GERDA: a novel Ge-detector operation technology for neutrinoless ββ decay searches

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for the GERDA collaboration

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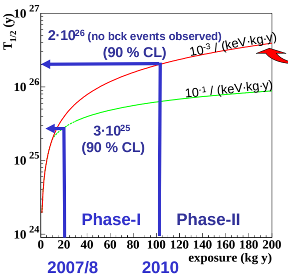
The Gerda 0ν2β experiment

GERDA is a new experiment for the search of ^{76}Ge neutrinoless ββ decay at the **Gran Sasso Laboratory** (LNGS). Ge detectors made out of isotopically enriched (~86%) material inside a cryogenic fluid shield.



Goal background for GERDA Phase II:

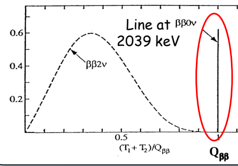
10^{-3} counts/(keV kg y)

Experimental sensitivity:

with bck → $T_{1/2}^{0\nu} \propto a\varepsilon\sqrt{\frac{MT}{BR}}$

$T_{1/2}^{0\nu} \propto a\varepsilon MT$ ← Bck free

- ε = detection efficiency
- a = ββ isotope fraction → enrichment
- M = mass of detector in kg
- T = measurement time in years
- B = background index in cts/(keV kg y)
- R = energy resolution at $Q_{\beta\beta}$ in keV



Process signature: if $\beta\beta_{0\nu}$ exist a line appears at $Q_{\beta\beta}$

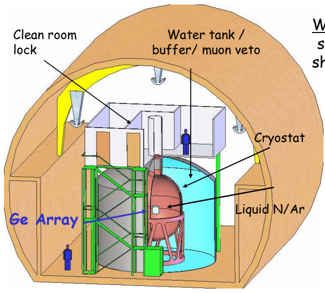
Experimental procedure

Phased approach:

Phase I: existing detectors of former HM & IGEX experiments, properly refurbished to be operated naked in LN

Phase II: new detectors

GERDA design: graded shielding. Inner **liquid N/Ar shielding** + external **water buffer**



Water: additional γ shielding, neutron shielding, Čerenkov muon veto

No high-Z material surrounding the detectors

Background from external γ rays can be reduced below 10^{-3} counts/keV kg y

Additional background reduction from: material selection (expecially for parts close to detectors), detector anti-coincidence, segmentation, pulse shape analysis

Phase I detectors

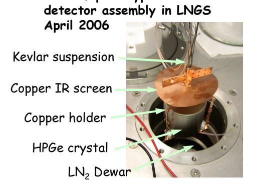
Eight enriched detectors from the former Heidelberg-Moscow and IGEX experiments have been underground for more than ten years => Internal cosmogenic background reduced. Total mass 17.9 kg. A procedure for the removal from their actual cryostat, re-contacting and mounting inside LN bath while keeping their radiopurity quality has been developed.

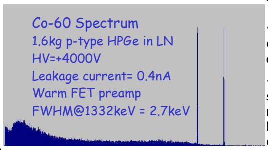
Detectors	ANG1	ANG2	ANG3	ANG4	ANG5	RG1	RG2	RG3
FWHM [keV]	2.54	2.29	2.93	2.47	2.59	2.21	2.31	2.26
Mass [kg]	0.968	2.906	2.446	2.400	2.781	2.150	2.194	2.121

IGEX detectors RG1-3

Heidelberg-Moscow detectors ANG1-5

Test of prototype HPGe detector assembly in LNGS April 2006





Phase I Detector Array

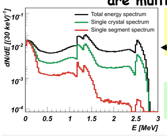
To suppress γs bck:

- Ge-Ge and eventually Ge-LAr anticoincidence
- Minimize mass of & select mounting materials.

New mounting ~ 50 g. Conventional Cu cryostat ~ 3-4 kg.

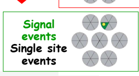
Segmented detectors for Phase II

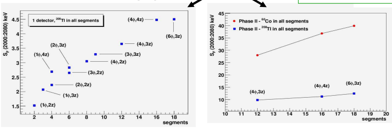
The segmentation of the diode read-out is a powerful background rejection tool, to be used in the Phase II of GERDA; γs (bck) events are multi-site, while ββ are single-site



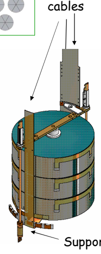
Background rejection due to crystal and segment anti-coincidence for ^{60}Co in germanium

Study of background rejection for several segmentation options





Electronic cables



Support

Possible design for a 18-fold (3z, 6φ) segmented crystal

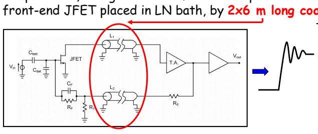
Suppression Factor @ Q_{bb} due to anticoincidence between crystals and segments for a **(3z,6φ) crystal segmentation.**

Source	Crystals AC	Segment AC
Muons (LN bath)	27	80
Ge68 in Ge	2.5	18
Co60 in Ge	3.2	39
Co60 in holder	6.7	157
Tl208 in Ge	2.6	13
Tl208 in holder	2.2	5

Front-end electronics: 1st solution

Cold BF862 JFET (inside LN bath) + warm hybrid preamplifier (outside LN bath)

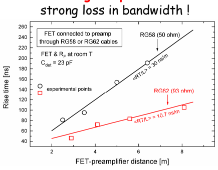
The hybrid preamplifier, typically realized with BJTs, cannot work at cryogenic temperature, owing to carrier freeze-out phenomena. It has been connected to the front-end JFET placed in LN bath, by **2x6 m long coaxial cables**.



