

Status and perspectives of the COBRA experiment

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Abstract

COBRA is a neutrinoless double beta decay ($0\nu\beta\beta$) experiment using an array of Cadmium-Zinc-Telluride semiconductor detectors, the isotope of interest being ^{116}Cd with a Q-value of 2814 keV. To investigate the experimental challenges of operating CdZnTe detectors in low background mode and to identify potential background components, a demonstrator setup is operated at the Gran Sasso underground laboratory (LNGS) in Italy, while additional studies are proceeding in surface laboratories. The experiment consists of monolithic, calorimetric detectors of coplanar grid design (CPG detectors). These detectors have a size of $1\times 1\times 1\text{ cm}^3$ and are arranged in four layers of 4×4 detectors. An overview of the current status and of future perspectives is given. Results of pulse shape analyses are presented as well as background estimates using the data collected so far.

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Selection and peer review is the responsibility of the Conference lead organizers, Frank Avignone, University of South Carolina, and Wick Haxton, University of California, Berkeley, and Lawrence Berkeley Laboratory

Keywords: neutrinoless double-beta-decay, low background

1. Introduction

The COBRA experiment [1] is planning to use a large amount of CdZnTe (CZT) room temperature semiconductor detectors for the search of neutrinoless double beta decay ($0\nu\beta\beta$). CZT contains 9 candidate isotopes for $0\nu\beta\beta$, including electron capture and positron decay modes. The isotope with the highest Q-value of 2813.50(13) keV [2] in the two electron mode is ^{116}Cd . This isotope is the main target of the search, since its Q-value lies above the highest relevant naturally occurring gamma line (^{208}Tl at 2614.6 keV).

To demonstrate the potential of COBRA and study the experimental challenges of such an experiment, a setup of 64 CPG (coplanar grid) detectors is installed at the LNGS. These detectors have a size of $1\times 1\times 1\text{ cm}^3$ and are arranged in four layers of 4×4 detectors. They are surrounded by a shielding of ultrapure copper and lead, complemented by an additional layer of borated Polyethelene and an EMI-shielding. To decrease the background from airborne radon, the setup is continuously flushed with nitrogen. For further details see [3].

The CPG technology was developed as a method to compensate for the poor transport properties of holes in CdZnTe [4]. With this readout approach, energy resolutions of better than 2% FWHM at 662keV can be achieved with commercially available detectors. One side of a CPG detector is covered by an uniform cathode, while two anode grids are patterned on the opposite side in the form of two interlocking combs (see Figure 1). These anodes are kept at slightly different potentials and are read out separately. The amplitudes

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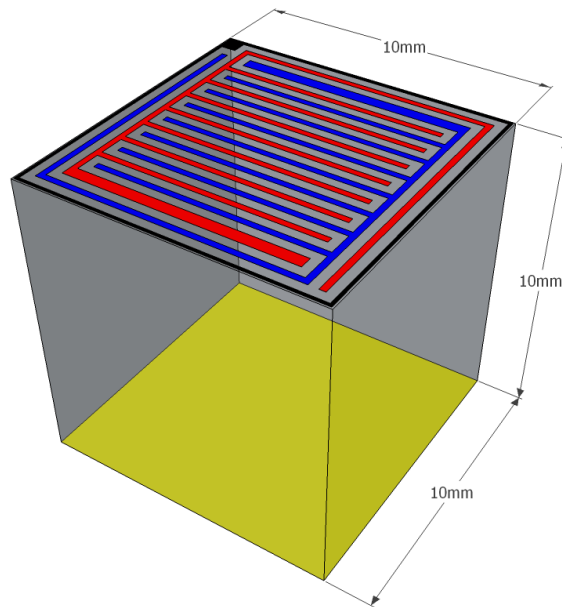


Fig. 1. Schematic drawing of a CPG detector indicating the anode grids (blue and red) and the cathode (yellow).

of these two pulses form the basis of event reconstruction, using the electron signal only. The hole signal is too poor to be useful and thus the cathode is not read out.

At what fraction the collected charge is divided among the two anodes depends on the spatial distance of the energy deposition towards them. Thus, the pulse heights can be used to reconstruct the position of the energy deposition with respect to the axis connecting the cathode and the anode side, henceforth called the interaction depth z , with $z = 1$ cm indicating the cathode side. A refined model for the calculation of the interaction depth, including first order trapping effects, has recently been presented in [5]. This gives an accuracy in z of about 0.1 mm.

In addition, the time-dependent development (pulse-shape) of the anode pulses can be exploited to get further information about an event. For example, it has been shown in [6] that the discrimination between single-site and multi-site events (SSE/MSE) is possible. For this reason, the COBRA demonstrator setup is read out by FADC with a sampling rate of 100 MHz. Furthermore, pulse-shapes are used to identify lateral surface events in the data of the COBRA demonstrator setup, as described in [7].

