Recent progress of the COBRA experiment

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Abstract. The COBRA experiment uses CdZnTe semiconductor detectors to search for neutrinoless double beta decays. The main focus is on the isotope ^{116}Cd, with a decay energy of 2813.5 keV well above the highest naturally occurring gamma lines. Also ^{130}Te and ^{106}Cd, a double β^+ emitter, are under investigation.

An overview of the recent improvements of the COBRA low-background set–up at the LNGS underground laboratory is given, including first results obtained with new FADC readout electronics which allows background reduction by pulse-shape analysis. Furthermore studies on detector characterization, the use of liquid scintillator for background suppression and Monte-Carlo simulations of the shielding are presented. Also pixelated detectors and their capabilities of background reduction are discussed.

1. Introduction

The aim of COBRA is the search for neutrinoless double beta decay ($0\nu\beta\beta$) with a large number of cadmium zinc telluride (CdZnTe) semiconductor detectors [1]. Several candidate $0\nu\beta\beta$ isotopes are intrinsic to the CdZnTe detector material, among them two of the most promising isotopes, ^{116}Cd and ^{130}Te. ^{116}Cd is the most important isotope for COBRA due to its high Q—value of 2813.5 keV [2]. This decay energy is well above the highest naturally occurring gamma background (2614.5 keV from ^{208}Tl). ^{130}Te is interesting for $\beta^-\beta^-$ decay due to its high natural abundance of 33.8%. Also ^{106}Cd with a high Q–value of 2771 keV for positron decay in combination with electron capture is considered.

For a large scale experiment, an array of CdZnTe detectors with a total mass of 420 kg enriched in ^{116}Cd is proposed. This allows for coincidence studies to search for decays to excited states and to reduce background. With a background rate of 10^{-3} counts/keV/kg/year, the experiment would be sensitive to half–lifes $T_{1/2}^{0\nu}$ larger then 10^{26} years. CdZnTe detectors, like semiconductors in general, provide good energy resolution and are very clean with respect to radioactive impurities. The "Source = Detector" approach of COBRA makes a large detector mass easily achievable. A big advantage of CdZnTe detectors is the operation at room temperature.

2. Detector Technologies

Within the COBRA R&D program, two different detector technologies are investigated: Coplanar grid detectors (CPG) and pixelated detectors.

CdZnTe used as a semiconductor detector, has a high detection efficiency for γ–rays due to its high density (5.78 g/cm^3) and large atomic numbers (Z$_{Cd}$=48, Z$_{Zn}$=30, Z$_{Cd}$=52). As the

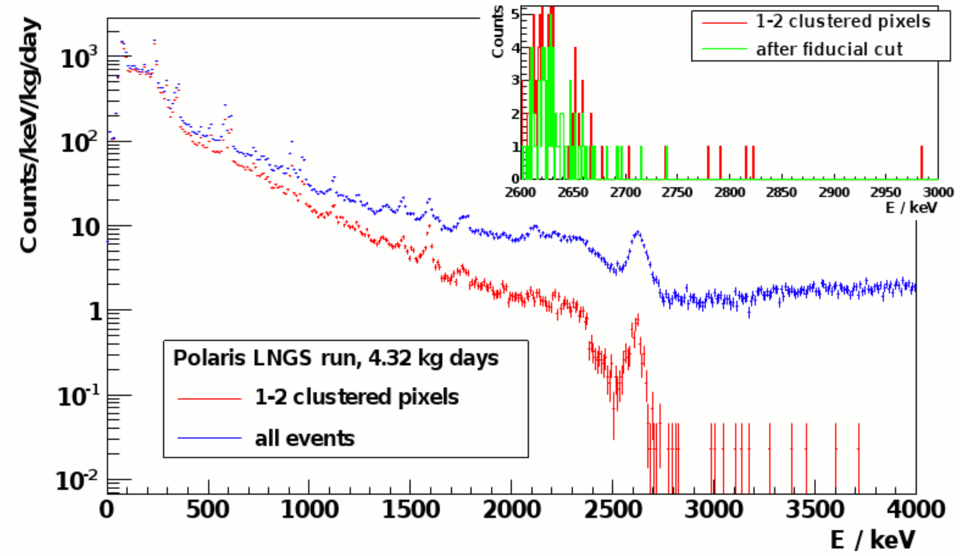

Figure 1. Background spectra of the Polaris detector at LNGS with and without analysis cuts. The cuts to one or two neighbouring pixel and a fiducial volume (up right) remove all events in the region of interest around 2813.5 keV.

