Operation of bare HPGe detectors in LAr/LN_2 for the GERDA experiment

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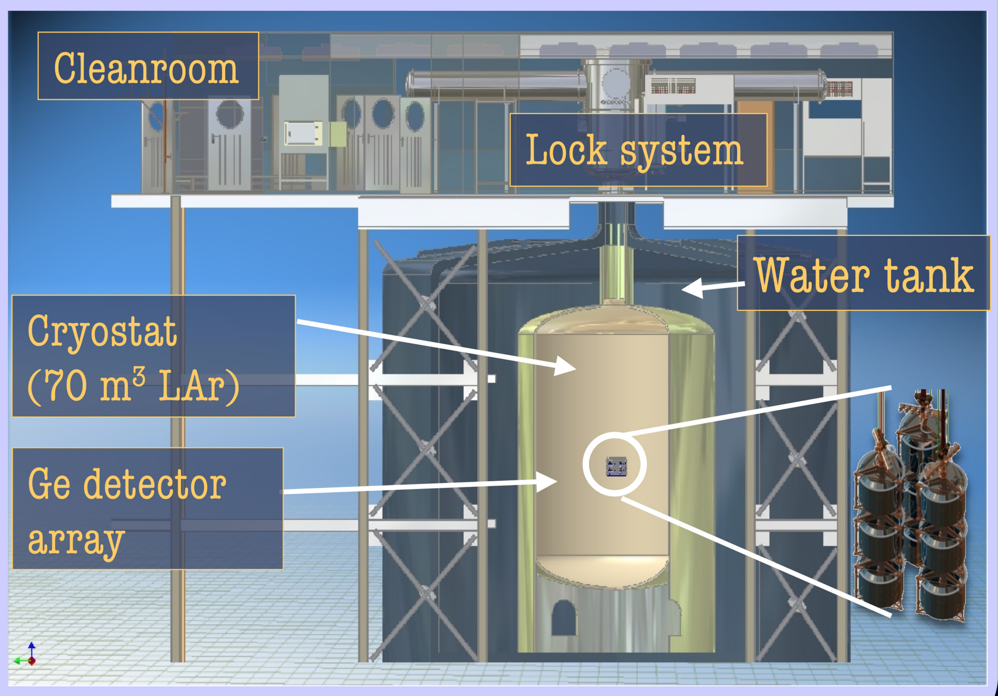
GERmanium Detector Array at LNGS[1]

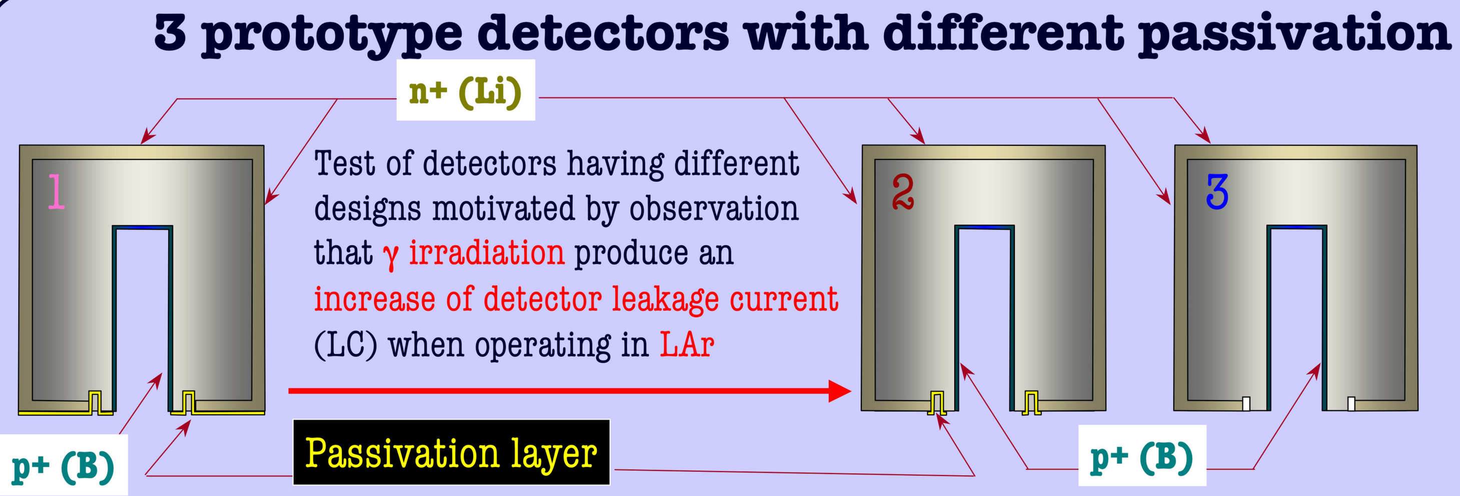
GERDA is designed to search for $0\nu\beta\beta$-decay of ^{76}Ge using high purity germanium detectors (HPGe), enriched in ^{76}Ge, directly immersed in LAr which acts both as shield against γ radiation and as cooling medium. The experiment aims at a background 10^{-3} cts/(kg · y · keV) and energy resolution ≤ 4 keV at $Q_{\beta\beta}$=2039 keV.

