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A Low-Noise Charge Sensitive Preamplifier for Ge Spectroscopy Operating at Cryogenic Temperature in the GERDA Experiment

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The GERDA Experiment:

The GERDA experiment [1] has been proposed in 2004 as a new ^{76}Ge double-beta decay experiment at LNGS (Gran Sasso National Laboratory) of INFN (National Institute of Nuclear Physics). It consists of a facility where Germanium detectors made out of isotopically enriched material are operated inside a cryogenic fluid shield. The facility will serve a triple purpose: i) prove the Majorana nature by searching for the 0nbb of ^{76}Ge with a sensitivity of $T_{1/2} > 10^{25}$ y; ii) probe the neutrino mass at the level of 300 meV, in a couple of years of data taking and iii) demonstrate as a pioneering low radiation level facility the reduction of background by 2-3 order of magnitudes below.

The CC2 Charge Sensitive Preamplifier

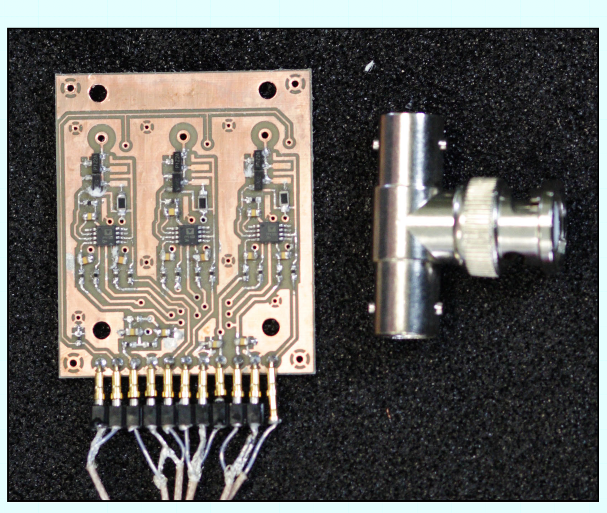
The requirements of low radioactivity and cryogenic operation impose very stringent conditions on the design and manufacturing of the charge sensitive preamplifiers.

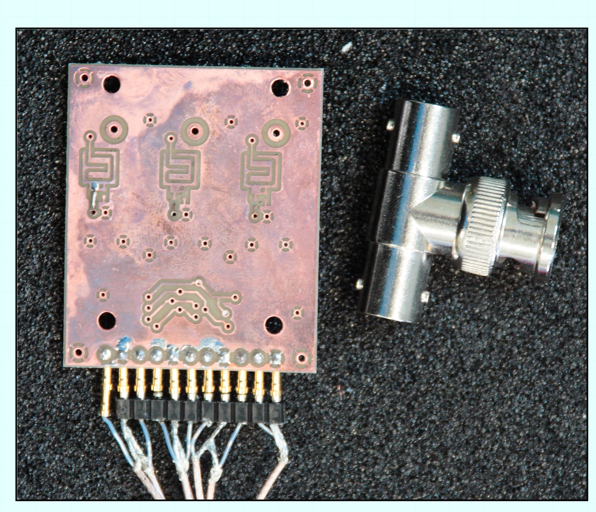
A few circuits have been designed and tested as the front-end electronics of the GERDA experiment, e.g. the "PZ0" charge sensitive preamplifier (CSP) [2, 3].

Preamplifier signals are driven out of the cryostat by means of low-impedance coaxial cables, up to a dedicated digital acquisition system based on free running ADCs (see N28-315 poster).

The CC2 is a low-noise hybrid CSP, based on two main active components: the BF862 n-channel JFET (NXP Semiconductors) as the front-end device and a subsequent CMOS operational amplifier. We tested different commercially available operational amplifiers and eventually selected the AD8651 (Analog Devices) as the most satisfactory candidate.

Specific design attention has been dedicated to both the circuit schematic and the printed circuit board layout in order to achieve high immunity to the electrical disturbances conducted by the low voltage power supply cables. As the GERDA experimental set-up currently consists of very thin and resistive coaxial cables connecting the Germanium detector to the room temperature area outside of the cryostat (in order to minimize the radioactive background level), this feature has proved to significantly contain the amount of the inter-channel cross-talk and the CSP susceptibility to conducted noise.





