The GALATEA test-facility for High Purity Germanium Detectors

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Abstract
GALATEA is a test facility designed to investigate bulk and surface effects in high purity germanium detectors. A vacuum tank houses an infrared screened volume with a cooled detector inside. A system of three stages allows an almost complete scan of the detector. The main feature of GALATEA is that there is no material between source and detector. This allows the usage of alpha and beta sources as well as of a laser beam to study surface effects. A 19-fold segmented true-coaxial germanium detector was used for commissioning.

Keywords: Germanium detectors

1. Introduction

High Purity Germanium (HPGe) detectors are used in many low background experiments, especially for neutrinoless double beta decay \cite{1} and direct dark matter \cite{2} searches. HPGe detectors will also be used in future large-scale experiments. This requires complete understanding and characterisation of such detectors. Unavoidable background events are identified based on knowledge of detectors response. A good understanding of the detector response is also essential for further detector development. When developing detectors, it is essential to have a flexible test-facility. It is, in general, desirable to completely scan the detector surfaces. The vacuum test-facility GermaNium LAser TEst Apparatus (GALATEA) presented here was designed to study the properties of HPGe detectors in detail, with a focus on surface effects \cite{3}. In order to perform these studies, non penetrating

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radioactive sources are used to scan the detector surfaces. The sources are collimated towards the detector; there is no material on the path of the probing particle.

2. The experimental setup

The GALATEA test-facility is based on a vacuum tank housing a system of three stages surrounding the detector holder. The latter is cooled by a liquid nitrogen reservoir via a copper cooling finger. The three-stage system is used to move two collimated radioactive sources, one across the top and one around the mantle of the detector. The collimators slide along two slits in an infrared (IR) shield surrounding the detector (see section 2.3 Fig. 5 (b)). This system allows an almost complete scan of a cylindrical detector. Figure 1 depicts the schematic of GALATEA.

![Figure 1: Schematic view of the interior of the GALATEA test-facility.](image)

2.1. The vacuum chamber

The main vacuum chamber, which basically contains the whole setup, is based on a 65 cm high stainless steel cylinder with an inner diameter of 60 cm and a wall thickness of 5 mm, see Fig. 2 (a). The system is closed by a stainless-steel lid. Between lid and body, a modular chamber with four measurement ports is mounted, see Fig. 2 (b). The ports host two different pressure gauges and an inlet vent to purge the system with gaseous
nitrogen. The presence of two pressure gauges with different operating ranges and different positions assures an excellent monitoring of the vacuum quality. Towards the bottom of the chamber, there is a DN 160 ISO-K weld-on nozzle which connects the main volume to a DN 160 ISO-K stainless steel cross with six DN 160 ISO-K flanges. The cross hosts the cable feed-throughs and pipes serving internal instrumentation, the stage motors, the detector read out and the cyotank [4]. A turbo pump is connected to one of the DN 160 ISO-K flanges of the cross through a VAT gate-valve (shutter). The shutter is used to disconnect the vacuum volume from the pump in order to eliminate microphonic effects which, otherwise, would make the detector operation impossible.

Figure 2: a) technical drawing [4] of the main vacuum chamber and the lid. b) technical drawing [4] of the modular chamber housing the measurement ports.

All seals, but the one for the lid, are metallic. The lid is sealed with a viton O-ring. The viton O-ring preserves a good vacuum while allowing to open and close the facility multiple times. The use of metallic seals in all the other flanges is, however, crucial to maintain a good vacuum ($\approx O(10^{-6})$ mbar) for several days without pumping.
2.2. The cryogenic system

Germanium detectors have to be operated at cryogenic temperatures, ideally at about 100K. GALATEA is equipped with an internal 30 liters stainless steel cryostat, automatically refilled, see Sec. 3, with liquid nitrogen (LN$_2$). It is located on the bottom of the main vacuum chamber and has a cylindrical shape with an outer diameter of 48 cm and a total height of about 16 cm. The cryotank rests on three bolts with a contact area of $\approx 7 \text{ mm}^2$ each to minimize its thermal coupling to the outside wall. A copper cooling-finger, 290 mm long, 16 mm in diameter, emerges through a ceramic flange on top of the cryotank. Ceramic was chosen to electrically decouple the detector holder sitting on top of the cooling-finger from the rest of the setup. As shown in Fig. 3, the top of the cryotank is covered by a Polytetrafluoroethylene (PTFE) plate, 27 cm x 27 cm x 4.5 cm, supporting the three-stage system. It acts both as a thermal and an electrical insulator between the stages and the cryotank.