GERDA phases and corresponding sensitivities (90% CL):

- ✓ Phase I
  - – Operation of reprocessed enriched HDM[2] and IGEX[3] detectors (17.9 kg), reprocessed natural Genius-TF[4] detectors (15 kg)
  - – $T_{1/2}$> $3 \cdot 10^{25}$ y, m_{ee}< 270 meV
- ✓ Phase II
  - – New segmented crystals (20 kg enriched diodes+several of natural Ge)
  - – $T_{1/2}$>$1.5 \cdot 10^{26}$ y, m_{ee}< 110 meV
- ✓ Eventually Phase III
  - – Ton scale array in worldwide collaboration
  - – $T_{1/2}$>$2 \cdot 10^{27}$ y, m_{ee}< 40 meV



3 prototype detectors with different passivation layers (PL)



Test of detectors having different designs motivated by observation that γ irradiation produce an increase of detector leakage current (LC) when operating in LAr

Detector 2

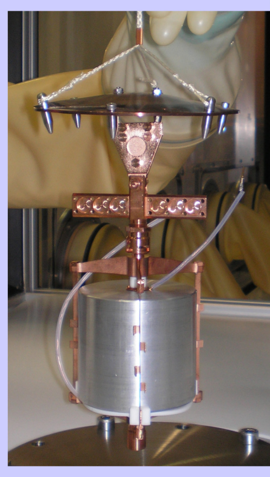
Detector 1: whole lower surface passivated **Detector 2**: PL in the groove **Detector 3**: no PL

GERDA Phase I prototype detectors

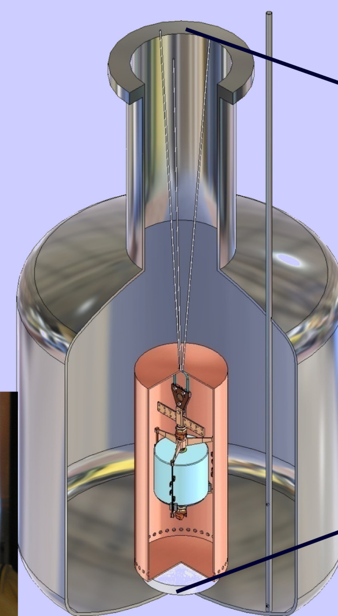
Non-enriched bare HPGe detectors operated in LAr/LN_2 to investigate effect of:

- ✓ Phase I detector assembly
- ✓ Detector handling
- ✓ Refurbishment technology

on **long term stability** and **spectroscopy performances.**

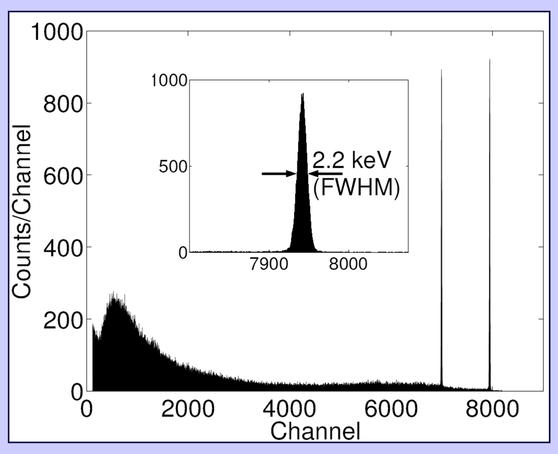


Low mass holder made of ultrapure materials with known radioimpurities: low-activity Cu (80 g), PTFE, Silicon.