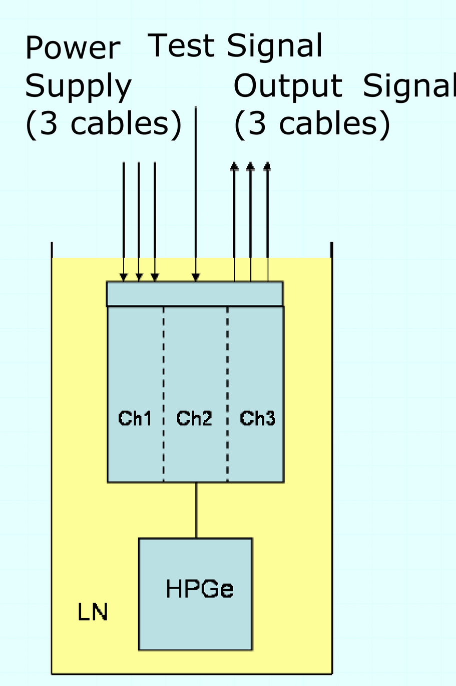
Front and back side of the 3 channels CC2 CSP (PCB size is 38 mm x 45 mm).

Test with the SUB Ge detector

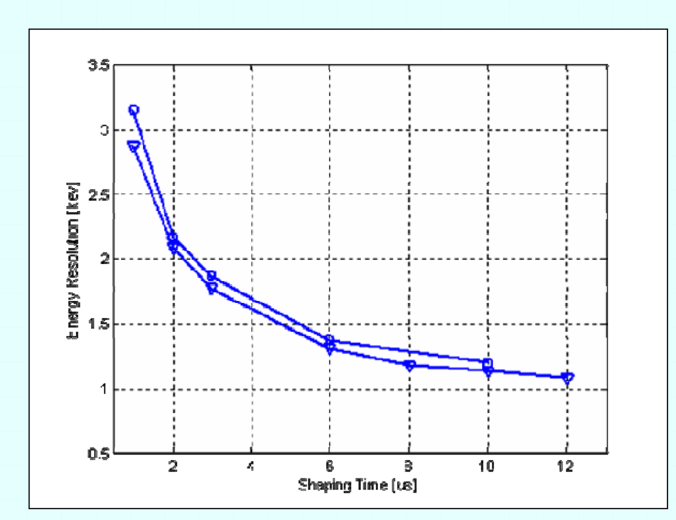
We coupled the CC2 charge sensitive preamplifier to a Germanium encapsulated detector (the "SUB", manufactured by MPI Heidelberg) in Milano and obtained the satisfactory results reported in the following.

CSP intrinsic best energy resolution at liquid Nitrogen temperature (with no added input capacitance) of 0.7 keV, with 2.2 eV / pF noise slope (all values are FWHM, for 12 us shaping time, in Ge detectors); best energy resolution (SUB Ge detector) of 1.96 keV for ^{22}Na; 15 MeV guaranteed energy dynamic range (for 0.5 pF feedback capacitor); 50 Ohms driving capability of 10 meters long coaxial cables; signal rise time less than 55 ns with terminated, long cables and energy of incoming events up to 15 MeV; inter-channel cross-talk less than 0.1%; estimated linearity better then 1/1000; power consumption less than 45 mW/channel.

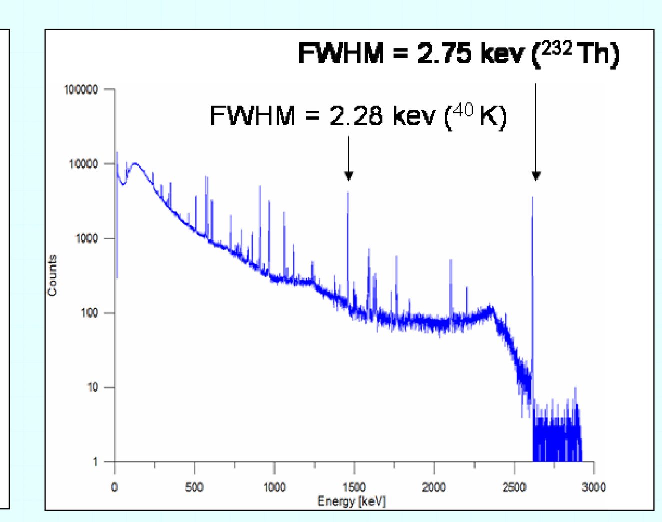
Additional benefits of the proposed CSP design are also robustness, affordability, reduced manufacturing efforts and time.



