Test of GERDA Phase II Detector Assembly

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GERDA Phase II

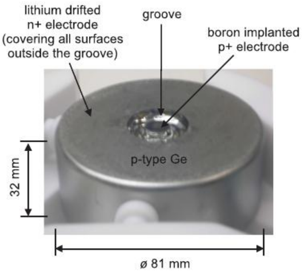
Sensitivity to the lower limit of the half life scale of the neutrinoless double beta decay ($0\nu\beta\beta$)

$$T_{1/2} \propto \epsilon a \sqrt{\frac{Mt}{BI\Delta(E)}}$$

ϵ: detection efficiency,
a: abundance of ^{76}Ge
M: mass [kg],
t: exposure time [yr],
BI: background index [$\frac{counts}{keV \cdot kg \cdot yr}$],
$\Delta(E)$: energy resolution in ROI at $Q_{\beta\beta} = 2039$ keV

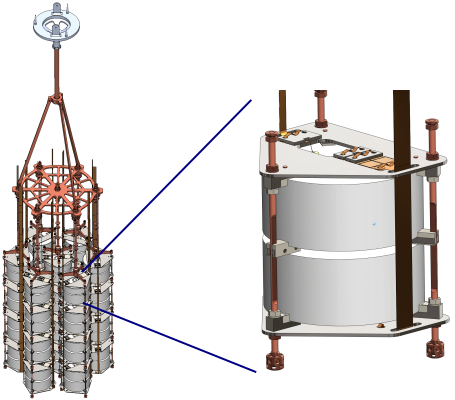
In GERDA Phase II:

- 30 new BEGe detectors, about 20 kg of enriched germanium
- Improved energy resolution $\Delta(E)$
- BI of $1 \cdot 10^{-3}$ $\frac{counts}{keV \cdot kg \cdot yr}$ by
  - enhanced pulse shape discrimination against background events with BEGe's and
  - LAr veto
- Specially designed low radioactivity holders and electronics



Picture of BEGe detector from JINST 5 P10007

Phase II Detector Array



The Phase II Detector Array

- 7 strings in total
- BEGe detectors are mounted in pairs
- Semi-coaxial detectors from Phase I separately
- Each string contains a maximum of 4 BEGe pairs or 4 coaxial detectors

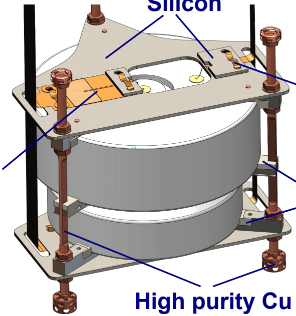
Possible Detector Arrangement

- A dense packing of detectors means better anti coincidences
- 4 strings with 15 BEGe pairs mounted back-to-background and 1 natural coaxial detector
- 2 strings with 7 enriched coaxial detectors from Phase I
- 1 string with three natural coaxial detectors

Phase II Detector Holders

Low - Mass Holders

- Material in direct vicinity of detectors needs to be reduced
- Reduce total mass of holders as much as possible
- Electrical contacts (HV and signal) realized by ultrasonic wire bonding
- Replace Cu with Si



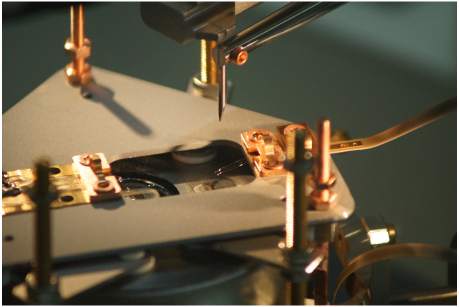
Material and Radioactivity Budget (^{228}Th only)

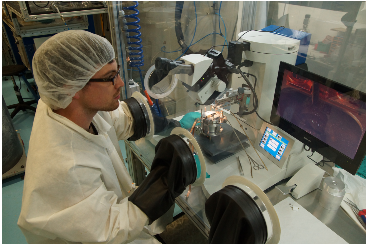
material	Phase I holder [g]	Phase I holder [μBq]	Phase II holder [g]	Phase II holder [μBq]
Cu	80	$<$1.6	26	$<$0.5
Si	1	-	40	-
PTFE	10	0.5	2	0.1
Bronze	-	-	1	$<$0.02