generated holes are mostly trapped while drifting to the cathode, the coplanar grid technology was developed for CdZnTe detectors [3]. The anode is structured into two comb–shaped parts on a slightly different potential. The difference signal between these two anodes is then independent from the interaction depth and proportional to the deposited energy. Energy resolutions better than 2% FWHM at 2614.5 keV with cost efficient CPG detectors were achieved.

In case of pixelated detectors, the anode is structured as an array of isolated pixels. With this readout approach, tracking capabilities are added to the pure energy measurement of CPG detectors. This allows for fiducial volume cuts or even direct particle identification, if the pixel pitch is very small. This kind of detectors act like semiconductor time–projection–chambers and offer a unique possiblity of background discrimination. Due to the small pixel effect [4], the pixel technology solves the vanishing hole signal problem itself. The different pixel systems under investigation within the COBRA R&D program can be divided into large volume detectors (2 - 6 cm^3) with large pixel pitch ($\sim$1 mm) and thin detectors (0.3 - 2 mm) with small pixel pitch ($\sim$100 μm).

With a size of $2 \times 2 \times 1.5\,cm^3$ and a mass of 36 g, the Polaris system from the University of Michigan belongs to the large volume detectors. An energy resolution of 0.5% at 662 keV has been reached with this type of detector [5]. Although direct particle identification is not possible with 11×11 pixels, cuts to boundary and clustered pixel reduce the background significantly. A Polaris detector with a resolution of 2% took low background data at the Laboratori Nazionali del Gran Sasso (LNGS) for 125 days and zero events remain in the interval of 2 FWHMs around 2813.5 keV after both cuts, corresponding to 4 counts/keV/kg/year (Figure 1). This result shows the excellent background rejection capability of the system, that has not been optimized for low–background application.

With sizes of $14 \times 14 \times 1\,mm^3$ (CdTe detectors) respectively $14 \times 14 \times 0.3\,mm^3$ (Si detectors), the Timepix system belongs to the category of thin detectors with small pixel pitch (256×256 and 128×128 pixels are considered). Acting like a solid state TPC, the Timepix detector allows for track reconstruction and therefore direct particle identification. As alphas, betas and muons

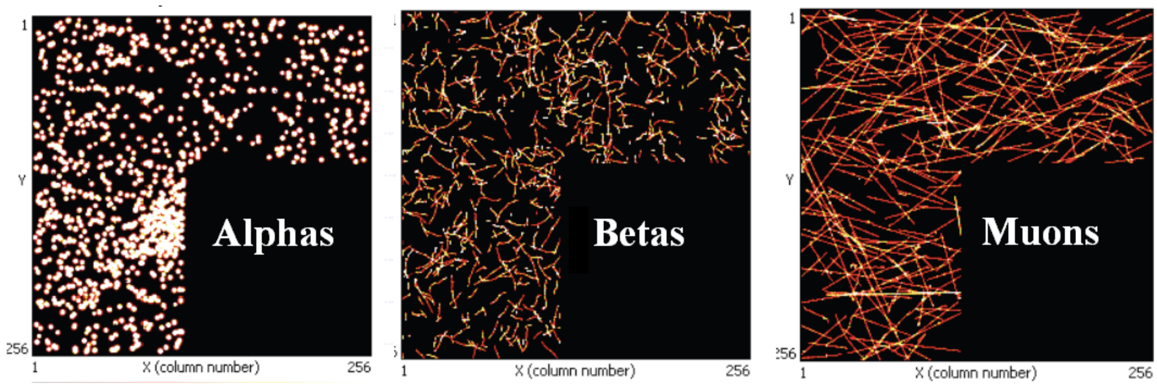

Figure 2. Measurements of alphas, betas and muons with a Si–Timepix detector. Due to the small pixel pitch, track reconstruction and direct particle identification is possible.

are clearly distinguishable, background events can be significantly rejected (Figure 2).