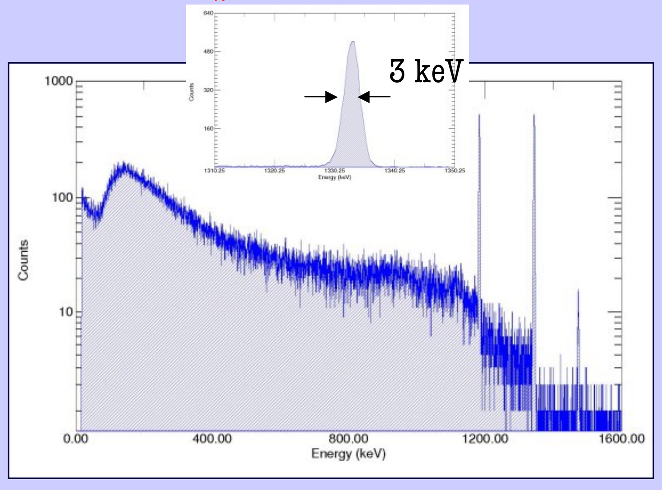


70 l Dewar (LAr or LN_2)

GDL is a GERDA underground facility at LNGS, equipped with 2 clean benches where Phase I detectors are tested. Detectors are manipulated in a closed, ultraclean environment under N_2 atmosphere.



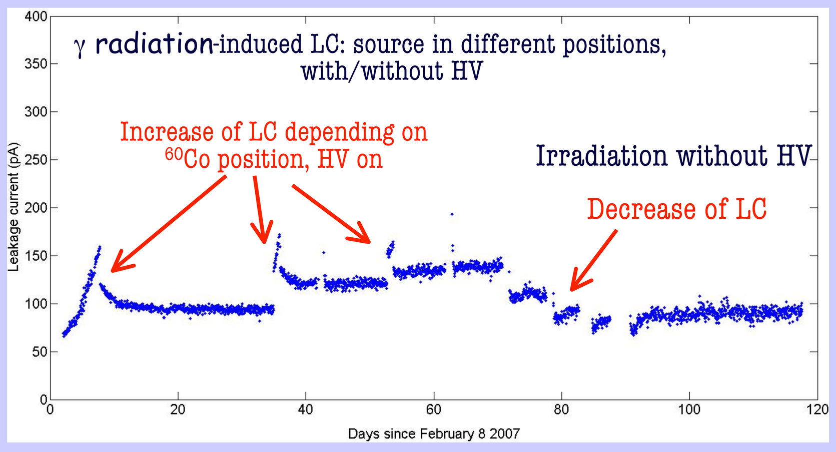
^{60}Co energy spectrum measured by the detector mounted in the low mass Cu holder in LN_2 . Warm electronics @ 40 cm from detector. FWHM = 2.2 keV @ 1330 keV

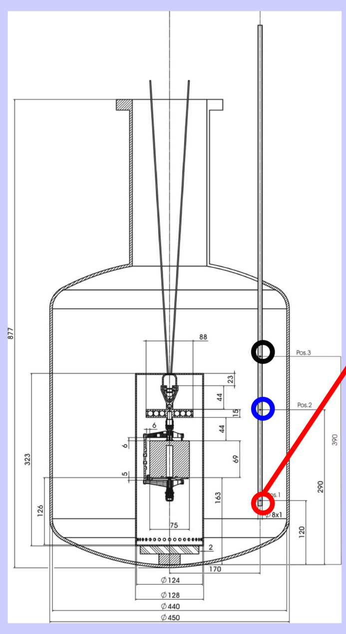


^{60}Co spectrum measured in GDL with detector 2 in LAr mounted in the low mass Cu holder. Warm electronics @ 80 cm from detector. FWHM = 3 keV @ 1330 keV

γ radiation induced leakage current (LC)