The schematic drawing of the electrical connections of the 3 ch. CSP and the SUB detector to and from the warm electronics outside of the cryostat during the preliminary tests (over 2 weeks).



The measured energy resolution (FWHM) (with 33 pF simulated Ge detector capacitance) is shown as a function of the spectroscopy amplifier shaping time for two different JFET power supply voltage levels (triangles: 6 V; circles: 12 V).



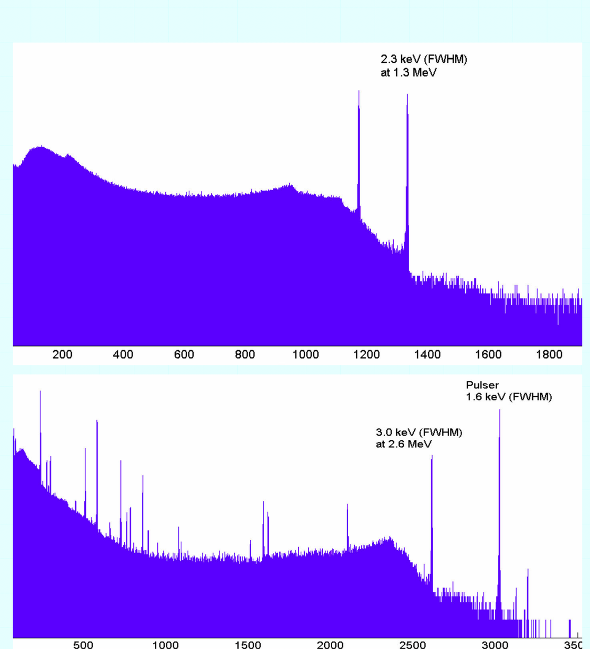
One of the experimental energy spectra acquired with the SUB detector, for a low activity ^{232}Th source (2.75 keV FWHM energy resolution) and the radioactive natural background.

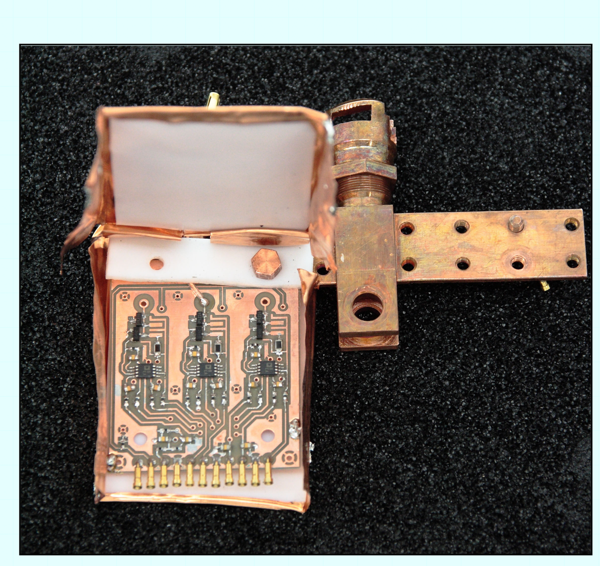
Tests at the LNGS underground facility

At LNGS we connected the CSP to non-encapsulated Germanium detectors of both low capacitance (≈ 1-2 pF, BEGe type, in the LArGe set-up) and subsequently to a string of 3 coaxial detectors with intermediate capacitance (≈ 30 pF). All detectors and CSPs have been operated inside cryostats filled with liquid Argon.