3. COBRA LNGS test set–up and R&D program

CPG detectors are used for low background data taking at the test set–up at the LNGS underground laberatory. The main background sources in the past were the red passivation of the detectors and radon from the air. With a new passivation and a nitrogen flushing system, a background rate of ~ 5 counts/keV/kg/year was reached. Six half–life limits above 10^{20} years and seven half–life limits within a factor 3 of world best were measured [6].

The set–up moved to the former Heidelberg–Moscow hut in spring 2011 and was greatly improved (Figure 3). The first layer of the passive shielding consists of high purity copper, followed by 2 ton of lead. Ultra low background lead is now used for the inner brick layer. The lead ist surrounded by a radon–tight foil and constantly flushed with nitrogen. The set–up is completed by an electromagnetic shielding and 7 cm of boron loaded polyethylen against neutrons.

The set–up can house 64 CPG detectors. Since summer 2011, 16 detectors are running with a new FADC readout (Struck SIS3300). With pulse–shape analysis, noise and surface events can now be rejected. Also, the discrimination of single–site and multi–site events is feasible and leads to further background reduction capabilities. Prior to installation at LNGS, all CPG detectors are scanned with a highly collimated ^{137}Cs source to determine their performance, especially energy resolution and charge collection efficiency. The radiopurity of all used materials at LNGS is measured at the Dortmund–Low–Background–HPGe–Facility (DLB). The facility offers an overburden of 10 m.w.e. and is equipped with an active muon veto. The ultra low background high–purity germanium detector in use has a mass of 1.2 kg and a relative efficiency of 60%.

For further reduction of background events originating from the detector passivation, the operation of bare CPG detectors in liquid scintillator is investigated. As liquid scintillators can be produced very radiopure, they are suitable as a clean shielding material. Liquid scintillator also enhances the detection efficiency and can be used as an active veto. In addition, detailed Monte–Carlo studies are carried out to determine the optimal shielding design of a large scale experiment.

4. Conclusion

The COBRA collaboration investigates CdZnTe semiconductor detectors for a next generation neutrinoless double beta decay experiment. CdZnTe offers innovative and promising possibilities

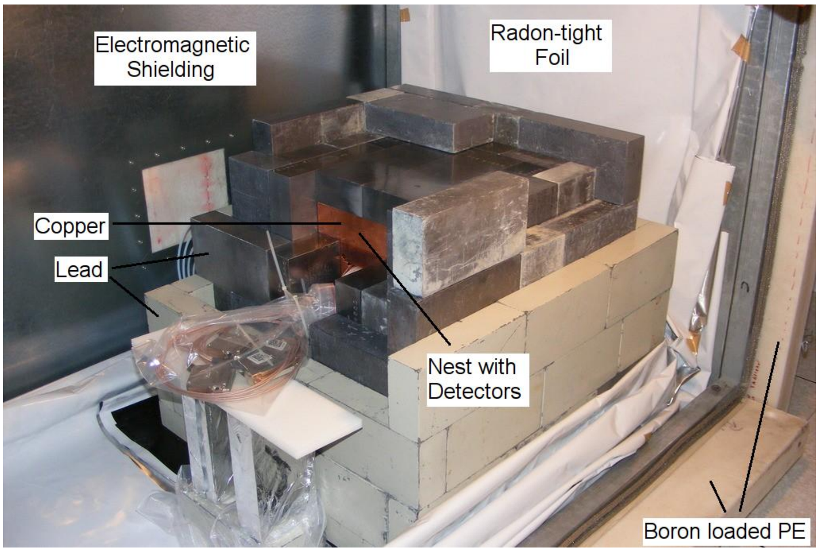

Figure 3. The R&D test set–up at LNGS. The nest inside the copper shielding can house 64 CPG detectors.

for an ultra low background experiment. The COBRA experiment is currently in the R&D phase with a renewed set–up at LNGS. With CPG detectors, six half–life limits above 10^{20} years and seven half–life limits within a factor 3 of world best were achieved. Pixel detectors, allowing for further background reduction, are also under investigation. The technique of a semiconductor TPC is a unique feature in this field.

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