The COBRA collaboration

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Abstract

The aim of the COBRA experiment (Cadmium Zinc Telluride 0-Neutrino Double-Beta Research Apparatus) is to search for the existence of neutrinoless double beta-decay (0\textnu\beta\beta-decay) and to measure its half-life. The COBRA demonstrator at LNGS is used to investigate the experimental issues of operating CZT detectors in low background mode while additional studies are proceeding in surface laboratories. The current demonstrator consists of 64 monolithic, calorimetric detectors in a coplanar grid (CPG) design. These detectors are 1×1×1\,\text{cm}^3 in size and are operated in an array of 4×4×4 crystals. As a semiconductor material, Cadmium-Zinc-Telluride (CdZnTe or simply CZT) offers the low radioactivity levels and good energy resolution required for the search for 0\nu\beta\beta-decay. Furthermore, CZT naturally contains several double beta-decay candidates. The most promising is \isotope[116]{Cd} with a \textit{Q}-value of 2.8 MeV, which lies above the highest prominent \gamma-line occurring from natural radioactivity. In 2017 the main research activity aimed to upgrade the experiment to the so-called eXtenden DEMonstrator COBRA XDEM.

1
1 Activities at the LNGS

1.1 The COBRA demonstrator

The COBRA collaboration currently operates a demonstrator setup consisting of 4×4×4 detectors at the LNGS. The detectors are made of CDZnTe (CZT) – a commercially available room temperature semiconductor. Due to the poor mobility of holes inside CZT, a special readout electrode has to be used to compensate for this effect. COBRA uses a so-called coplanar grid (CPG) consisting of two interlocking comb-shaped anodes held at slightly different potentials. The bias in between is referred to as grid bias (GB). This way, only one electrode collects the charge carriers created via a particle interaction in the end. A bias voltage (referred to as BV) at the order of -1 kV forces the electrons to drift towards the CPG anode. The electrode at the lower potential collects these electrons and is called the collecting anode (CA) while the other one acts as a non-collecting anode (NCA). The complete signal reconstruction relies only on the induced electron signal, that is why CZT is referred to as single charge carrier device. Details on the reconstruction can be found in [5].

Each crystal is 1.0×1.0×1.0 cm³ in size and has a mass of about 6 g. Several isotopes, which are candidates for double beta-decays, are present in CZT according to their natural abundances. An overview can be found in Table 1. The most promising are ¹¹⁶Cd due to the high $Q$-value of 2814 keV and ¹³⁰Te because of its high natural abundance of about 34% and considerably high $Q$-value of 2527 keV. The results of the most recent peak search analysis for five $\beta^-\beta^-$ g.s. to g.s. transitions can be found in [6]. No signal was found, consequently, lower half-life limits could be set for the investigated double beta transitions on the order of $10^{19} - 10^{21}$ years. For the $0\nu\beta\beta$-decay of ¹¹⁴Cd the world’s leading limit was achieved.

Table 1: List of $0\nu\beta\beta$-decay candidates contained in CZT with their corresponding decay modes, natural abundances [7] and $Q$-values [6].

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Decay mode</th>
<th>Nat. ab.</th>
<th>$Q$-value [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>⁶⁴Zn</td>
<td>$\beta^+ / EC, EC/EC$</td>
<td>49.17%</td>
<td>1095.70</td>
</tr>
<tr>
<td>⁷⁰Zn</td>
<td>$\beta^-\beta^-$</td>
<td>0.61%</td>
<td>998.50</td>
</tr>
<tr>
<td>¹⁰⁶Cd</td>
<td>$\beta^+\beta^+, \beta^+ / EC, EC/EC$</td>
<td>1.25%</td>
<td>2775.01</td>
</tr>
<tr>
<td>¹⁰⁸Cd</td>
<td>$EC/EC$</td>
<td>0.89%</td>
<td>272.04</td>
</tr>
<tr>
<td>¹¹⁴Cd</td>
<td>$\beta^-\beta^-$</td>
<td>28.73%</td>
<td>542.30</td>
</tr>
<tr>
<td>¹¹⁶Cd</td>
<td>$\beta^-\beta^-$</td>
<td>7.49%</td>
<td>2813.50</td>
</tr>
<tr>
<td>¹²⁰Te</td>
<td>$\beta^+ / EC, EC/EC$</td>
<td>0.09%</td>
<td>1714.81</td>
</tr>
<tr>
<td>¹²⁸Te</td>
<td>$\beta^-\beta^-$</td>
<td>31.74%</td>
<td>865.87</td>
</tr>
<tr>
<td>¹³⁰Te</td>
<td>$\beta^-\beta^-$</td>
<td>34.08%</td>
<td>2526.97</td>
</tr>
</tbody>
</table>