2. Current status

The first layer (4×4 detectors) of the demonstrator setup has been installed in November 2011. Since then, the other three layers have been subsequently added; the final one at the end of 2013. By the end of 2013 about 100 kg-days of data have been collected, with roughly 10 kg-days of additional data being accumulated every month. Calibrations using a thorium and a potassium source are performed every few weeks. Figure 2 displays the data as of summer 2013 in the form of a scatter plot, showing the interaction depth over the energy deposition. At very low depths, distortions in the energy reconstruction occur as a consequence of the CPG design. At the cathode surface (interaction depth $z = 1$), the contamination with alpha emitters produces high-energy events at about 3 MeV and 5 MeV. Both the low-depth distortions and the high-depth surface events can be efficiently removed using the interaction depth information. Using the pulse-shape analysis from [7] to remove also lateral surface events, the background rate can be further reduced, as can be seen in Figure 3. This leads to a background rate of approximately 1 counts/keV/kg/y in the region of interest around 2814 keV, given per unit mass of detector material (CdZnTe). The relative

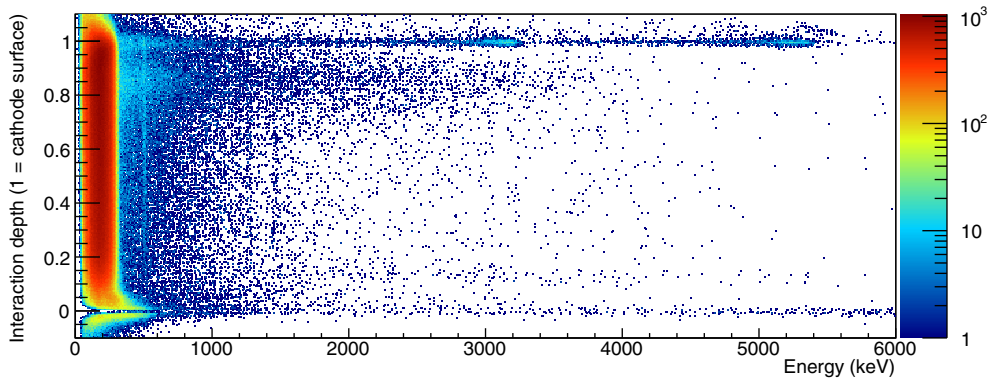


Fig. 2. Distribution of events in interaction depth and energy from 68.8 kg-days of low-background data. The two high energy regions on the cathode surface are identified as alpha contaminants. Three gamma lines (vertical) are also visible. The region below 400 keV is dominated by the β -decay of ^{113}Cd (half-life $8 \cdot 10^{15}$ years). At low interaction depths, well-understood distortions caused by the detector design and reconstruction artifacts can be seen.

efficiencies for the $0\nu\beta\beta$ decay signals of these cuts are estimated at 95% for the cathode cut and 82% for the lateral surface cut.

In Figure 3, two alpha peaks are evident for the data including the cathode surface events, but no peaks are seen if only the lateral surface events are kept. This is expected, as the cathode side is covered by only about 200 nm of metal, whereas the lateral surfaces are encapsulated in transparent paint of several $10 \mu\text{m}$ thickness. Thus, the measured energy of alpha radiation from the lateral surfaces is attenuated. Nonuniformities in the paint thickness will generally lead to a continuous spectrum. Laboratory tests with collimated alpha and gamma radiation have confirmed the effectiveness of the lateral surface cut, as has been shown in [7].

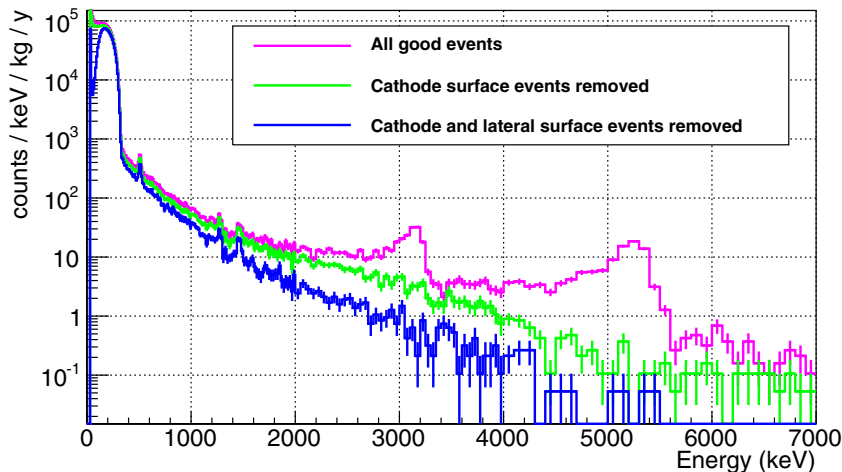


Fig. 3. Background rate spectrum before and after the removal of surface events.

