The COBRA Experiment

[1]**J.R. Wilson**[2]

Department of Physics and Astronomy, University of Sussex, Brighton, BN1 9QH, UK

E-mail: drjeannewilson@gmail.com

Abstract. The COBRA experiment aims to use a large array of CdZnTe semiconductor detectors to search for neutrinoless double beta decay. The COBRA collaboration are currently operating a small proto-type array of crystals in a low-background environment. This paper presents the current status of the experiment, results from current and previous proto-types and future prospects for COBRA.

1. Concept

COBRA aims to search for neutrinoless double beta decay ($0\nu\beta\beta$) in CdZnTe semiconductor crystals[1]. There are actually 9 candidate $0\nu\beta\beta$ isotopes, 5 in the form of $\beta^-\beta^-$ emitters, intrinsic to the detector material, but measurements will focus on ^{116}Cd. This has the highest Q-value at 2.8 MeV, beyond all the single gamma-lines from the natural decay chains which would be problematic in contaminating signal regions at lower energies. CdZnTe, in common with other semiconductors, can be produced cleanly with low levels of intrinsic radioactive background and offers good energy resolution. Unlike many semiconductors though, CdZnTe can be operated at room temperature without the need for expensive cryogenics close to the detectors.

For a neutrino mass of about 50 meV, as suggested by neutrino oscillation data, the half-life of ^{116}Cd is of order 10^{26} years (exact values depend on the nuclear matrix elements). As with all neutrinoless double beta decay searches, the COBRA experiment will require low backgrounds, good energy resolution and a large detector mass to measure this. To obtain sensitivity to $T_{1/2} = 10^{26}$ y in 5 years of operation, a resolution of ΔE<2% (FWHM), and a background rate in the signal region of <0.001 counts/keV/kg/year are required. Resolutions of <2% at 2805 keV have already been achieved, and improvements are anticipated with better quality detectors and by cooling the detectors and electronics by a few degrees.

2. Status

Small proto-types for the COBRA experiment have been operating in the LNGS laboratory in Italy, which provides a shielding equivalent to ≈3500 m of water. 4.34 kg·days of data were collected with an initial proto-type consisting of four 1 cm^3 crystals. This was the first operation of CdZnTe crystals in a low background, underground environment and the data were used to study the detector properties and the major sources of background in the crystals. Despite the small detector mass, less than 25 g, the data revealed a number of interesting results including a measurement of the 4-fold forbidden beta decay of ^{113}Cd[2] which yields

[2] For the COBRA collaboration

Isotope and Decay		T_{half} limit (years, 90% C.L.)	
		Current Data	Previous
$\beta^-\beta^-$ Decays			
^{116}Cd	to g.s	6.05×10^{19}	3.14×10^{19}
^{130}Te	to g.s	3.44×10^{20}	9.92×10^{19}
^{130}Te	to 536 keV	2.49×10^{20}	3.73×10^{19}
^{116}Cd	to 1294 keV	$2.80\ \times10^{19}$	4.92×10^{18}
^{116}Cd	to 1757 keV	$3.03\ \times10^{19}$	9.13×10^{18}
^{116}Cd	to 2027 keV	3.14×10^{19}	1.37×10^{19}
^{116}Cd	to 2112 keV	4.16×10^{19}	1.08×10^{19}
^{116}Cd	to 2225 keV	2.67×10^{19}	9.46×10^{18}
^{130}Te	to 1794 keV	1.45×10^{20}	
^{130}Te	to 1122 keV	9.48×10^{19}	
^{114}Cd	to g.s.	4.71×10^{20}	
$\beta^+\beta^+$ Decays			
^{64}Zn	$0\nu\beta^+$EC to g.s.	1.18×10^{18}	2.78×10^{17}
^{64}Zn	0ν2EC to g.s.	$\mathbf{7.43\times10^{18}}$	1.19×10^{17}
^{120}Te	0ν2EC to g.s.	$\mathbf{1.13\times10^{17}}$	2.68×10^{15}
^{120}Te	0ν2EC to 1171keV	$\mathbf{3.43\times10^{16}}$	9.72×10^{15}
^{106}Cd	$0\nu\beta^+\beta^+$ to g.s.	5.12×10^{18}	4.50×10^{17}
^{106}Cd	0ν2EC to g.s.	$\mathbf{5.48\times10^{18}}$	5.70×10^{16}
^{106}Cd	$0\nu\beta^+\beta^+$ to 512keV	7.17×10^{17}	1.81×10^{17}

Table 1. Preliminary half-life limits derived from data obtained with the first 16 crystals of the current COBRA proto-type, compared to results previously published by the collaboration in Ref. [3]. Values in bold exceed current World-best limits.