A detailed description of the COBRA demonstrator can be found in reference [8]. This publication reports on hardware aspects like the DAQ electronics as well as the experimental infrastructure to monitor and ensure a stable operation under low background conditions. The experimental setup is located on two floors referred to as the upper and lower hut. The lower hut is a clean-room like environment hosting the actual detector setup, the passive shielding and the first stage of electronics. The signals are transmitted via 20m CAT 6 Ethernet cables to the upper hut where the main electronics and data-acquisition is located. Figure 1 shows an overview of the different shielding layers of the demonstrator in the lower hut.
The outermost layer consists of 7 cm borated polyethylene acting as a shield against neutrons. Following, there is a frame of welded metal plates to prevent the first part of the readout chain to be affected by electromagnetic interferences (EMI). Inside this EMI box the custom made and actively cooled preamplifier devices are placed. The inner shielding consist of a multi-layered structure of standard lead, ultra low activity lead and copper surrounding the detectors themselves. This inner shielding is embedded into a polycarbonate box which is continuously flushed with evaporated dry nitrogen to prevent radon from diffusing into the setup.

1.2 Maintenance shifts

The overall working time spent on-site at the LNGS was about 40 man-days in 2017. Four shifts have been carried out to maintain the COBRA demonstrator and to prepare the upgrade to the extended demonstrator XDEM.

A first preparation shift was carried out in April to take care of most of the mechanical tasks. This included the construction of a new cable tree for the differential signal transmission between the lower and the upper hut. The cable route is the same as for the existing demonstrator, going from the EMI shield in the lower hut through a wall in the back of the hut and then upstairs. Both feedthroughs at the wall of the lower and upper hut had to be widened in order to hold the additional cabling. Afterwards an intensive cleaning campaign took place to restore the clean-room like conditions in the lower hut before considering to open the inner shielding of the experiment. During this shift one of the batteries inside the uninterruptible power supply (UPS) system was exchanged. The faulty battery caused a lot of signal noise on all channels since there was no filtering of the LNGS input power anymore. In this two week period before the planned maintenance, the operation of some detectors was only possible at very high trigger thresholds of several hundred keV. Furthermore, the DAQ electronics suffered from several short
power shortages which are normally covered by the UPS system. As a consequence two FADCs stopped working properly, hence, the data of eight detectors could not be recorded in this time. Fortunately, the power supply of the detector array was not affected since this is backed up by a separate UPS unit in the lower hut. The situation was resolved by installing a new UPS battery in the upper hut and exchanging the faulty FADCs with spare devices. One of the FADCs could be fixed rather easily by flashing the firmware but the status of the second one seems to be unrepairable.

In order to prepare the intended low-threshold $^{113}$Cd run, the coolant in the cooling system of the pre-amplifier stage was replaced from pure water to a special cooling liquid. This upgrade makes it possible to cool the first stage of electronics, which is located inside the EMI shield close to the detectors, more aggressively down to temperatures of -20°C. The effect of the improved cooling will be discussed later in section 2.1. By the end of the first shift a complete calibration of the demonstrator with the available $^{22}$Na and $^{228}$Th calibration sources was performed. At this time 55 out of 64 detectors were active and performed without any issues. Unfortunately it was discovered shortly afterwards that the demonstrator faced another problem with a different part of the electronics. This issue turned out to be even more dramatical than the faulty UPS battery. After three weeks of intensive remote controlled testing it was decided that an additional shift is needed to resolve the new problem of coincident signal noise on all channels.

Right after the on-site shift in April a lot of effort was spent to identify the origin of the new noise incident via remote. A closer look into the data revealed that the overall trigger rate of all channels had increased by several orders of magnitude and that most triggered events were in coincidence. These characteristics were completely different from what had been observed before the lately completed on-site shift. The operation with a reasonably low trigger rate was only possible for arbitrary high thresholds of about 1-2 MeV, which was not sufficient for the planned measurement of the $^{113}$Cd spectrum.

