Search for Neutrinoless Double Beta Decay with the COBRA Experiment

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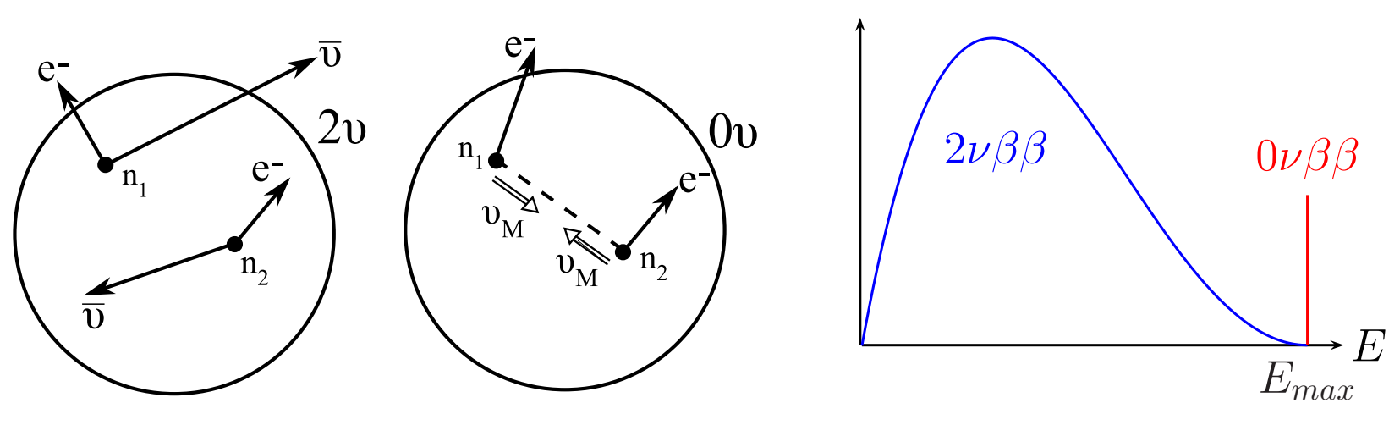
Neutrinoless Double Beta Decay

For some nuclei, a decay via a single β-decay is energetically not allowed, but a conversion to a lower state via two subsequent β-decays, i.e. a Double Beta Decay, through a virtual intermediate state is possible. The modes most frequently discussed are the neutrino accompanied and the neutrinoless $\beta^-\beta^-$- decay

$$(Z,A) \rightarrow (Z+2,A) + 2\,e^- + 2\,\bar{\nu}_e \quad (2\nu\beta\beta)$$
$$(Z,A) \rightarrow (Z+2,A) + 2\,e^- \quad (0\nu\beta\beta)$$



Principle of Double Beta Decay and energy spectrum of summed energies of the e^-. Unlike the $2\nu\beta\beta$ decay spectrum the $0\nu\beta\beta$ energy spectrum is mono-energetic.

The first mode is a higher order Standard Model process, whereas the existence of the second process has not been confirmed yet. $0\nu\beta\beta$-decay can only occur if at least two conditions are fulfilled: The neutrino has to be a so-called Majorana particle, i.e. its own anti particle. If this is the case, e.g. a helicity flip enables $0\nu\beta\beta$ decay. For a helicity flip, the neutrino has to have a rest mass, which has been shown by neutrino oscillation experiments. But unlike these the $0\nu\beta\beta$ half-life

