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A Multi-Channel Digital Acquisition System for Ge Spectroscopy 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 Digital Acquisition System

The developed system is based on a 4-channels DAQ, in mechanical NIM standard [2], that fully exploits the performance of Germanium detectors in terms of energy resolution, bandwidth and linearity. Among its main characteristics are: choice of single ended or differential input standard; selectable inversion of polarity and selectable attenuation (0dB / 12 dB); signal conditioning with selectable gain (0-6-12-18 dB) and offset correction; anti-aliasing filtering with 30 MHz bandwidth; fully differential architecture to minimize the effect of common-mode disturbances, acquisition rate of 100 MHz with 14 bits resolution.

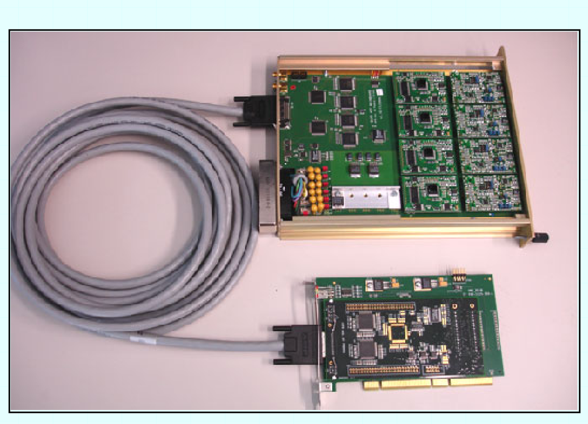
The system design is modular, i.e. each one of the 4 DAQ channels is composed of a mother-board and two small daughter-boards, one for analog signal conditioning and the other one for analog to digital conversion of signals. The mother-board provides mechanical support, ADC signals collection and serialization for high-rate transmission into commercially available twisted copper cables.

Up to 6 DAQ NIM modules, i.e. 24 acquisition channels, can be connected to a unique personal computer, running the Linux operating system, by means of far-end custom-made PCI receiver boards operating in direct memory access (DMA) mode in order to maximize the data transfer rate.

Among the new functionalities recently added to the front-end DAQ system, by means of programmable logic devices (FPGA) are: e.g. i) a bi-directional asynchronous serial (UART) link between the user PC and any individual channel of the DAQ system; ii) a digital trigger with user definable thresholds for every channel, able to detect even very low level pulses with small amplitude-to-time skew; iii) a digital estimator of baseline level for each channel, working even in presence of low-to-medium rate (100/200 cps) of incoming events.

The back-end side of the DAQ system has recently been upgraded to improve the maximum sustainable transmission rate value, which is now 120 MByte/s (limited to 60 Mbytes/s in case of data storage on disk); the PCI receiver boards provide the acquisition clock to the flash ADCs and handle the initial synchronization procedure between all the acquisition channels (inside or outside of this DAQ system). A user friendly interface is provided on the PC side in order to control the acquisition process, to store or retrieve data to or from the disk and to control also powerful on-line calculations: e.g. moving window deconvolution, trapezoidal filtering, histogramming of energy estimations, etc.

The 4-channels DAQ NIM module, showing differential and single ended input connectors.



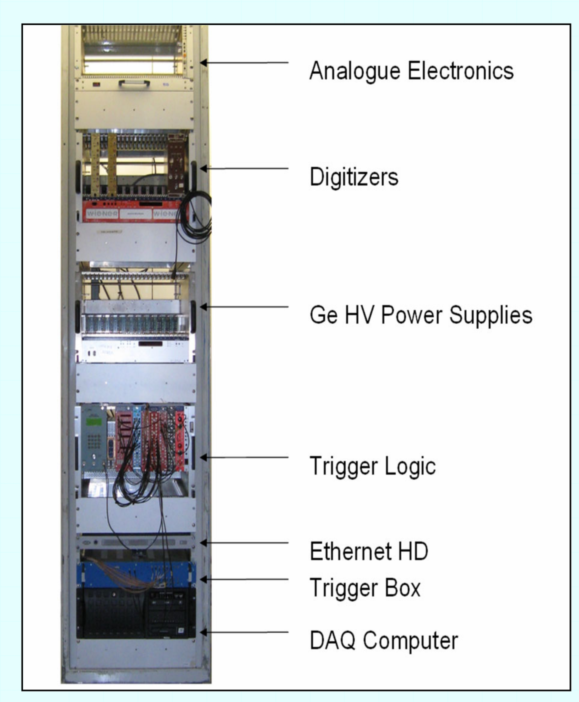
The DAQ NIM module (analog front-end and ADC boards visible on the right) is connected to the PCI receiver board by LVDS signals through commercially available twisted cables.