No indication for the root cause of the sudden appearance of this new noise problem was identified before the arrival of the shifters at LNGS. On-site, the origin was found to be related to the bias supply of the detectors inside the main electronic rack in the lower hut. It was possible to rework the custom-made converter boxes from MPOD Redel multi-pin to the Sub-D 8w8 cable standard used for the detector supply cables. After fixing the problem, the demonstrator went back to smooth operation, thus, the preparation of the dedicated $^{113}$Cd could be continued.

As starting point for the anticipated $^{113}$Cd low-threshold run a third shift was carried out at LNGS when stable operation and the final ambient temperature were reached. Already in the beginning of 2017 the collaboration started the purchase of two new calibration sources from the company Eckert&Ziegler. The collaboration would like to thank the LNGS staff for their advice and help with the required paperwork, that minimized any delay in the delivery process. Both sources finally arrived at LNGS by the end of May. The first one is a replacement for the old $^{228}$Th source (LNGS-ID: 50) due to the fading activity of only about a few 100 Bq. It was found that reasonably high statistics can be achieved with the new $^{228}$Th source of about 10 kBq activity in a couple of hours compared to several days using the old one. Secondly, a $^{152}$Eu source (LNGS-ID: 142) of the same geometry with 5 kBq activity was purchased that features a intense $\gamma$-line at 122 keV. This line allows for the study of the detector performance and resolution at low energies not far away from the average trigger threshold. The previous lowest available $\gamma$-line at 239 keV was coming from $^{212}$Pb as part of the $^{228}$Th decay chain. Both
lines cover the energy range of the $^{113}$Cd decay with an endpoint of about 320 keV and are of special interest for the upcoming spectral shape analysis. It turned out that it is challenging to see the low-energetic $^{152}$Eu for the outermost detectors while using the calibration source at the central position within the detector array. This is mainly due to self-shielding effects of the detectors and the underlying strong Compton continuum of the higher energetic lines. To partly overcome this problem, the $^{152}$Eu irradiation was repeated for two additional central positions between the two upper and lower detector layers. The benefit of this improved positioning is still under evaluation.

The last shift in 2017 aimed to exchange the instrumentation of the nitrogen dewar that is used to heat the inside of the vessel to increase the evaporation rate for a continuous flushing of the inner shield of the experiment. The system had failed several times in the past and was entirely renewed in 2016. Unfortunately the exchange of the final part was delayed due to problems with the manufacturing of parts of the instrumentation. During the installation end of December 2017 the new instrumentation was slightly damaged but could be repaired on-site. Consequently, an additional iteration of the instrumentation design was developed which will improve the overall performance of the flushing system. The installation of this new instrumentation will be done during the upgrade to the COBRA extended demonstrator in early 2018.

2 Data-taking and analysis

In 2017 roughly two months of data-taking were lost due to the incident with the faulty UPS battery and consequent noise problems. The data quality of the first six months of 2017 is still under review. The second half of 2017 was dedicated to a special low-threshold run to investigate the fourfold forbidden non-unique $\beta^-$-decay of $^{113}$Cd. The aim is to contribute to the scientific discussion regarding the so-called quenching of the weak axial-vector coupling strength $g_A$ in nuclear processes. In reference [9] it is shown that the spectral shape of this highly forbidden $\beta$-decay is especially sensitive to the effective value of $g_A$.

2.1 Dedicated $^{113}$Cd run

More than 98% of the events recorded by the COBRA demonstrator are originating from the $\beta$-decay of $^{113}$Cd. This decay was already studied with an early predecessor of the current COBRA setup what resulted in a half-life of $(8.00 \pm 0.11{stat} \pm 0.24{sys}) \times 10^{15}$ years and a $Q$-value of $322.2 \pm 0.3{stat} \pm 0.9{sys}$ keV [10]. Due to the long half-life the average decay rate of $^{113}$Cd can be used to study the detector stability with an intrinsic monitor as was reported in [11].