γ irradiation of detector 1 operating in LAr results in an increase of the LC. Typical value is 40 pA per day of irradiation, with a 44 kBq ^{60}Co source at a distance of ≈15 cm: the increase depends on the ionization rate (IR) in LAr (evaluated by Monte Carlo)

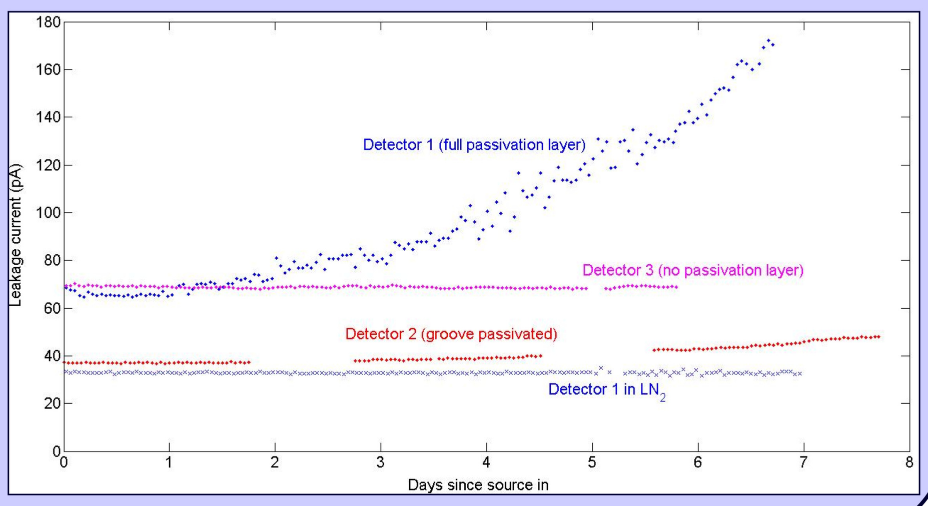




Source position	IR in Ge [kHz]	ΔLC [pA/d]	IR^{MC} in LAr [kHz]
1 (≈15 cm)	1.5	45±5	1.71
2	1.3	13±5	0.56
3	0.5	5±5	0.17

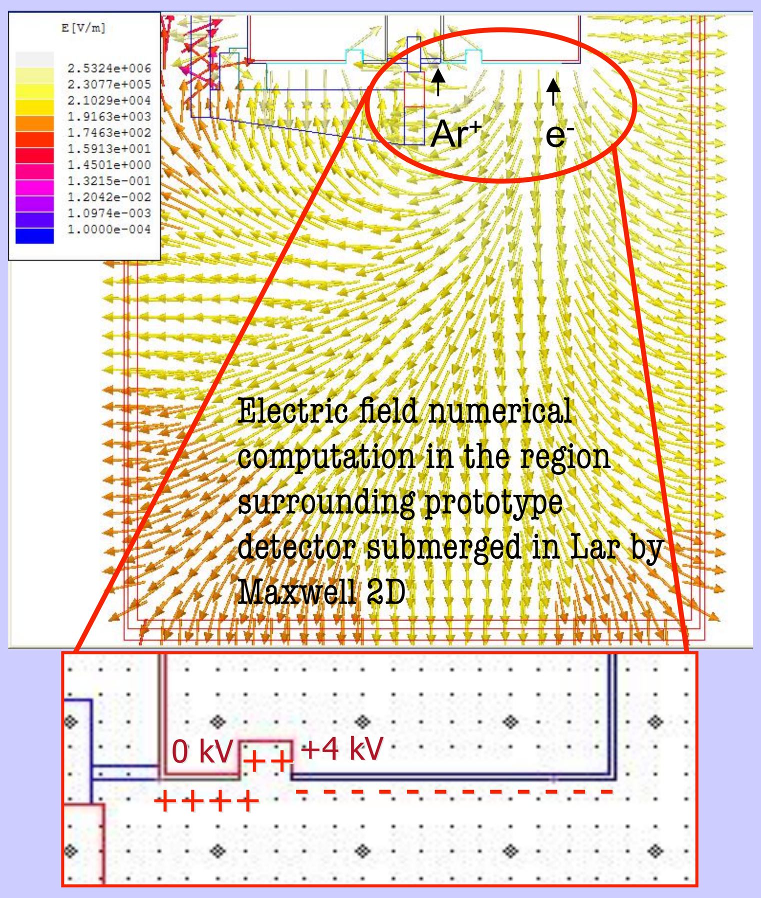
- ✓ LC increase is proportional to the ionization rate in the LAr volume facing the detector borehole side, but
- ✓ the process is totally reversible: LC recovers at few pA values when irradiating without HV and with warming cycles

- ✓ detector 2 (PL only in the groove) in LAr, shows a LC increase rate lower than the case of detector 1 (1.4 pA/d);
- ✓ detector 3 (no PL) does not show any increase of LC;
- ✓ detector 1 operated in LN_2 does not show any increase.