In a rough estimation this means:

- In Phase I we had 2.1 μBq per detector, about **1 μBq per kg detector mass**
- In Phase II we will have 0.6 μBq per BEGe pair (coax detector), about **0.4 (0.3) μBq per kg detector mass**

Contacting





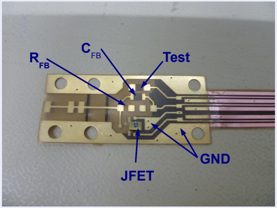
Phase II Contacts

- HV bias and signal contacts are realized with ultrasonic wire bonds
- Bonding is done in the underground lab at LNGS
- The bonds are made from 25 μm Al wires
- Direct bonding on Germanium not possible
- Thin Al spot evaporated on detector by manufacturer Canberra

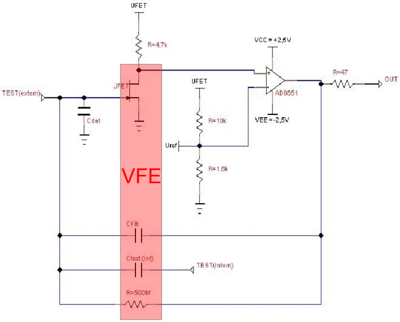
Phase II Electronics

The two Stages

- Very front-end electronic (VFE) with JFET, feedback resistor and capacitor printed on flex substrate



- CC3 for amplification



schematic of CC2

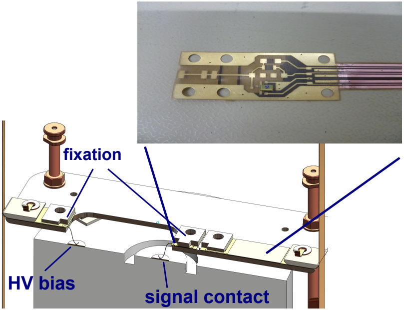
Advantage of Separation

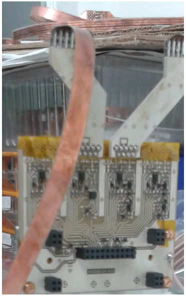
- BEGe detectors have low capacitance
- The capacitance of any cable between detector and JFET adds to the input capacitance $C_{in} \propto$ noise
- Thus, shorter cables means less noise
- Allows to put CC3 at larger distance to detectors and to reduce radioactivity budget

Phase II Electronics

First Stage: VFE

- Front-end electronics on flex substrate
- The VFE is located at the Si plate as close as possible to the read-out electrode
- FE flexes also signal stripes to the second stage

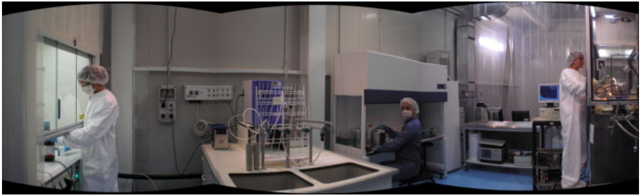




Second Stage: CC3

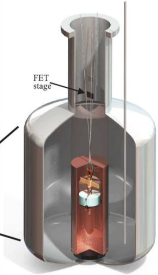
- Maximum distance to first stage 85 cm
- 4 channels
- Amplifies the signal
- Sends feedback signal back to VFE