After finalizing the hardware optimization for the low-threshold operation, the ambient temperature was lowered by increasing the cooling power of the pre-amplifier stage (see Figure 2). It was found that a temperature setting of $-10^\circ C$ is sufficient to reach a reasonably low temperature of about 2$^\circ C$ close to the pre-amplifier boxes. The operation at this temperature should prevent immediate condensation of moisture in case of a failure of the nitrogen flushing. The temperature effect on the signal noise and detector performance was studied in [12]. Compared to room temperature, a lower operation temperature is beneficial since the thermal noise component of the signal noise is reduced while the detector resolution for CZT is optimal around 10$^\circ C$. Since there is no thermal insulation of the setup, the temperature of the lead castle housing the detectors is slightly higher than for the directly cooled preamplifier devices, but stable at about 9$^\circ C$. At the same time the trigger threshold for each channel was optimized by monitoring the overall trigger rate.
Figure 2: Temperature surveillance of the COBRA demonstrator in the lower hut. The ambient temperature outside the shielding (green) is rather constant at 22°C. The temperature increases on short time scales indicate on-site activity at LNGS or a fail of the cooling unit due to short blackouts. The other two sensors are located inside the EMI shield (blue) and inside the radon shield (red) on top of the lead castle. This location is most representative for the actual detector temperature and was stable at 9°C for the complete 113Cd measurement.

Figure 3: Threshold variation of the COBRA detectors operational in the low-threshold 113Cd run. The solid lines indicate the average threshold per detector layer. Except for layer two most of the detectors could be operated with a threshold below 100 keV. Layer two suffers from the aftereffects of the noise problems that occurred in April 2017.

When the thermal equilibrium for the final temperature setting was reached, a complete calibration run was performed as mentioned in section 1.2. All detectors that revealed problems during the pre-calibration or an unstable trigger rate, which hints to noise problems, were switched off. In a second iteration, detectors with a comparable high threshold were deactivated to prevent possible cross-talk effects and to ensure a stable operation. An impression of the threshold variation can be seen in Figure 3. Finally, the low-threshold 113Cd run was started on July 31st. By monitoring the average trigger rate for each channel, the energy threshold for each detector was set on a weekly basis over the complete data-taking period. The data-taking was stopped in
February 2018 after an exposure of more than 1 kg day per single detector was reached. This allows for a single detector analysis to investigate the $^{113}\text{Cd}$ $\beta$-spectrum with a statistical ensemble. An overview of the analysis will be discussed in the next section.

2.2 $^{113}\text{Cd}$ spectral shape analysis

The COBRA collaboration has access to a set of $^{113}\text{Cd}$ template spectra calculated for different nuclear frameworks in dependence of the weak axial-vector coupling strength $g_A$. The calculations have been carried out for $g_A \in [0.8, 1.3]$ using the nuclear shell model (NSM) and two further frameworks for comparison. Figure 4 illustrates the complex $g_A$ dependency of the $\beta$-electron momentum distribution in form of a two-dimensional plot for the NSM.

Figure 4: Two-dimensional representation of the $g_A$ dependence of the $^{113}\text{Cd}$ spectral shape in the NSM. In order to compare the theoretical templates with the COBRA data, the decay rate for each $g_A$ slice is normalized to the accessible energy range limited by the individual detector threshold and the $Q$-value of the decay.

In order to compare such templates with the actual COBRA data, detector effects such as a finite energy resolution, an energy dependent signal efficiency as well as the individual detector threshold have to be taken into account. This is done by folding the templates with the resolution function $\text{FWHM}(E)$ and the energy dependent detection efficiency $\varepsilon(E)$. Afterwards the templates are normalized according to the accessible energy range per detector. The detector dependent $\text{FWHM}(E)$ is determined from calibration data using $\gamma$-lines between 122 keV and 2614 keV while $\varepsilon(E)$ is known from a Monte Carlo simulation based on GEANT4.

To achieve independence of the number of provided input templates and to compare the COBRA data for arbitrary $g_A$ values over the whole available $g_A$ range, an interpolation method based on so-called splines was developed \cite{13}. A spline is a collection of several polynomial functions over a range of points referred to as knots $(x_n, y_n)$. In between two neighboring knots a polynomial is defined by a set of boundary conditions. In contrast to a conventional parameter fit, no optimization process is involved since the spline is uniquely defined by the knots and the boundary conditions. Per definition all knots and so the original points of the templates are contained in the spline as well. For the interpolation the TSpline3 class of the ROOT software package \cite{14}
is used, which utilizes polynomials of grade three for the spline. The final comparison of the theoretical templates and the COBRA single detector spectra is done with a $\chi^2$ test to find the best match template and $g_A$ value.

