^{76}Ge detector R&D strategy for LEGEND

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Large Enriched Germanium Experiment for Neutrinoless ββ Decay (LEGEND)

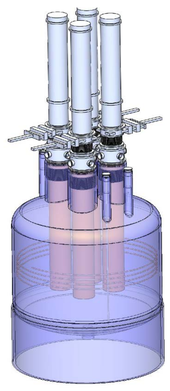
Mission

*The collaboration aims to develop a phased, ^{76}Ge based double-beta decay experimental program with **discovery potential** at a half-life beyond 10^{28} years, using existing resources as appropriate to expedite physics results.*

Staged approach

First phase:
- Up to 200kg of Ge
- Modification of existing GERDA infrastructure at LNGS
- BG goal: 5x lower, 0.6 cts/(FWHM·t·yr)
- Sensitivity > 10^{27}yr
- Start in 2021

Subsequent phases:
- 1000kg of Ge (staged)
- BG goal: 30x lower, 0.1 cts/(FWHM·t·yr)
- Sensitivity > 10^{28}yr
- Location: TBD
- Required depth under investigation



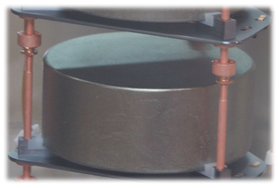
52 institutions, ~250 members

Univ. of New Mexico
L'Aquila Univ. and INFN
Gran Sasso Science Inst.
Lab. Naz. del Gran Sasso
Univ. of Texas
Tsinghua Univ.
Univ. of Cal. Berkeley and LBNL
Leibniz Inst. for Crystal Growth
Comenius Univ.
Lab. Naz. del Sud
Univ. of North Carolina
Sichuan Univ.
Univ. of South Carolina
Jagiellonian Univ.
Banaras Hindu Univ.
Tech. Univ. Dortmund
Tech. Univ. Dresden
Joint Res. Centre Geel
Chalmers Univ. of Technology
Max Planck Inst. für Kernphysik
Dokuz Eylül Univ.
Queens Univ.
Univ. of Tennessee
Argonne Natl. Lab.
Univ. of Liverpool
Univ. College London
Los Alamos Natl. Lab.
Lund Univ.
INFN Milano Bicocca
Milano Univ. and INFN Milano
Natl. Res. Center Kurchatov Inst.
Natl. Res. Nucl. Univ. MEPhI
Max Planck Inst. für Physik
Tech. Univ. of Munich
Oak Ridge Natl. Lab.
Padova Univ. and INFN Padova
Czech Tech. Univ.
Princeton Univ.
North Carolina State Univ.
South Dakota School Mines Tech.
Univ. of Washington
Academia Sinica
Univ. Tübingen
Univ. of South Dakota
Univ. of Zürich
Joint Inst. Nucl. Res.
Inst. Nucl. Res. Russ. Acad. Sci.

Achieved detector performance

BEGe detectors in LAr @ Gerda – LNGS, Italy[1]:

30 enriched detectors – 20.0 kg
$\langle M \rangle$ = 0.67 kg /det.
ΔE^{BEGe} = **2.9 keV** at 2039 keV
BI^{BEGe} = $\mathbf{1.0 \times 10^{-3}}$ **c /keV/kg/y**



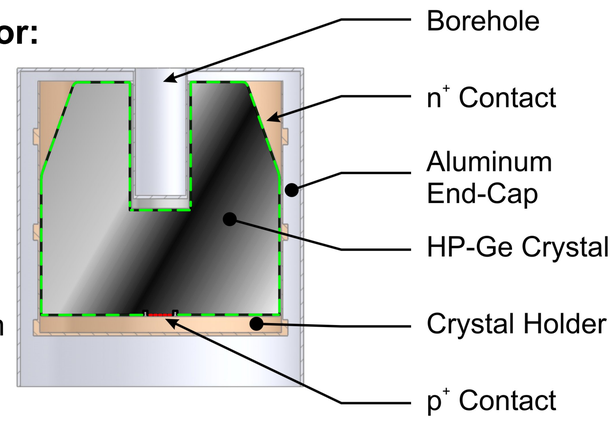
PPC detectors in vacuum @ Majorana – SURF, US[2]:

35 enriched detectors – 29.7 kg
$\langle M \rangle$ = 0.85 kg /det.
ΔE^{PPC} = **2.5 keV** at 2039 keV
BI^{PPC} = $\mathbf{1.6 \times 10^{-3}}$ **c /keV/kg/y**

New detector technology

p-type Inverted Coaxial Point Contact Ge detector:

- First design proposed in 2011[3]
- Features a well on the opposite p+-contact side
- Large active mass up to 3 kg
- 30%-40% surface to volume ratio reduction as compared to Gerda BEGe and Majorana detectors
- Excellent energy resolution: 0.11% at 2 MeV in vacuum
- Excellent Pulse Shape Discrimination (PSD) between signal and background events

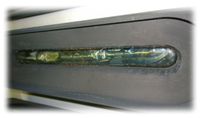


➢ **Reduced background due to smaller number of channels**

Production

Close follow-up at each step in term of process cleanliness, yield and cost:

1. Enrichment in ^{76}Ge up to 88%
2. Reduction of GeO_2 and zone refinement to electronic grade metal

3. Zone refinement to detector grade and Czochralski crystal pulling

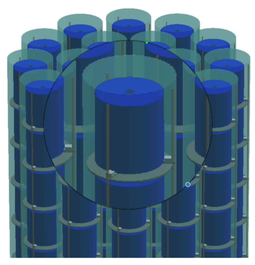

Credit: ORTEC @ PSeGe 17 workshop

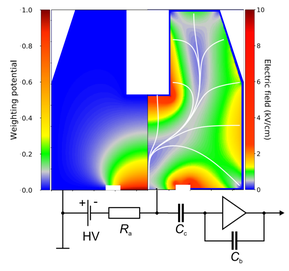
4. Conversion into detector

At least four companies involved in the R&D phase

Simulation

- Two independent codes for fields and signal calculation: ADL and `siggen`. **Electrostatic simulation guiding the detector production process** (geometry, depletion voltage, minimal electric field)

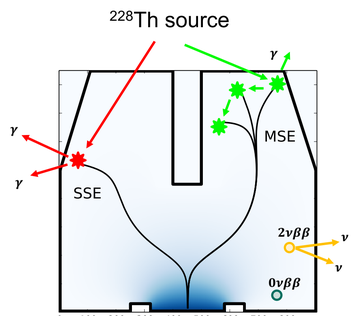




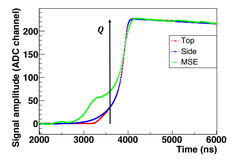
- Monte-Carlo simulation using MaGe (G4 based)
- Qualitative validation of background rejection
- L200 background model (see M. Green poster)
- Many detailed studies on-going:
  - Electronics modeling
  - Surface energy deposition
  - Position reconstruction

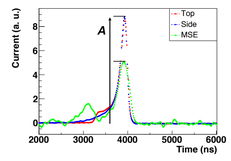
Natural ICPC characterization

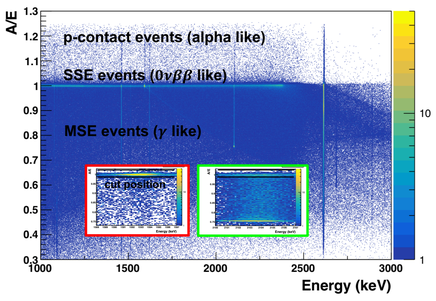
5 detectors studied in vacuum at HADES, Felsenkeller, MPIK, TUM
PSD performance evaluated by means of a ^{228}Th source



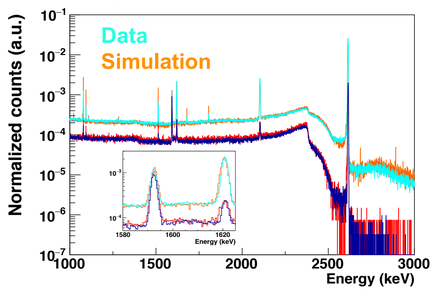
^{228}Th double escape peak = proxy for signal
^{228}Th single escape peak = proxy for bkg
PSD parameter: A/E (max. current over energy)







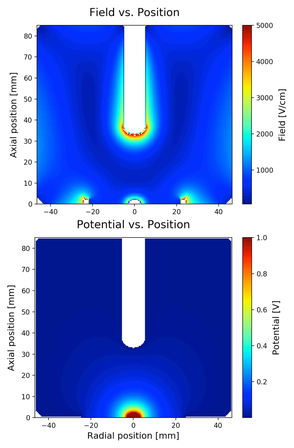
^{228}Th energy spectrum before/after PSD[4]

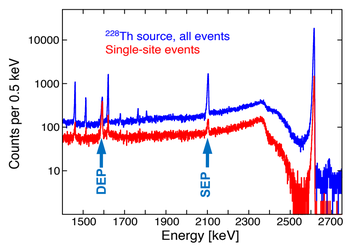


R&D for larger detectors

Larger detectors require fewer readout front ends, cables, and detector holders, reducing background contamination. They also reduce costs.

ORNL-supported R&D into larger detectors (> 3 kg) is underway
- 3-kg prototype produced by AMETEK, fully characterized, currently being modified
- 6-kg prototype in production by PHDs Co.





Conclusion

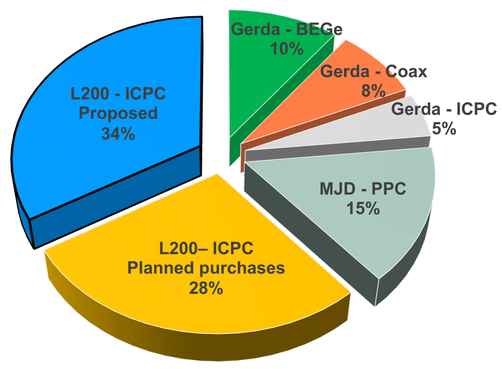
Inverted Coaxial Point Contact Ge detectors are suitable for large scale ^{76}Ge $0\nu\beta\beta$ decay search

Expected lower background contribution (cables, holders, surface to volume ratio)

6 natural det. characterized in Europe / US
+ 3 additional to come in the US
+ 5 enriched det. recently installed in Gerda
(see T. Comellato poster)

Production and deployment of up to 95 detectors by July 2021, with a target mass of 175 kg for L200

L200 detectors



Anticipated schedule

Jan 2018	First L200 enriched material purchase
Nov 2020	Start installation of detectors
July 2021	Data taking with LEGEND 200

References:

[1] Gerda collaboration PRL 120.132503 (2018)
[2] Majorana collaboration PRL 120.132502 (2018)
[3] R.J. Cooper, D.C. Radford, P.A. Hausladen, K. Lagergren NIMA 665 25-32 (2011)
[4] A. Domula, M. Hult, Y. Kermaidic et al. NIMA 891 106-110 (2018)

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