Integration Tests

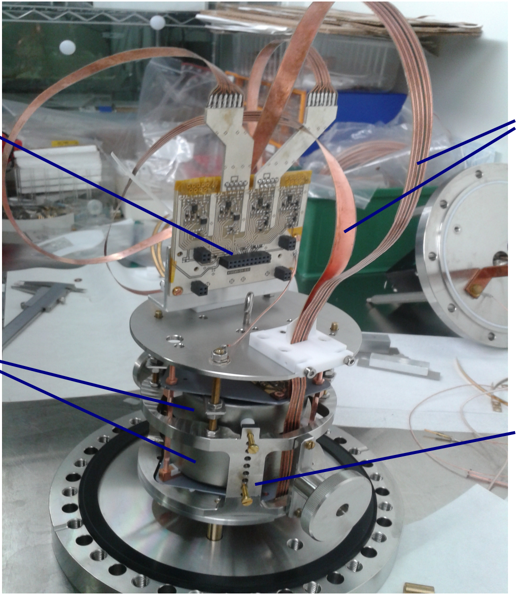


Integration Tests in the in underground Germanium Detector Lab (GDL) at LNGS

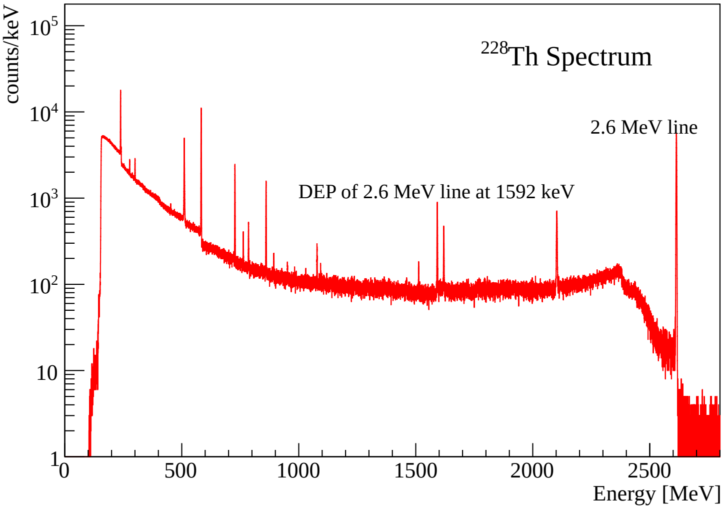
- Tests electronics, mounting procedure, electrical contacts in close to final conditions
- Integration tests are performed in LAr cryostat and
- glove box with nitrogen atmosphere.
- ^{228}Th calibrations as done in GERDA are taken



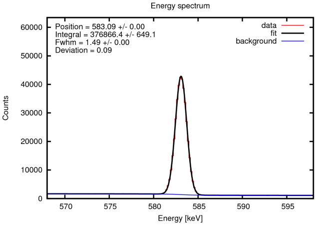
Integration Tests II

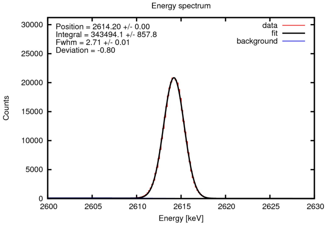


Energy Spectrum



Energy Resolution 2/B Ge-9 BEGe





Peak [keV]	fitted peak position [keV]	FWHM [keV]	Resolution [%]
583.191	583.09 $\pm$ 0.00	1.49 $\pm$ 0.00	0.26
1592.537	1592.17 $\pm$ 0.01	2.14 $\pm$ 0.02	0.13
1620.500	1620.03 $\pm$ 0.01	2.12 $\pm$ 0.03	0.13
2614.533	**2614.20 $\pm$ 0.00**	**2.71 $\pm$ 0.01**	**0.10**

Comparison of Energy Resolution with CC3 and in Vacuum Cryostat

- Energy resolution with **CC3** in LAr and final cable length: 2.7 keV at 2.6 MeV (**0.10%**)
- Energy resolution in **vacuum cryostat**: 2.4 keV at 2.6 MeV (**0.09%**)
- But CC3 rather simple compared to Canberra preamplifier
- Achieved energy resolution with the low background CC3 is very good!

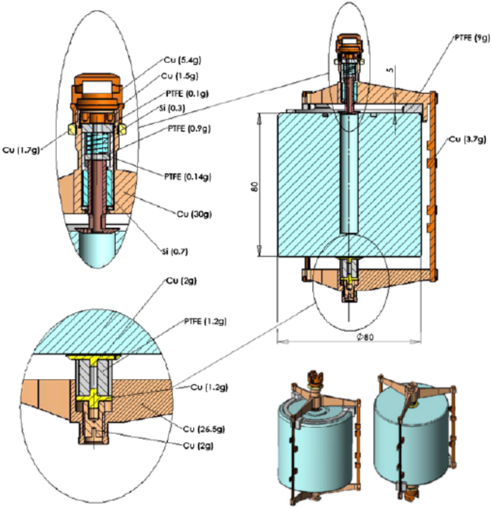
Conclusion and Outlook

- The new detector supports introduce less radioactivity
- The new electronics has a good energy resolution
- The bond wires provide a reliable low mass contacting solution
- Further integration tests with prototype detectors are ongoing