An empirical model to explain LC increase

Ionization of LAr volume facing the PL, due to γ irradiaton, produces pairs Ar^+/e^-. The diode bias Electric field dispersed in LAr driftes both Ar^+ and e^- toward the PL. Along their path e^- are eventually trapped by electro-negative species (O_2, CO_2).



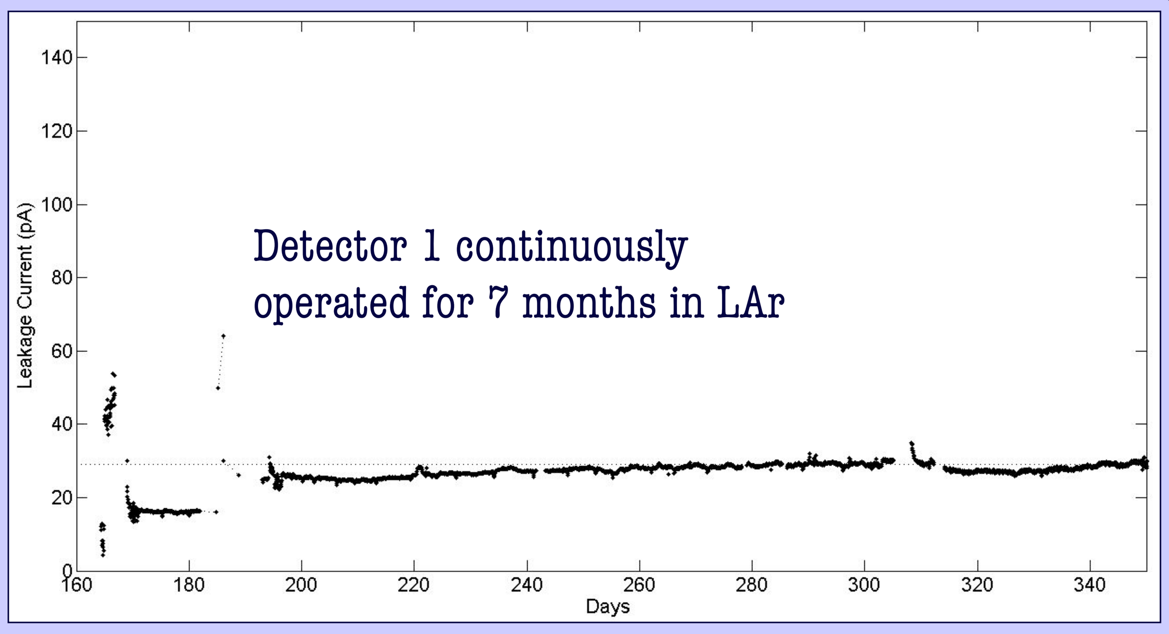
• Charge collected on the PL induces a decrease of resistivity ($\Delta R=10^{14}\ \Omega$, for ΔI=40 pA and HV=4 kV), causing an increase of the detector surface LC. The rate of the increase depends on the charge collection rate, on the density of trapped charge and on the starting value of the PL resistivity. The steady bulk Ge diode LC is unaffected by γ irradiation.

• Irradiation of crystal HV OFF, causes a decrease in LC, i.e. an increase of PL resistivity. This can be explained either by γ ray ionization in the PL itself or by the effect of the UV (128 nm) scintillation light of LAr.