![Figure 3: On top of the cylindrical cryogenic tank, a PTFE plate (white) surrounds the ceramic flange for the cooling finger. On the right side, an aluminum structure which houses the readout electronics is mounted.](image)

To thermally insulate the inside from the outer wall, a thermal shield, made of 3 layers of super-insulation foil, COOLCAT$^1$ covers most of the inner surface. Figure 4 shows the mesh (stainless steel) used to hold the

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$^1$Multi-layer cryogenic foil: each layer consists of 10 spot welded sub-layers, made of double-sided aluminized 6 $\mu$m polyester-film (perforated), interleaved with 10 sub layers of polyester knit-woven spacer $^2$.
insulation foil approximately 1 cm apart from the outer wall. To further reduce the thermal coupling between the cryotank and the outside wall, the side surface of the cryotank itself is also covered by three layers of COOLCAT.

Figure 4: Left: cylindrical mesh with COOLCAT foil. Right: lid insulation.

2.3. The IR shield and the detector holder

Significant heat load on the detector will increase the leakage current and, thus, the noise. Therefore, the detector is surrounded by a cylindrical infrared, IR, shield made out of copper. The copper shield was electropolished and silver coated to both minimize oxidation on the surface and achieve good reflectivity for IR radiation. It is 109 mm high and has an inner diameter of 110 mm. It shields the detector from the rest of the system, especially from the electronics which is located close by, see Fig. 3. The IR shield is in direct contact with the base-plate of the cooled detector holder, see Fig. 5. This thermal contact is critical to keep the radiation load on the detector sufficiently low, so that it can be kept at a temperature of around 100 K.

The IR shield has two slits, about 2 mm wide, one on the top and one on the side. The collimators slide along these slits, moved by two linear stages. The shield and the linear stages are rotated by a circular stage, see Sec. 2.4. To avoid grounding problems, the IR shield and thus the detector are
carefully electrically decoupled from the motor system by means of PTFE tubes and nuts. The PTFE also guarantees a good thermal insulation.

2.4. The three stage system and the collimators

Three ultrahigh vacuum (UHV) motorised stages, designed for cryogenic temperatures between 80 and 100 K, move two collimated sources over the detector surface. Figure 6 shows a sketch, illustrating the scanning principle.

One collimated source is placed on top of the detector. For commissioning, an $^{241}$Am $\alpha$-source was used. Due to the low penetration power of $\alpha$ particles, this facilitated the study of the thickness of the dead layer of the detector and other surface effects. A second motor controls the vertical movement of the source covering the mantle. For commissioning, a $^{152}$Eu gamma source was mounted. The many gamma lines of the $^{152}$Eu source facilitated studies probing different depths in the detector. The contact material between the sliding collimators and the IR shield is black Murtfeldt [6], a plastic causing almost no friction between the two components, suitable for cryogenic temperatures and not transparent to IR. The aluminum-made collimator holders are fixed to their respective stages. Each collimator has 5 tungsten segments. Segments with central bore holes between 1 and 3.2 mm diameter are available. Figure 7 shows the stage plus collimator system.
Figure 6: Scanning principle: two linear motors (PLS-85 UHV CRYO, PImiCos), one on top and one on the side of the detector, sit on a rotation stage (DT-120 UHV CRYO, PImiCos) which moves the whole system in the azimuthal angle $\phi$. The linear motors have a precision of $\approx 1\,\mu m$ while the rotational one has a precision of about $0.02^\circ$. Figure taken from [4].

Figure 7: a) the three stage system. b) the stage plus collimator system fully installed in GALATEA. The top slider has a range of about 52 mm, the vertical one covers about 76 mm along the side of the detector while the rotational motor can go from 0 to $\approx 350$ degrees.
2.5. A special detector prototype

A special true-coaxial n-type HPGe detector was mounted and investigated in GALATEA during commissioning. This cylindrical detector, called Supersiegfried (SuSie), is 70 mm high, has an inner bore hole radius of 5.05 mm and an outer radius of 37.5 mm. The detector mass is 1634.5 g. It has a 5 mm thick segment on top of an 18-fold segmented detector \[7\], see Fig. 8. The thin extra layer, 19th segment, on top is unsegmented in \(\phi\) It was especially designed to study surface channel effects and charge trapping \[8\].

