Institute of Physics Publishing Journal of Physics: Conference Series **39** (2006) 353–355
doi:10.1088/1742-6596/39/1/092 TAUP 2005: Proc. Ninth Int. Conf. on Topics in Astroparticle and Underground Physics

Status and perspectives of the COBRA double beta decay experiment

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Abstract. The COBRA experiment is going to use a large amount of CdZnTe semiconductor detectors to perform a search for various double beta decay modes. The current status of the experiment is presented, as well as first results. A half-life measurement of the 4-fold forbidden non-unique beta-decay of ^{113}Cd has been performed. Improved half-life limits for the ground state transitions of ^{64}Zn for $0\nu\beta^+/EC$ and $0\nu EC/EC$ have been obtained. A short outlook on future activities is given.

1. Introduction

The idea of COBRA is to use a large array of CdZnTe semiconductor crystals [1]. CdZnTe contains 9 double beta isotopes, 5 in the form of $\beta^-\beta^-$–emitters. Among them are ^{130}Te and ^{116}Cd as the most promising ones for the neutrino mass search and ^{106}Cd as one of only six known $\beta^+\beta^+$-emitters in nature. Advantages of the COBRA project are:

- Source is equal to detector. The isotopes of interest are intrinsic to the detector itself. This is always the most preferred approach.
- Semiconductor. Semiconductors are well known to have excellent energy resolution and can be produced cleanly.
- Room temperature detectors. For practical purposes this is an enormous advantage.
- Modular design. The modular design offers the chance for an easy upgrade. In addition, it will allow significant background reduction, because high energy photons are likely to hit several detectors, while double beta decay is a single detector event.
- The Q-value of ^{116}Cd is beyond all single gamma-lines from natural decay chains, resulting in a significant background reduction.
- Pixelisation. The very exciting option of pixelisation would offer additional information in the form of tracking and vertex reconstruction. The device would act as a ,,solid state TPC".

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- High sensitivity to double β^+ modes. Three different decay channels can be considered for the latter

$$\begin{aligned} (Z,A) &\rightarrow (Z-2,A) + 2e^+ + (2\nu_e) \\ e^- + (Z,A) &\rightarrow (Z-2,A) + e^+ + (2\nu_e) \\ 2e^- + (Z,A) &\rightarrow (Z-2,A) + (2\nu_e) \end{aligned} \tag{1}$$

where the last two cases involve electron capture (EC). In case of neutrinoless double EC an additional gamma has to be emitted to conserve energy-momentum.

2. Current status

The data presented are obtained with four 1 cm^3 CdZnTe detectors provided by eV-PRODUCTS based on coplanar grid technology, i.e. reading out only the electron signal. Previous results based on measurements with a 0.5 cm^3 commercial detector at the surface can be found in [2]. Data taking has been performed in the Gran Sasso Underground Laboratory (LNGS) in Italy providing a shielding of about 3500 mwe. The four bare detectors are mounted in a copper brick separated from all preamplifier electronics by about 25 cm. This copper brick itself is part of a (20 cm)^3 cube made out of electropolished copper and a further passive shielding of 15 cm of lead. The whole setup is located in a Faraday cage made from copper plates. The cage is surrounded by a neutron shield, consisting of 7 cm thick boron-loaded polyethylene plates and additional 20 cm of paraffin wax.

The energy resolution and stability of the detectors is calibrated regularly with the help of ^{137}Cs, ^{60}Co and ^{228}Th sources. The data taking period consists of three parts: First a CAMAC DAQ system was used and a pertinax crystal holder, which has been replaced for the second period with a holder made out of delrin. Additionally, the original Lemo cables for signal readout have been replaced by a kapton foil. In a third step, the CAMAC DAQ was exchanged for a VME DAQ.

3. Results

Aside of double beta limits a measurement of ^{113}Cd beta decay has been performed. The transition $^{113}\text{Cd} \rightarrow {}^{113}\text{In}$ is characterised as a $1/2^+ \rightarrow 9/2^+$ transition. Hence it is a 4-fold forbidden non-unique decay ($\Delta I = 4$ and no change in parity). Only three isotopes of this type are known, ^{50}V, ^{113}Cd and ^{115}In. As can be seen in figure 1 in all four detectors ^{113}Cd spectra with an endpoint energy of about 320 keV can be seen consistently. The final sample comprises a statistics of 0.86 kg×d and a half-life of

$$T_{1/2} = (8.2 \pm 0.2(\text{stat.})^{+0.2}_{-1.0}(\text{sys.})) \cdot 10^{15}\text{yrs} \tag{2}$$

has been deduced. This half-life is in good agreement with the values quoted in [3, 4]. A comparison with the electron energy spectrum of the ,,Table of Isotopes Web-page" has been performed. As can be seen in figure 1 the spectral shape is not supported by the data. The spectra are normalised to the total number of events in the range of 100-320 keV. For details see [5].