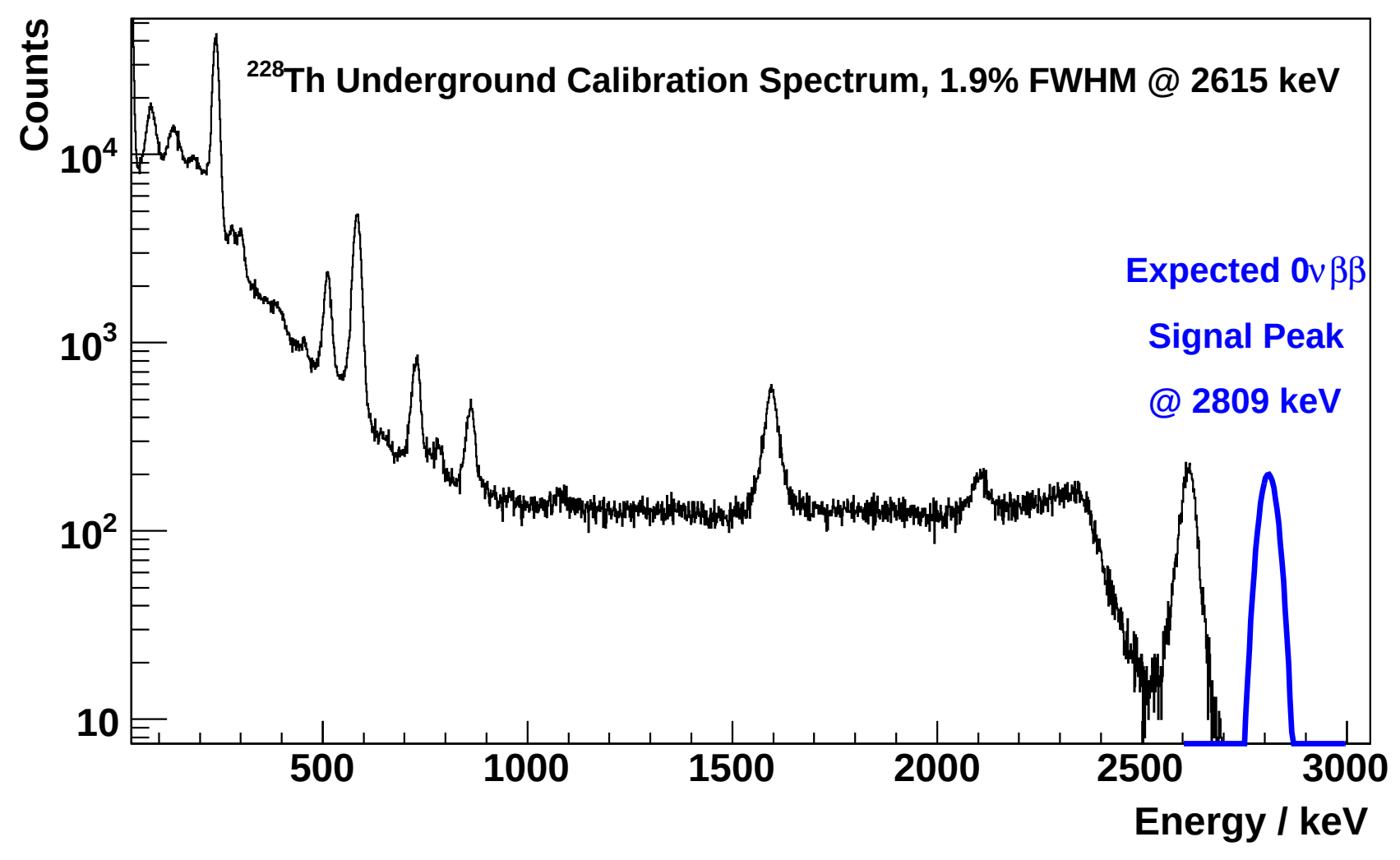
$$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}(Q,Z) \cdot \left|M^{0\nu}_{GT} - M^{0\nu}_{F}\right|^2 \cdot \frac{\langle m_{\nu_e}\rangle^2}{m_e^2}$$

(with the phase space $G^{0\nu}$ and the nuclear matrix elements $\left|M^{0\nu}_{GT} - M^{0\nu}_{F}\right|$) is directly connected not only to differences between neutrino masses but directly to the effective Majorana neutrino mass $\langle m_{\nu_e}\rangle$ itself.

The COBRA Experiment

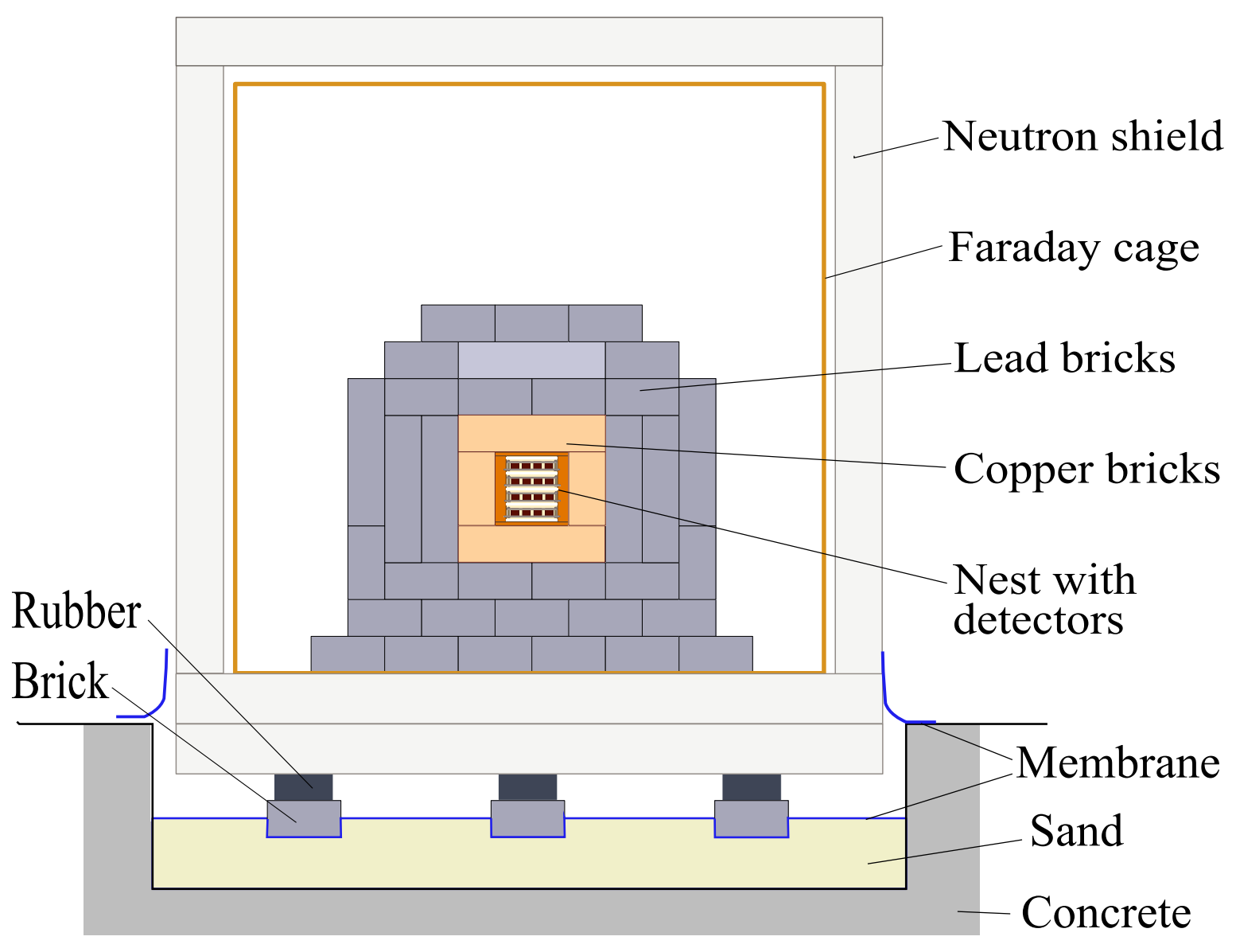
The aim of COBRA is the search for $0\nu\beta\beta$ decays with an array of CdZnTe semiconductor detectors [1]. Cd, Zn and Te contain several double beta candidates, including also $\beta^+\beta^+$ decay candidates. ^{116}Cd is the most important isotope for COBRA due to its high Q–value of 2809 keV. ^{130}Te is interesting for $\beta^-\beta^-$ decay due to its high natural abundance and ^{106}Cd is one of the most promising $0\nu\beta^+\beta^+$ candidates.