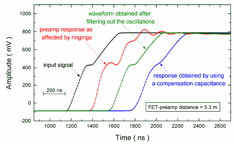
The delay lines in the feedback loop cause oscillations in the circuit response. They can be eliminated in two different ways:

- strongly compensating the loop
- numerically de-oscillating the signal after sampling.

Strong compensation: strong loss in bandwidth !



Numerical FIR filter: rise time of ~ 33 ns with C_{det}=23pF ! The oscillations are canceled out, while preserving the high-frequency content of the signal.



The obtained noise performance is adequate for γ spectroscopy:

ENC = 178 e⁻ rms at τ_{shap} = 10 μs, with C_{det} = 23 pF and JFET at T = 77 °K

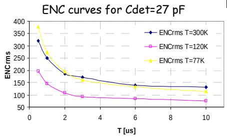
Front-end electronics: 2nd solution

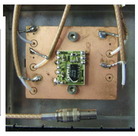
Cold monolithic JFET preamplifier (inside LN bath)

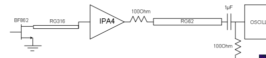
IPA4 monolithic JFET preamplifier, developed for gamma spectroscopy in cryogenic environment has been tested at LN temperature and showed superior noise performances, and, once operated with an external input FET as first stage, satisfying time performances to implement PSA.

Minimum ENC for IPA4 operated with external input BF862 FET and inhibiting integrated J1, is 150 e- rms at τ_{shap} = 10 μs, with Cdet = 27 pF and JFET at T = 77 °K.

ENC curves for Cdet=27 pF

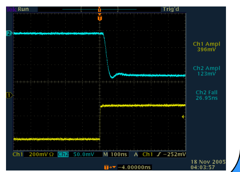






Measured pulse fall time for IPA4 preamp. Operated with integrated J1 or external BF862, at T =300K.

CD [pF]	τf [ns] (BF862)	τf [ns] (J1)
0	27	110
15	36	140
27	44	155



Front-end electronics: 3rd solution

ASIC CMOS preamplifier in LN bath

First rule to reduce significantly background is to minimize mass of each component close to crystals → integrated front end.

Two ASIC CMOS circuits under development and test

0.8 μm 5V CMOS single or differential ended preamp with:

- ❖ external input stage (JFET) or
- ❖ integrated input FET

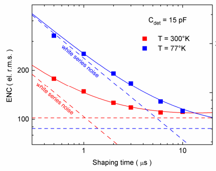
external feedback components

First measurement results at T=77°K

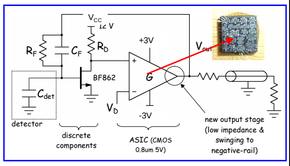
(C_F = 0.15pF, R_F= 1GΩ, C_{det} = 15pF)

- Negative output voltage swing: ~ 2.4 V
- Energy sensitivity (C_F = 0.15 pF) : ~ 185 mV/MeV after 50 Ω termination
- Input dynamic range: ~ 6.5 MeV
- Rise time: ~ 15 ns driving 10m cable
- Minimum ENC (C_{det}= 15pF) : 112 e⁻ at τ_{shap}=10μs
- Total power consumption: ~ 25 mW

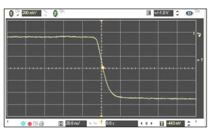
Comparison between noise measured at room temperature (T=300°K) and in LN (T=77°K)



Tested circuit structure: external BF862 JFET + 0.8μm 5V CMOS single-ended preamplifier



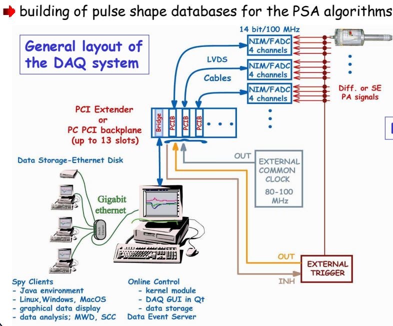
Acquired output signal driving a 50 Ω coaxial cable of ~ 10 m : rise time of ~ 15 ns



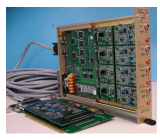
Digital sampling data acquisition system

- PSA to reduce the background produced by multi-site events
- digital filters can improve detector response when signals are affected by microphonics and/or high ripple
- detector test and characterization
- building of pulse shape databases for the PSA algorithms

General layout of the DAQ system



The digital sampling system



Input Signals: SE or Diff.

Signal conditioning boards
Gain – jumpers
Offset – front panel screw
Signal polarity
Antialiasing (< 40 MHz)

ADC boards 100 MHz/14 bit
ANALOG DEVICES AD6645

PCI Boards/FPGA 32/64 bit

Results obtained with a low-noise planar Ge detector