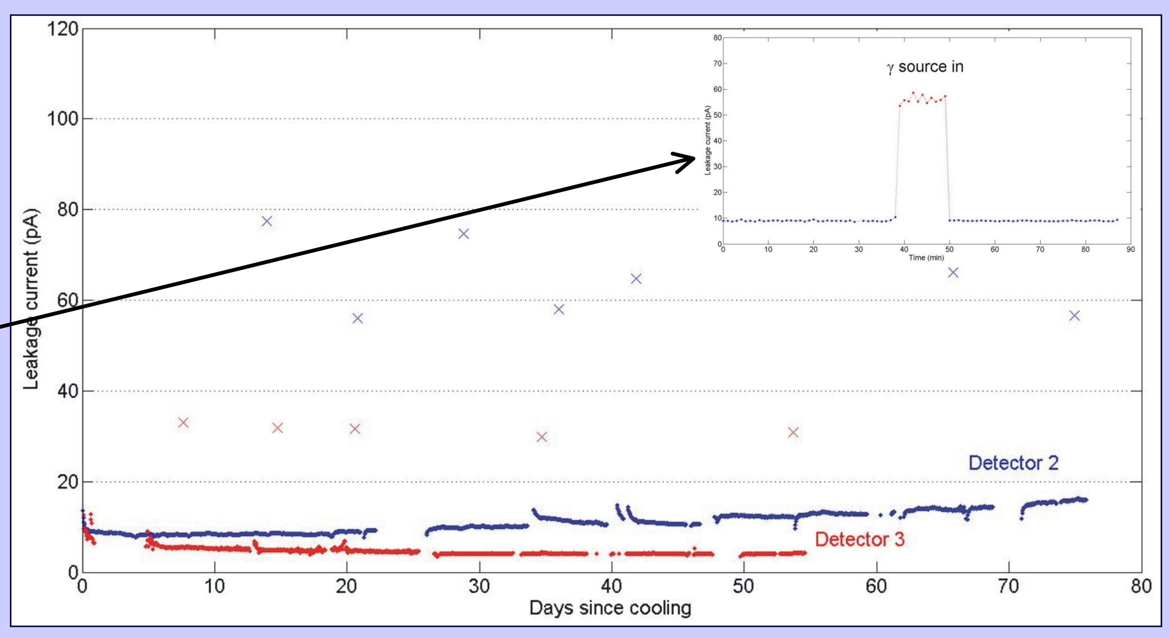
At this stage, the model is qualitative and empirical, but allows to explain most of the experimental results of the exstensive study carried out on the γ irradiation induced LC. Dedicated measurements to quantify the amount of collected charge and its influence PL, could make this model predictive.

Conclusions

- 2 years of operation of bare HPGe detectors in LN_2/LAr
  - – 3 prototype detectors with different PL design
  - – detector assembly for GERDA phase I detector successfully tested (same resolution as in the standard cryostat)
  - – energy resolution in LN_2 with warm electronics @ 40 cm from detector: FWHM=2.2 keV @ 1330 keV. Same resolution in LAr.
  - – energy resolution measured in GDL in LAr with warm electronics @ 80 cm from detector: FWHM=3 keV @ 1330 keV
  - – detector handling protocol defined (more than 50 cooling/warming cycles)
- Detector parameters stable over long-term measurement and not deteriorated after 1 year of continuous operation in LAr (10 pA–>10 pA)
- 1 year study with a prototype detector continuously operated in LAr under varying γ irradiation conditions
  - – γ irradiation results in an increase of the leakage current (LC) in detectors having PL. The increase depends both on the ionization rate of LAr volume facing the borehole side of the detector and on the design of PL
  - – γ radiation-induced LC is reversible by γ irradiation with HV off. From measurements, we have indication that UV scintillation, light produced by γ ray LAr ionization, can de-trap the charge.
  - – Reducing the size of the PL strongly suppresses γ radiation-induced LC
- GERDA will be calibrated ≈ 1/week for several minutes -> negligible increase of LC during the experiment live-time (< 10 pA)



Detector 2 and 3 continuously operated for 3 months in LAr. Each of them is weekly irradiated with ^{60}Co to simulate the effect of periodical calibrations in GERDA experiment



[1]The GERDA Collaboration, Proposal (2004), http://www.mpi-hd.mpg.de/GERDA/proposal.pdf

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[3]C. E. Aalseth et al., Phys. of Atomic Nuclei, Vol.63, No.7 (2000), pp.1225-1228.

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