Performances

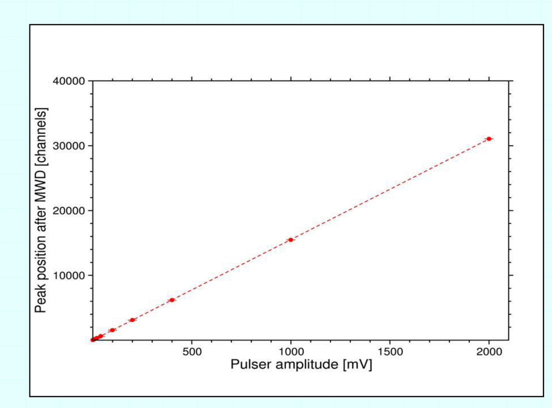
In order to evaluate the intrinsic performances of the DAQ system in terms of noise, linearity, bandwidth, effectiveness of the digital trigger, we connected it to a spectroscopy-grade pulser (Model PB5, BNC) and subsequently to a very low capacitance BEGe detector attached to a state-of-the-art charge sensitive preamplifier.

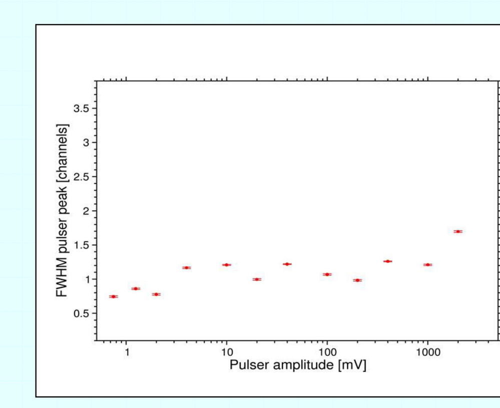
The DAQ non-linearity estimated with the pulser is of the order 1 channel over 16000. The preliminary performance of the DAQ system connected to the BEGe detector showed intrinsic energy resolution better than 0.63 keV FWHM, estimated on the 59.4 keV line of ^{241}Am, while the 1332.5 keV line of ^{60}Co was acquired with 1.63 keV FWHM (both results for 7 µs moving window deconvolution).

This energy spectrum has been acquired using the DAQ internal digital triggering algorithm. While not clearly visible due to its very low relative counting rate, a 11 keV energy line in the histogram sets, up to now, the minimum measured energy threshold for the sensitivity of this trigger with a Ge detector (dynamic range > 130). On the other hand, the trigger was able to react to pulser signals in a range from 2 V down to 0.5 mV (dynamic range > 4000). Additional investigation is currently going on the baseline estimation function.

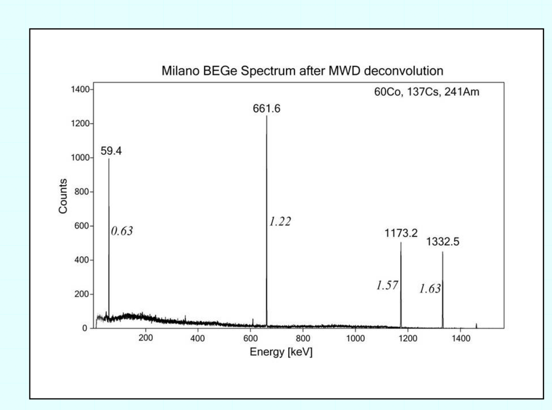


The whole DAQ system (16 channels) for the Germanium detectors of the GERDA experiment at the LNGS underground facility. Additional electronics modules are also present.

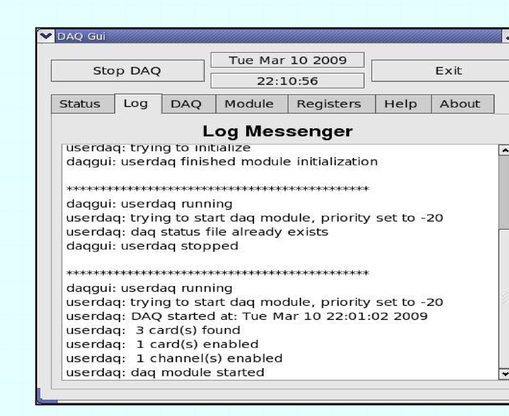




Results of the DAQ linearity test with the pulser, showing non-linearity errors within 1 channel over 16000.



Energy spectrum obtained with the DAQ in auto-triggering mode (1500 events/s), showing the energy resolution (FWHM) for various energy emission lines.