As a specific requirement of the GERDA experiment, a dedicated low-radioactivity design and corresponding printed circuit board layout have been carried out. The total amount of measured radioactivity from the PCB (excluding pins) is ≈ 170 µBq for ^{232}Th.

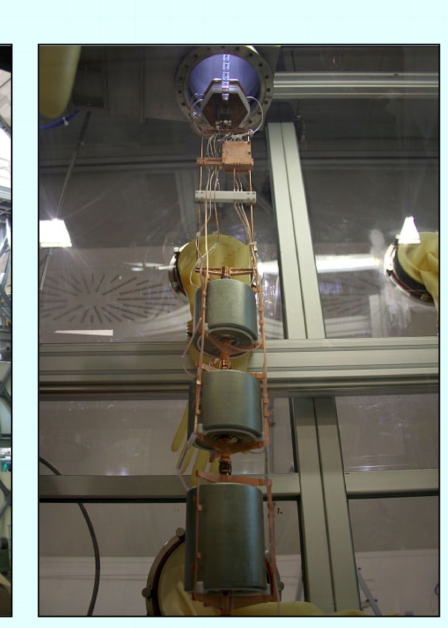
Among the key points to achieve this results (to be separately reported in the future) are: manufacturing of the CSP board on a specifically selected low-radioactivity substrate; minimization of the number of tantalum power-supply decoupling capacitors and integration of the low value capacitors, e.g. for input-to-output feedback of the CSP directly on the printed circuit board in order to eliminate the corresponding NP0 ceramic based devices.

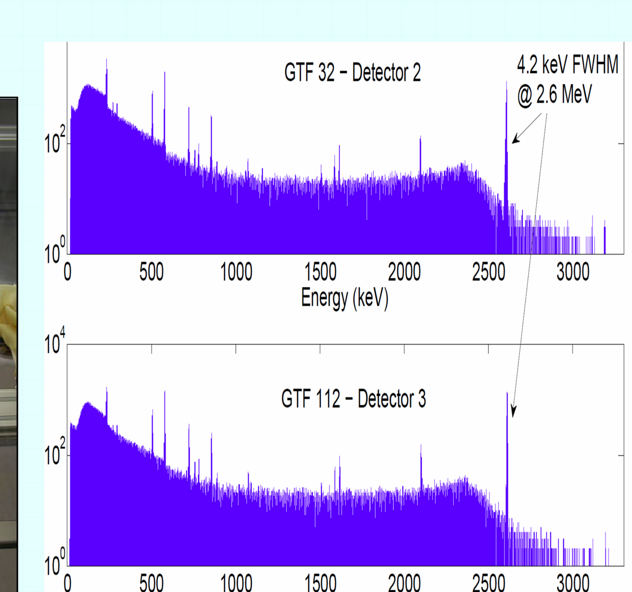




The LArGe experimental set-up, a Broad Energy Ge (BEGe) detector and the associated CC2 CSP readout electronics.

Energy resolution is: 3.0 keV FWHM @ 2.6 MeV (^{228}Th line); 2.3 keV FWHM @ 1.3 MeV (^{60}Co line); 1.6 keV FWHM @ 3 MeV (pulser line).





The GERDA water tank, containing the cryostat filled with liquid Argon, inside of which was the string of three natural Ge coaxial detectors.
Energy resolution was 4.2 keV FWHM @ 2.6 MeV (^{208}Tl line); the apparatus was not optimized yet and disturbances picked-up by the string of detectors limited the achievable energy resolution.

[1]: The GERDA experiment proposal: http://www.mpi-hd.mpg.de/gerda/reportsLNGS/mar05-tech-prop-v01.pdf and http://www.mpi-hd.mpg.de/gerda/reportsLNGS/proposal_21sept.pdf
[2]: "Spectroscopy Performances of the GERDA Cryogenic Charge Sensitive Amplifier Based on JFET-CMOS ASIC Coupled to Germanium Detectors", A D'Andragora et al., IEEE-Nuclear Science Symposium, Orlando, 2009
[3]: "A Cryogenic Low-Noise JFET-CMOS Preamplifier for the HPGe Detectors of GERDA", A. Pullia et al., IEEE-Nuclear Science Symposium, Dresden, 2008