The data analysis is currently ongoing and will be published in 2018.

### 2.3 Improved pulse-shape discrimination

During the processing of the raw pulses obtained from the single detectors, several quality criteria are used to discriminate between real physical events and events triggered by electronic noise or other disturbances. These criteria have been developed to ensure a maximized signal efficiency at high energies around the Q-value of $^{116}$Cd at 2.8 MeV. In the past it has been observed that some criteria are too strict in the lower energy region, which leads to different rates of the $^{113}$Cd decay compared between single detectors. Therefore, a careful review and evaluation process was done at TU Dresden. First results can be found in [15]. The data used for this study was recorded between June and September 2016 after firstly starting to lower the thresholds for the anticipated $^{113}$Cd investigation. An impression for the likelihood to have one event tagged by multiple quality flags is shown in Figure 5. For each flag $f$, two numbers ($p$ and $s$) can be calculated to quantify the level of overlapping with another flag $h$. The definitions are as following

$$s_f = \frac{\text{number of events, where any other flag triggered}}{\text{total number of events flagged by } f} = \frac{N(f|h \neq f)}{N_f},$$

$$p_f = \frac{\text{summed number of events of all other flags}}{\text{total number of events flagged by } f} = \frac{\sum_{h \neq f} N_h}{N_f}.$$

In the current implementation, already one flag is enough to declare an event as unphysical, which is sufficient for pulses with a rather high amplitude, hence, a high energy deposition. Currently, the implementation of a new event selection and the improvement of the existing framework is work in progress. The main idea is to evaluate each flag with respect to the uncertainty on the pulse quantities used in the flag declaration (e.g. rise time, pulse height) and to weight the single flags according to their impact.

Besides the data cleaning cuts, additional algorithms are used to reject background-like events while maintaining a high signal acceptance [2] [16]. Recently it was found that the successful discrimination between central and so-called lateral surface events (LSEs) can be combined with the developed method to distinguish between single- and multi-site events (SSEs and MSEs). This is done by using an adapted approach referred to as $A/E$ criterion, that was originally created for Germanium-based $\beta\beta$-experiment [17]. The quantity $A$ denotes the maximum amplitude of the current pulse and $E$ the deposited energy by a particle interaction. The current pulse is the first derivative of charge pulse that is directly reconstructed from the raw anode signals. MSEs feature smaller $A/E$ values compared to SSEs due to the imprints on the signal trace of the charge carriers’ drift through the detector bulk. The $A/E$ approach was successfully transferred to the COBRA CPG detector design and optimized with $^{228}$Th calibration data. The decay chain of $^{228}$Th features the deexcitation of $^{208}$Tl with the emission of a single photon of 2.6 MeV energy. At this high energy pair creation is the dominant interaction process with the detector material. The kinematics of pair creation lead to distinct areas in the energy spectrum that can be used as proxies for signal-like SSEs and background-like MSEs. These areas are the single-escape peak (SEP) at 2.1 MeV and the double escape peak (DEP) at 1.6 MeV. The SEP is expected to show a strong MSE fraction while the DEP features dominantly single-site
Figure 5: Impression of multi-flagged events. Every bin contains the number of counts selected by the corresponding pair of flags. On the diagonal, one can obtain the total number of counts for the given flag, whereas the histogram is symmetrical along the diagonal. The y-axis labels contain two numbers, $p$ and $s$, that quantify the level of overlapping of the flag $f$ with another flag $h$. It can be seen that some flag criteria show a complete overlap with another flag, which hints to some efficiency issues.

interactions. The energy dependent fraction of multi-site interactions after the optimization procedure can be seen Figure 6 for a single detector $^{228}$Th calibration.

For the shown calibration data the signal acceptance $\varepsilon_s$ for the DEP and background rejection $\varepsilon_b$ for the SEP are determined to

\[
\varepsilon_s = (94.8 \pm 1.6)\%, \\
\varepsilon_b = (62.4 \pm 2.4)\%.
\]

Similar efficiencies could be reached for all LNGS detectors.