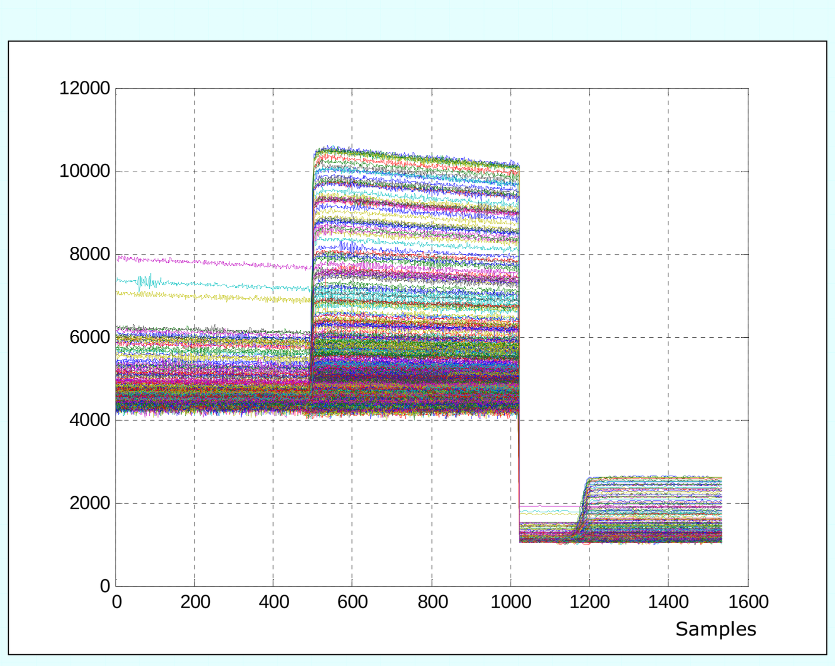


A sample view of the graphical user interface implemented on the PC in order to control the acquisition.

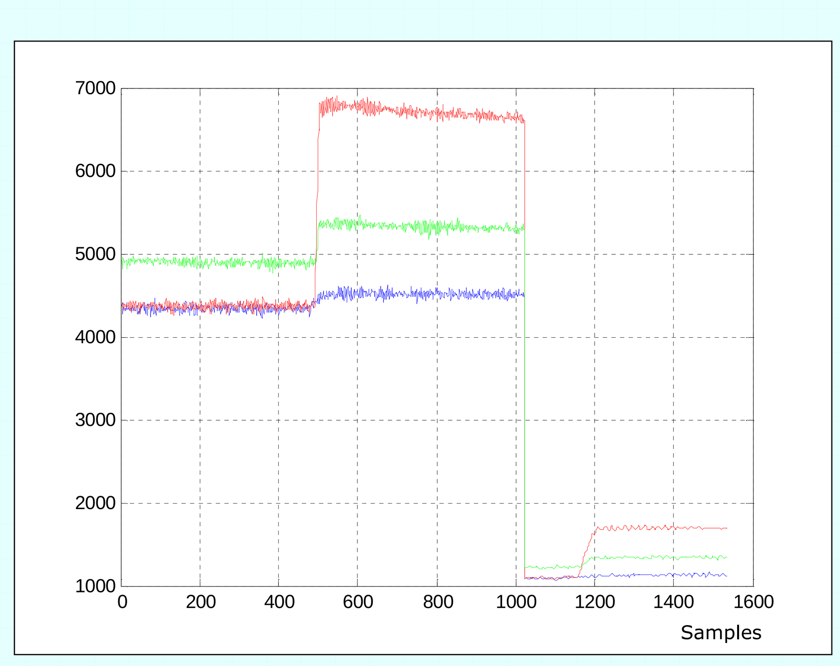
Tests at the LNGS underground facility

Several tests have been performed also at the LNGS underground facility, within the framework of the GERDA experiment. In the last months a string of three non-enriched and non-encapsulated Ge coaxial detectors has been connected to the CC2 Charge Sensitive Preamplifier (CSP) readout electronics (see N47-143 poster) and the three output signals have been acquired with this DAQ system. The results have also been validated by comparing those obtained with a commercially available system.

The experimental set-up as a whole (detectors, holder for the detectors, cables, cryostat, etc.) is still not specifically optimized from the electronic viewpoint and for spectroscopy energy resolution and, on the other hand, is clearly quite susceptible to disturbance pick-up. Still, the functionalities of the DAQ system have been tested and proved to work according to the specifications of the GERDA experiment. In the next months, additional work will be devoted to reduce the effects of disturbances on the Front-End (the charge-sensitive preamplifiers) and DAQ electronics.