- In summer the integration of the detectors in GERDA will start

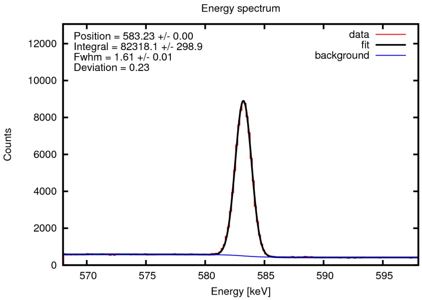
Bonus Slides

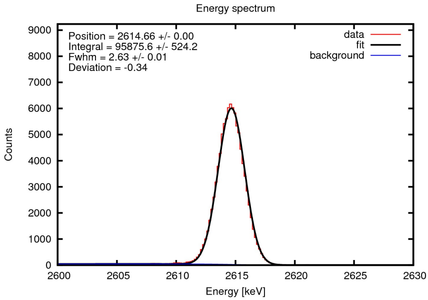
Phase I Detector Holders



Energy Resolution 4/C MiBEGe

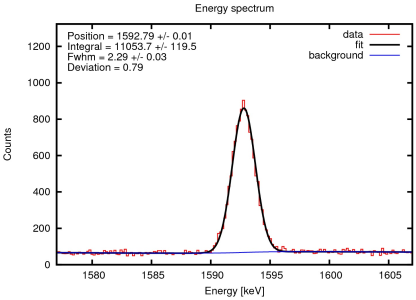
Peak [keV]	fitted peak position [keV]	FWHM [keV]	Resolution [%]
583.191	583.23 ± 0.00	1.61 ± 0.01	0.28
1592.537	1592.54 ± 0.01	2.15 ± 0.03	0.14
1620.500	1620.54 ± 0.03	2.16 ± 0.06	0.13
2614.533	**2614.66 ± 0.00**	**2.63 ± 0.01**	**0.10**

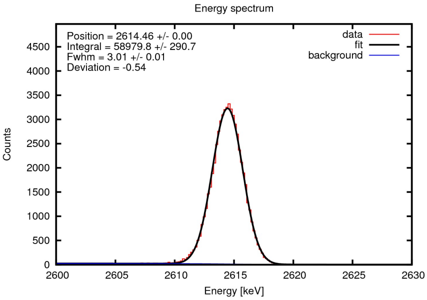




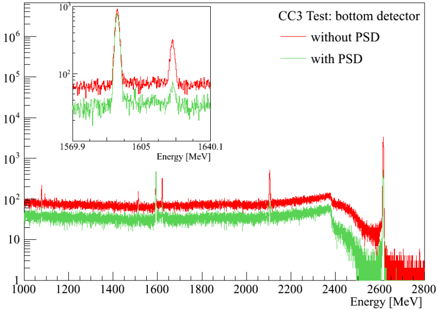
Energy Resolution 1/D Tübingen BEGe

Peak [keV]	fitted peak position [keV]	FWHM [keV]	Resolution [%]
1592.537	1592.79 ± 0.01	2.29 ± 0.03	0.14
1620.500	1620.87 ± 0.03	2.40 ± 0.06	0.15
2614.533	**2614.46 ± 0.00**	**3.01 ± 0.01**	**0.12**





Preliminary Pulse Shape Discrimination with 1/D Tübingen BEGe



PSD Efficiencies

Energy region	Survival fraction after PSD cut [%]
DEP 1592.5 keV	89.99 +- 0.74
FEP 1620.5 keV	13.62 +- 1.72
SEP 2103.5 keV	11.75 +- 0.54
FEP 2614.5 keV	15.34 +- 0.17
2004 - 2074 keV	48.33 +- 0.29

- Detector has in general a worse PSD than other prototypes
- The results are compatible with the PSD efficiencies reached with the Phase I BEGe's
- When passivation layer in detector groove is removed we expect better PSD results