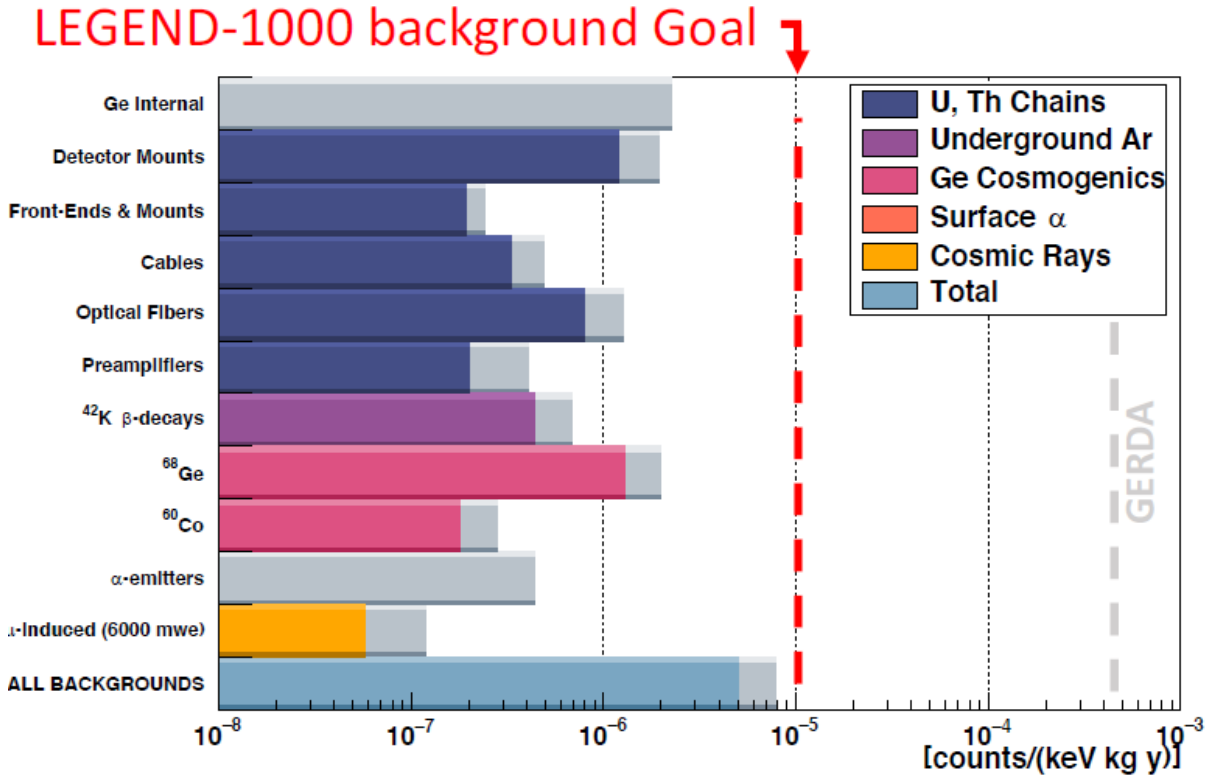
Backup

L200 background projections



- MC sims use assay results and data
- Grey band = uncertainty
- 5x better than GERDA (similar to the best GERDA detectors)
- Gain from larger detectors, cleaner cables, better LAr (purity and readout), better process controls in detector fab, better understanding of backgrounds

L1000 Background projections



- Larger detectors, better light collection, more space (less U/Th backgrounds)
- Suppression of 42-K backgrounds by using depleted LAr
- Lower muon induced backgrounds by going to SNOLAB
- Assume better control of surface contamination to reduce alphas