$T_{1/2} = (8.2 \pm 0.2(\text{stat.})^{+0.2}_{-1.0}(\text{sys.})) \cdot 10^{15}$ years. Half-life limits were calculated for a variety of possible $0\nu\beta\beta$-decays and are presented in Ref. [3].

In 2006, installation of a larger proto-type consisting of a 4×4×4 array of 1 cm^3 crystals commenced. So far, 7.85 kg·days of data have been collected with the first layer of 16 crystals, which is shown in figure 1. A refined likelihood analysis, which allows for different background levels, energy thresholds, resolutions and livetimes for each crystal was developed and applied to this data resulting in the new half-life limits presented in table 1.

Figure 1. A photograph of the first layer of the 64-crystal proto-type (left) and an artistic impression of the whole array in the copper mounting structure (right).

The other 48 crystals will be installed at LNGS in October 2007 with a number of modifications to the setup, including revised contacting methods to reduce cross-talk and pick-up. One major background was identified in the red-coloured passivation coating on the crystal surfaces. Alternative passivation coatings have been tested, resulting in a factor ≈5 reduction in the background in the region of interest between 2–3 MeV on the current background level of ≈150 counts/keV/kg/year. Simulations of the measured contamination levels indicate greater improvements are expected, suggesting other background components are now being observed.

Radon in the air surrounding the detectors could be an additional source of background. Early tests of flushing the system with nitrogen gas indicate a further factor of at least 3–4 reduction in background levels. New crystal production techniques are being investigated in collaboration with the Freiburg materials research institute, with the aim of producing radioactively pure crystals with enriched ^{116}Cd in the near future. A sophisticated shield has been designed for future phases of COBRA, which incorporates an active scintillator veto component for background rejection. Details of the design can be found in Ref. [4].

Techniques are also being investigated to actively reject backgrounds through the event topology. The 1 cm^3 cube size ensures that for $0\nu\beta\beta$-events, the emitted electrons are unlikely to escape the crystal, but a large proportion of high energy gamma ray events will deposit energy in more than one crystal through Compton scattering. The COBRA design is modular, allowing easy upgrade and offering the ability to discriminate such backgrounds by rejecting events where more than one crystal is triggered. Simulations for a 64,000 crystal array indicate that ^{232}Th chain backgrounds in the 2–3 MeV region can be reduced by more than 50% in this way.

The COBRA collaboration is also investigating the exciting possibility of pixellising the detectors to obtain tracking information that provides significantly more information for background rejection. For example, a 2.8 MeV α is only expected to travel a few μm in CdZnTe but βs from ^{116}Cd $0\nu\beta\beta$-decay are expected to travel 1–1.5 mm. Crystals with a pixel-pitch of ≈200 μm will be able to veto decays involving α-emission with nearly 100% efficiency (see Ref. [5] for more details). Tests of detectors with 1.6 mm pixels have produced promising results and recently, a detector with 50 μm sized pixels has been successfully created.

3. Summary

The COBRA experiment aims to search for neutrinoless double beta decay of ^{116}Cd with a sensitivity to half-lives greater than 10^{26} years with a large array of CdZnTe crystals. Resolutions of FWHM=2% at the peak energy (2.8 MeV) have already been obtained and improvements are expected. The background in the signal region will be minimised through careful selection of materials, a comprehensive shielding with active veto, and the use of timing and spatial coincidences to reject radioactive decay events. A new proto-type experiment is being deployed to investigate these issues.

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References

[1] Zuber K., *Phys. Lett.* B **519** 262 (2001)
[2] Goeßling G. et al, *Phys. Rev.* C **72** 064328 (2005)
[3] Bloxham T. et al, *Phys. Rev.* C **76** 025501 (2007)
[4] Stewart D. et al, *NIM* A **571** 651–662 (2007)
[5] Bloxham, T. and Freer, M., *NIM* A **572**, 2, 722–728 (2007)