2.4 Exploration of more physics channels

Given the total amount of data of the COBRA demonstrator array, several analyses have been started on other physics channels. Within the $g_A$ spectral shape investigation of $^{113}$Cd the data selection and pulse shape discrimination have been studied in more detail at lower energies. This leads to a better filtering and slightly decreased background. At the same time an ambitious program of data partitioning was started. The goal is to identify the runs with increased background index due to a fail of the nitrogen flushing and runs that were strongly affected by electromagnetic interferences. This will lead to a data set with reduced background and a smaller set that is enriched in background. The latter is of special interest to study the background composition. Preliminary studies have shown that a background reduction up to a factor of 4.6 can be reached with this partitioning technique. In combination with the updated
Figure 6: Fraction of identified multi-site interactions after optimization for a $^{228}$Th calibration with a CZT-CPG detector [4]. For comparison, the energy spectrum of $^{228}$Th in logarithmic scale is shown as well. Clearly visible is a high fraction of MSEs for the SEP at 2.1 MeV while there is only a rather small fraction of MSEs in the DEP at 1.6 MeV. Furthermore, the Compton continuum between 1 MeV and 2.3 MeV shows a comparable low MSE fraction, which is in agreement with the expectation. All $\gamma$-lines below 1 MeV show an increased MSE fraction due to the dominating process of primary Compton scattering followed by a photoelectric absorption.

$A/E$ pulse shape selection a $2\nu\beta\beta$ half-life measurement of $^{116}$Cd seems to be within range. In addition, a first multi-detector analysis has been started to search for positron emitting modes and excited state transitions. Combining detectors leads to an indication of a $^{40}$K background component which was barely visible in the single detector spectra. A large Monte Carlo campaign was started to explore the signature of EC/$\beta^+$ decays of $^{106}$Cd for the COBRA demonstrator.

3 Preparation of XDEM installation

The COBRA collaboration is aiming to upgrade the experiment with the installation of a new prototype detector layer consisting of nine 6 cm$^3$ detectors. As the new layer will be implemented into the existing setup without interfering with the current 4×4×4 array, the new stage is referred to as eXtended DEMonstrator (XDEM). The upgrade will almost double the sensitive detector mass and is the first major expansion since the finalization of the COBRA demonstrator in 2013. The preparation of the XDEM installation took place in 2017 and will be summarized in the following sections.

3.1 Detector characterization

In 2017 a total of ten 6 cm$^3$ CZT detectors were purchased by the COBRA collaboration. The two world-leading manufactures for CZT detectors eV Products (now Kromek, US) and Redlen technologies (Canada) were chosen based on the results obtained with very first prototypes. A detailed overview about the first detector characterization is given in [18]. Each detector is equipped with four CPGs on the anode side that are rotated by 90$^\circ$ and a common planar cathode electrode. This readout design is referred to as quad-CPG and overcomes the problem of too high leakage currents, which prevents the use of up-scaled versions of the 1 cm$^3$ detectors. It
Figure 7: Picture of CPG-CZT detectors investigated by the COBRA collaboration. The 1 cm$^3$ version in the front is used in the 4×4×4 array of the COBRA demonstrator. The larger 6 cm$^3$ crystals are prototypes that were studied in detail over the last two years. It was found that the up-scaled single CPG version (right) is facing problems with leakage currents limiting the achievable resolution. To overcome this problem, the anode side was segmented into four individual sectors (left) offering additional veto capabilities.

could be shown that the interaction depth reconstruction, which is a powerful tool to discriminate background, can be transferred to this new approach [3]. In Figure 7, a comparison of the different detector designs investigated by the COBRA collaboration is shown. The new quad-CPG detectors arrived in the middle of 2017 at TU Dortmund and were contacted and tested extensively. One improvement with respect to the treatment of the 64 detectors of the current demonstrator is the special care that was taken during the detector handling by the manufactures and in the surface laboratories. Also the packaging during the shipment was air-tight sealed, in contrast to previous orders. For the contacting a modified method was used compared to the demonstrator setup, as the electric connection is now done with the help of a highly radio-pure conductive epoxy and gold wires instead of the combination of a conductive lacquer and a conventional glue. This is a significant reduction of the number of potential background sources. The new method also allowed to contact the detectors almost completely at TU Dortmund in order to minimize the effort in the underground laboratory during the installation. Furthermore, the contacting has been performed in a clean laminar-flow environment and the detectors were kept in a nitrogen atmosphere during storage and testing. Together with the use of the guard-ring, which has been shown to be able to reduce surface related backgrounds from α-decays by more than three orders of magnitude [1], and the beneficial surface-to-volume ratio of the larger detectors, the collaboration is confident to reduce the background index significantly compared to the demonstrator setup.