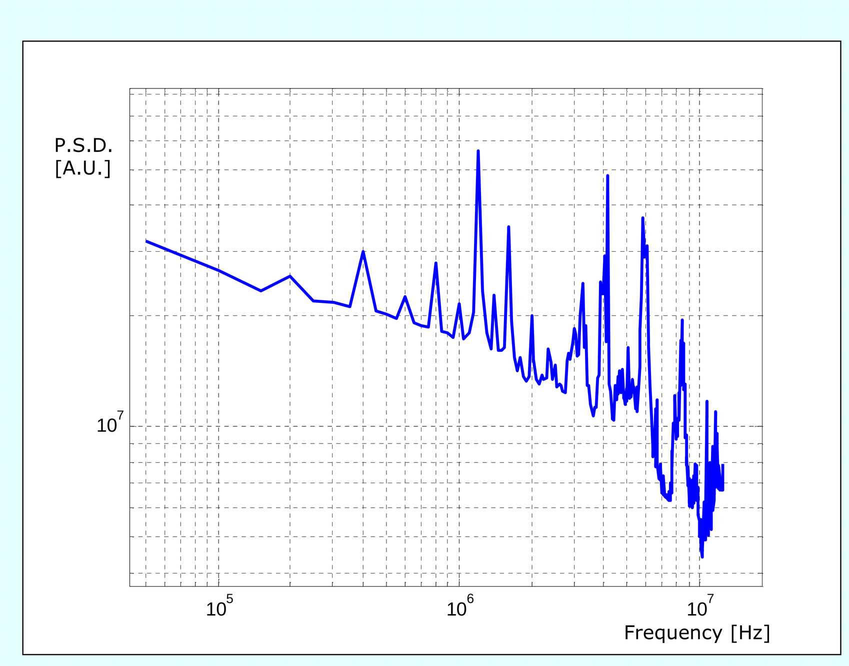
In order to estimate the performances of the DAQ system and of the subsequent numerical processing of pulses in terms of achievable energy resolution, several millions of events have been collected and stored during specific calibration runs with a Thorium radioactive source. In this figure, 2000 superimposed pulses are shown, both in the decimated form (by a factor of 4, up to sample 1024, corresponding to 40 us of time) and in the original form to preserve all the information of the signal front for pulse shape analysis (from sample 1025 to the end, corresponding to 5 us of time).



Three individual pulses are represented, clearly showing the presence of superimposed disturbances at specific frequencies.

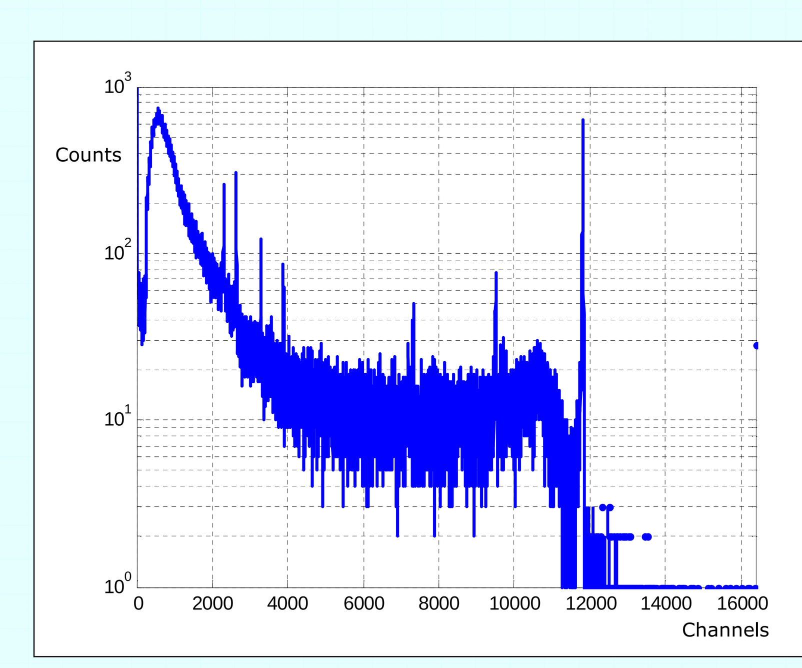
Almost the same amount of disturbance affects all the three DAQ channels, with a considerable level of correlation (around a factor of 0.8).

The dynamic range of the DAQ system during the calibration run was matched to that of the CC2 CSP (12 MeV), although the maximum energy of the calibration source was only around 2.6 MeV.



The power spectral density of noise, calculated over the baseline portion of a set of 20.000 pulses, clearly confirms the presence of high-frequency, narrow-banded disturbances, appearing as sinusoidal shapes in time.

Standard digital filters for energy estimation (like trapezoids) may suffer from such disturbances even more than their analog counterparts (like standard gaussian weighting functions). In case the residual amount of disturbances will still be relevant after basic optimizations, specifically optimized digital filters could be worth trying.



By applying a standard trapezoidal filter, 40 us long with 1 us flat top and no additional baseline subtraction, energy resolution of 4.5 keV FWHM has been achieved for the Thorium spectral line of 2.6 MeV. The available dynamic ranges of the charge sensitive preamplifier and DAQ system were nonetheless above 12 MeV. The digital trigger can then work over a dynamic range of at least a factor of 100, even in presence of picked-up disturbances.

[1]: 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]: "A Multi-Channel Digital Acquisition System for Nuclear Spectroscopy Experiments", S. Riboldi et al., 2009 IEEE-Nuclear Science Symposium.