Another feature noticeable in Figure 2 is the band of more intense background at an interaction depth between 0.75 cm and 0.95 cm. This is most likely due to alpha contamination on the detector support structure. The depth-dependence of the background can be exploited to reduce the background for the $0\nu\beta\beta$ decay search. The effective background rate based on an optimized sensitivity calculation at 2.8 MeV

is reduced to approximately 0.4 counts/keV/kg/y. The signal efficiency for the optimized sensitivity is approximately 95% relative to the nonoptimized case [3].

It has to be noted, that enough of the events caused by surface contamination survive all these cuts so that they still present the dominant background contribution. One of the corresponding alpha peaks has been identified as being evoked by Po-210. Thus, we mainly have to deal with the decay products of airborne radon accumulated at the detector surfaces. It is expected that this accumulation is enhanced due to the high voltage applied, which will be examined in further studies

3. Future perspectives

As shown in the previous section, the COBRA setup at the LNGS has already demonstrated the high potential of pulse-shape analyses to reduce the background. However, the pulse-shapes have not yet been used to analyse the contamination of the data with multi-site events. To optimise this analysis, a dedicated setup is currently employed, using the detection of compton scattered photons in a secondary sensor as an indication for single-site events in the primary CPG.

Another background reduction instrument at our disposal, that has not yet been put to use, is the coincidence analysis between multiple CPGs. This could be particularly useful to reduce background from neutron-induced gamma cascades. For this reason, a pulser allowing the synchronisation of the 64 CPGs of the current array has been installed in June 2013.

Both of these methods are not expected to reduce the background from surface contamination with alpha emitters. Therefore, different ways to either remove or prevent these contaminations are under investigation. This includes cleaning procedures as well as the detector handling between their production and their installation at the LNGS. For the present setup, neither a dedicated clean room nor a way to prevent exposure to radon previous to the installation had been available, leaving great potential for improvement.

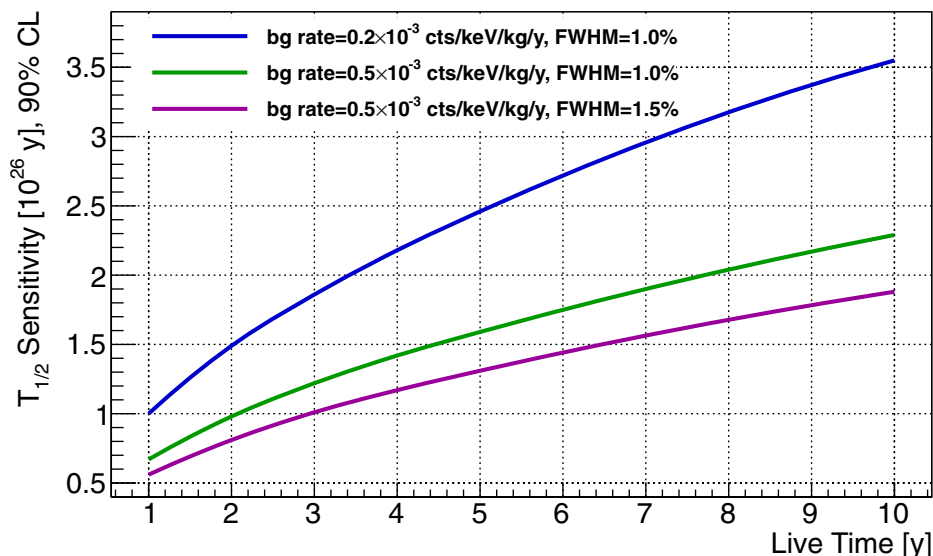


Fig. 4. Sensitivity estimations for a large-scale COBRA experiment for different background rates and energy resolutions (from [3]).

It also has been decided to use the largest ($2 \times 2 \times 1.5$) cm³ commercially available detectors in order to improve the surface-to-volume ratio. Figure 4 shows the sensitivity estimates for a large-scale experiment using 11,000 of such detectors, which corresponds to a total detector mass of roughly 400 kg. Further assumptions made for this estimation are an enrichment of 90% in ¹¹⁶Cd, an energy resolution of better than 1.5% (FWHM) and a background rate of less than 0.5×10^{-3} counts/keV/kg/y. Under these circumstances,

COBRA will be able to reach a sensitivity to an effective Majorana neutrino mass of less than $50 \text{ meV}/c^2$. Depending on the estimated number for the nuclear matrix element [8], this corresponds to a minimum ^{116}Cd half-life sensitivity of 1.0×10^{26} to 3.5×10^{26} years.

Other possible means to reach the extremely low background level needed for this kind of experiment could be pixelised detectors or the operation of the detectors in liquid scintillator. Pixelised detectors would allow for extremely effective background reduction by exploiting the topological information of the events, while the submersion in liquid scintillator would provide an extremely clean environment and additional shielding. Furthermore, it has been shown in [9] that it is possible to operate CdZnTe detectors in liquid scintillator without any additional passivation for the detectors. Thus, the lacquer presently coating the detectors could be completely eliminated as a potential background source. Both approaches are currently under investigation by the COBRA collaboration.

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