![Figure 8](image1.png)

(a) schematic view of the 19 segmented detector \[4\].

(b) the detector mounted in GALATEA.

2.6. Electronics and data acquisition

As shown in Fig. 3, an aluminum structure on top of the cryotank houses the main electronics board. It is mounted as close as possible to the detector in order to minimize the length of the read-out cables. The board supports 20 charge sensitive preamplifiers (CSA), PSC-823V, working with a RC-feedback circuit. The preamplifiers service the core and all the segment signals of the detector. The first stages of the preamplifiers are integrated on the board for the segment circuits. For the core circuit, the core Field Effect Transistor (FET) is integrated in the detector holder, right below the detector.

\[2\] A cylindrical coordinate system is used with the origin at the center of the detector and \(Z\) pointing upwards; \(\phi\) denotes the azimuthal angle.

\[3\] Each cm of cable adds 1 pF to the input capacitance affecting the preamplifier.
The grounding of the detector is provided from the preamplifier board via a massive copper band tightened to the cooling-finger on which the detector is mounted. The grounding scheme plays a fundamental role in the entire setup. A standard high voltage NHQ 206L iseg [8], HV, power supply is used to bias the detector. The HV is brought into the vacuum to the electronics board throughout a feed-through on one of the DN 160 ISO-K flanges of the cross. Figure 9 shows a schematic view of the electronics of the GALATEA teststand. More details can be found elsewhere [4].

The digitization of the preamplified signals takes place outside the vacuum chamber. A digital multichannel data acquisition (DAQ), XIA PXI Compact PCI, model PXHI-18 [9], with 75 MHz sampling rate is used. The DAQ records not only the energy and the time of the event but also the pulse in an up to 15 μs long window. This allows offline pulse shape analysis.
3. The online monitoring and the automatic LN\textsubscript{2} refilling system

The GALATEA operational conditions are monitored by a multiple-sensors system. The pressure, temperatures of different components, and the LN\textsubscript{2} level inside the cryotank are constantly recorded. The online monitoring system is important for safe operation. As mentioned in Sec. 2.1, the setup is equipped with two pressure sensors. Figure 10 shows the pressures measured by the sensors during operation. Two different regimes are clearly visible. The lower pressure, \( \approx O(10^{-8}) \) mbar, regime corresponds to the pumping, i.e. non-measuring, phase. The higher regime refers to the measuring phase when the turbo pump is turned off and its volume is separated from the vacuum volume after closing the shutter. As can be seen, the GALATEA tank ensures a vacuum of the order of \( \approx O(10^{-6}) \) mbar for more than 100 hours without pumping, allowing for extended measuring phases. This vacuum performance was achieved by rigorous conditioning during which the chamber and all other inside parts, but the detector and the electronics board,
were heated up to $\approx 150^\circ$C for several weeks while pumping. The electronics board together with the preamplifiers were conditioned separately at a temperature of about 80$^\circ$C. Many components had previously been cleaned in an ultrasonic bath and wiped with isopropanol. The temperature is monitored using PT100 temperature sensors placed in six different places inside the vacuum volume. The sensors are connected to the cryotank, the cooling-finger, the detector holder, the IR shield, the stages and the mesh holding the COOLCAT insulation foil. These sensors are fixed to the components by using a vacuum compatible glue in order to guarantee a good and uniform thermal contact. In Fig. 11, the temperature behavior is shown. As expected, the coldest parts are the cryotank, the cooling-finger, the detector and the IR shield. As these components have the best thermal contact to the LN$_2$, their temperatures are the most sensitive to the LN$_2$ level inside the cryotank. This is, indeed, reflected in the oscillating pattern of their temperatures, as clearly visible in Fig. 11. The oscillation amplitude for the detector holder is $\approx 4$ K. The monitoring of the temperatures, especially as close as possible to the detector, is very important since the pulse length changes with the temperature.

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**Figure 11:** Temperatures behavior inside GALATEA.
The LN\textsubscript{2} level inside the cryostat is monitored via a quadrupole capacitance measurement of a stainless-steel double cylinder capacitor \cite{12}, \cite{13}. The working principle is to measure the capacitance of a double cylinder capacitor which is located inside the cryotank, submerged in the LN\textsubscript{2}. The quadrupole measurement is performed by using two PT100 sensors, one placed at the bottom of the capacitor (minimum sensor) and one at the top (inner maximum sensor), as shown in Fig. \ref{fig:fig12}.