On the double beta side a peak search for all $\beta^-\beta^-$ -emitters have been done by using a maximum likelihood method. The total accumulated exposure corresponds to 3.82 kg × days. The results are preliminary half-life limits of 1.18×10^{19} yrs (^{116}Cd) and 5.67×10^{19} yrs (^{130}Te) with 90 % CL. New world best limits (90 % CL) have been obtained for the $0\nu\beta^+/EC$ and $0\nu EC/EC$ ground state transitions of ^{64}Zn being 5.07×10^{18} yrs and 9.52×10^{16} yrs respectively.

4. Outlook

One significant method for background reduction due to the high granularity of the detectors should be coincidences. While double beta decay can be considered as a single detector event,

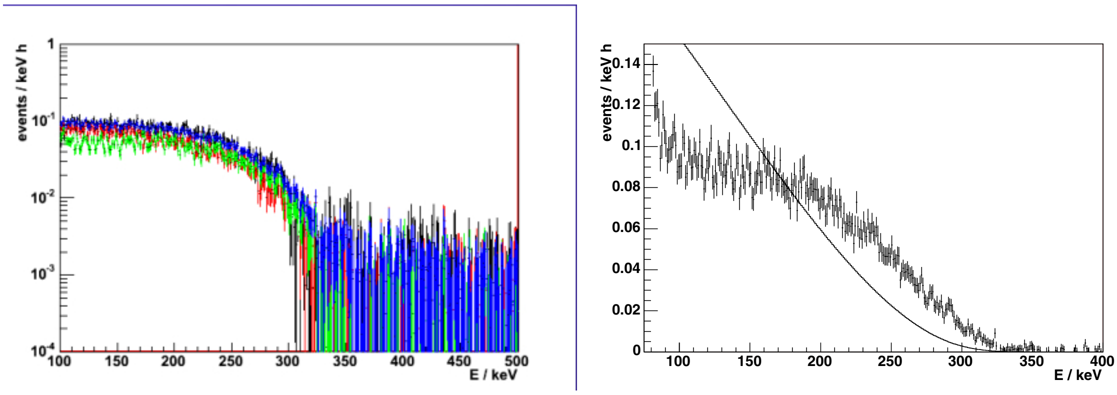

Figure 1. Left: Low energy range of all four CdZnTe detectors. As can be seen they all result in a consistent spectrum below 320 keV due to ^{113}Cd decay. Right: Measured energy spectrum of the summed detectors (histogram) compared to the expected shape as expected from the Table of Isotope Web-page (line) indicating no good agreement. The spectra are normalised to the number of events between 100-320 keV.

high energy gamma rays will scatter around in the array. In the current set-up about 0.2 % of the observed events are coincidences. However, as Monte Carlo simulations show this array is much too small to prove the power of the coincidence technique. Hence, currently a $4 \times 4 \times 4$ array of 1 cm^3 CdZnTe detectors is in preparation which will have a total detector mass of about 0.5 kg, an increase in detector mass by a factor 16. Test measurements on all detectors are ongoing and the array will be installed at LNGS by the end of 2005. An active shielding component in form of a liquid scintillator besides the existing passive copper and lead shielding is under investigation. This would also act as an signal enhancer for all excited state transitions and modes involving a positron. Last but not least, work on pixelated detectors has started and first measurements have been performed.

The currently considered final design would consist of a $40 \times 40 \times 40$ array, enriched to 90 % in ^{116}Cd. This would result in a total mass of about 420 kg of CdZnTe.

5. Summary

COBRA is a new approach to double beta decay using CdZnTe semiconductor detectors. Since spring 2004, four CdZnTe detectors have been running 2004 at LNGS and the first interesting results such as a half-life measurement of ^{113}Cd have been obtained. An upgrade to 64 detectors with a total mass of about 0.5 kg will happen in the near future. Complementary work on pixelated detectors and active veto elements also acting as signal enhances have started.

Acknowledgments

We thank the Laboratori Nazionali del Gran Sasso for its hospitality and support and V. Tretyak for providing us with the DECAY0 generator.

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