The characterization of each detector included the determination of the ideal working point (combination of grid and bulk bias, Figure 8) as well as measurements to determine the individual relative efficiency. All characterization measurements were taken in a nitrogen atmosphere to prevent any radon contamination, which turned out to be the dominant background component for the current setup. Furthermore, the electrical behavior was characterized with current-voltage (I-V) measurements and a number of different γ-sources have been used to study the energy resolution of the detectors. One of the detectors was also used for a new investigation of
the guard-ring electrode with the goal to show the possibility to suppress also β-decays on the surface by cutting on the pulse height of the guard-ring electrode.

3.2 Plan for implementation

The installation of COBRA XDEM requires to rework parts of the inner passive shielding. The new detector layer will be located on top of the current demonstrator array in a new copper housing. For the innermost parts of the detector housing electro-formed OFHC copper is used that has been stored underground at the Dresden Felsenkeller laboratory for more than five years. All copper parts were electro-polished by an external company and treated according to a multi-stage cleaning procedure at LNGS prior the installation. The cable feedthroughs and routing for the calibration tube is made from certified ultra-low activity lead and arrived at LNGS in December 2017. The installation of the XDEM setup was done in March 2018 within a two week lasting shift. Some impressions of the installation are depicted in Figure 9. The nine best performing detectors were selected and put in a frame of Polyoxymethylen (POM). This frame was then put into the copper housing surrounded by one layer of ULA lead and two additional layers of standard lead. The air-tight radon cage around the lead castle had to be renewed in order to included the additional readout of the XDEM channels. The preamplifier stage including the cooling section was upgraded as well. It could be confirmed that all detector contacts are electrically working although not all channels can be read out at the time of this report. The commissioning of COBRA XDEM is ongoing but from preliminary data taken in the laboratories and at LNGS it is already clear that the new detectors will surpass the COBRA demonstrator in terms of achievable resolution and background index.
Figure 9: First impressions of the upgrade to COBRA XDEM. Left: new copper housing made from electro-polished OFHC copper and calibration routing. Middle: final XDEM detector layer consisting of a POM holder and nine 6 cm$^3$ quad-CPG detectors. Right: installed XDEM detector layer within the copper nest on top of the COBRA demonstrator array.

4 Summary and outlook

The main activities of the collaboration in 2017 were the preparation and start of a dedicated $^{113}$Cd measurement with the COBRA demonstrator and the preparation of the upgrade towards COBRA XDEM. The demonstrator setup was optimized for low-threshold operation to cover a maximum range of the fourfold forbidden non-unique $\beta$-decay spectrum of $^{113}$Cd. The spectral shape of the $\beta$-electron distribution is highly sensitive to the effective value of the weak axial-vector coupling strength $g_A$ involved in nuclear processes. An analysis strategy was developed to extract the best matching theoretical template for an assumed value of $g_A$. A dedicated $^{113}$Cd run was started in July 2017 with optimized detection thresholds and operation conditions. The data-taking was stopped in February 2018 and the results of the spectral shape analysis will be published soon.

The analysis of the demonstrator data was expanded towards more physics channel with focus on the $2\nu\beta\beta$-decay of $^{116}$Cd using an advanced data partitioning. The sensitivity to more exotic double beta-decay modes such as EC/$\beta^+$-decays is currently studied with Monte Carlo simulations.

The collaboration purchased ten new prototype quad-CPG detectors to upgrade the experiment to COBRA XDEM. All detectors passed the quality requirements in terms of energy resolution and overall performance. From the characterization point of view the new XDEM detectors will surpass the average of the current demonstrator detectors. The nine best performing detectors were successfully installed in March 2018 at LNGS, which almost doubles the sensitive mass of COBRA. The commissioning is still ongoing and not all channels are operational at the moment, but first calibration and physics data is already looking very promising. First results and a background characterization are expected for the end of the year.
List of publications in 2017


References