![Figure 12: Technical drawing of the cryogenic tank together with the LN\textsubscript{2} monitoring and refilling sensors system \cite{4}.](image)

The capacitance, $C$, of a cylindrical capacitor is given as

$$C = 2\pi \varepsilon_0 \varepsilon_r \frac{L}{\ln \frac{D_1}{D_2}}, \quad (1)$$

where:

- $D_1 = 8$ mm, outer diameter of the capacitor;
- $D_2 = 4$ mm, inner diameter of the capacitor;
- $L = 130$ mm, capacitor height;
- $\varepsilon_0$ vacuum dielectric constant;
- $\varepsilon_r$ dielectric constant of the medium (see Fig. \ref{fig:fig13}), which in this case can be either LN\textsubscript{2} ($\varepsilon_r = 1.43$ \cite{14}) or gaseous N\textsubscript{2} ($\varepsilon_r \approx 1$ \cite{14}).
There is a linear relation between C and the LN$_2$ fill level inside the capacitor, i.e. inside the cryotank. This linearity is clearly demonstrated in Fig. 14. The good thermal insulation of the system allows a LN$_2$ refilling cycle of about 40 hours.

A big LN$_2$ reservoir is placed next to the setup to provide the LN$_2$ supply. It is connected to the inlet port of the cryotank and is opened when the minimum PT100 sensor inside the cryogenic vessel is not at LN$_2$ temperature anymore. The refilling stops when the sensor placed at the end of the LN$_2$ outlet pipe (maximum sensor, see Fig. 12) reaches LN$_2$ temperature.
Figure 14: Time evolution of the capacitance of the double-cylinder capacitor monitoring the LN$_2$ fill level. When $C \approx 24$ pF the cryotank is full, while $C \approx 20.5$ pF starts a refill of the cryotank. A totally empty tank corresponds to $C \approx 18.5$ pF.

4. Commissioning

Figure 15 shows one of the first spectra of the core and the segments, taken during a calibration run using an uncollimated $^{228}$Th source placed outside the vacuum tank. After crosstalk correction, the spectra were calibrated using the $^{208}$Tl line which corresponds to 2614 keV. More details about the crosstalk correction procedure can be found elsewhere [4].

The energy resolution, defined as the FWHM of a gamma-peak, was evaluated for some of the most prominent peaks for both the core and the segments (1 to 18), see Table 1. Each peak was fitted with a Gaussian plus a first order polynomial function. The energy resolutions of the core and the 18 segments at 2.6 MeV ($^{208}$Tl) are $(5.92 \pm 0.04)$ keV and $(3.52 \pm 0.05)$ keV respectively [4].

A graphical representation of Table 1 is shown in Fig. 16. The small dependence of the resolution on the energy indicates that the dominant con-
Figure 15: Calibrated and crosstalk corrected $^{228}$Th spectra for the core (blue), the sum of the single-segment event histograms of segments 1 to 18 (green) and the 19th segment (red).

| Energy [keV] | FWHM [keV] |
|-------------|------------|
| Core        |            |
| 511         | 5.05 ± 0.17|
| 728         | 4.19 ± 0.32|
| 1408        | 5.44 ± 0.02|
| 1460        | 5.71 ± 0.05|
| 2204        | 5.52 ± 0.25|
| 2614        | 5.92 ± 0.04|
| Segments    |            |
| 511         | 3.14 ± 0.14|
| 728         | 2.63 ± 0.21|
| 1408        | 3.34 ± 0.02|
| 1460        | 3.10 ± 0.05|
| 2204        | 4.23 ± 0.32|
| 2614        | 3.52 ± 0.05|

Table 1: Energy resolutions for different gamma peaks, for both the core and the overlay of segments 1 to 18.

The contribution to the energy resolution comes from the electronics.
Figure 16: FWHM vs energy, both for the core (blue) and for the overlay of segments 1 to 18 (green).
5. Outlook

The GALATEA test-facility is now fully operational and studies with a collimated α-source are ongoing. Further studies with low-energy gamma lines and β-radiation are planned. Eventually, the installation of a tunable infrared laser is foreseen for more detailed studies of surface effects.

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