Advantages of COBRA



- The decay energy of ^{116}Cd lies above the highest naturally occurring γ–background
- Semiconductors have a good energy resolution and are intrinsically clean
- The source = detector approach maximises the detection efficiency
- Because CdZnTe is is a room temperature semiconductor, operation of the detectors is comparatively uncomplicated
- The high granularity of a detector array allows a search for coincident signatures such as $0\nu\beta\beta$ decays in excited states and can be used to reduce background
- CdZnTe has received more and more interest in recent years. Consequently, there has been major progress with these detectors and an end too the development of this technology is inconceivable

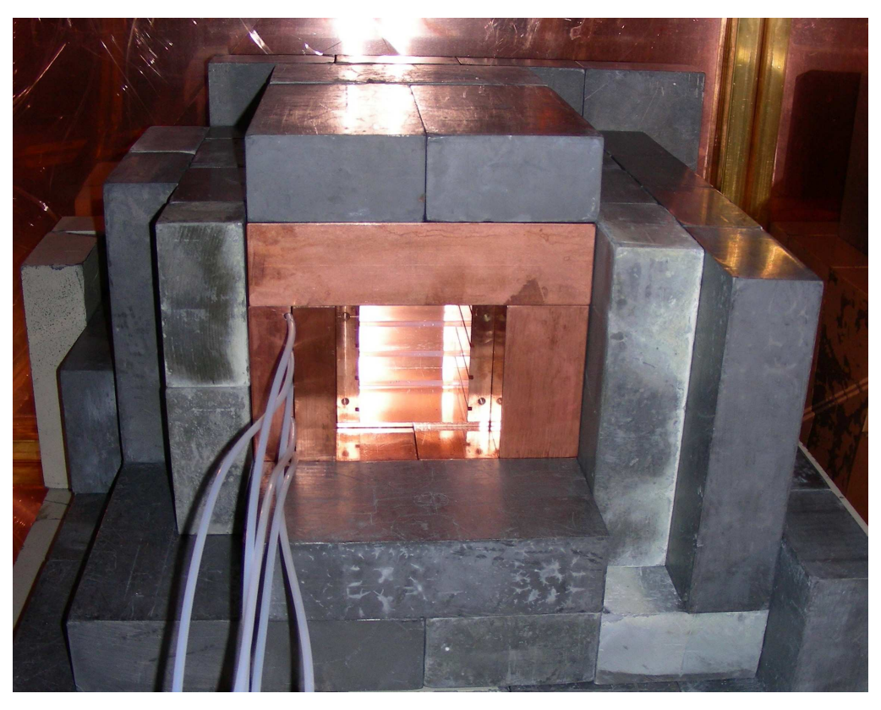
Test Set-up at the LNGS



Background studies for the COBRA experiment are performed at the Italian underground laboratory LNGS with commercially available 1 cm^3 CdZnTe Coplanar Grid (CPG) detectors. The current test set-up can house 64 of these detectors. It has recently been extended to perform background measurements with pixelated CdZnTe detectors.

At LNGS the cosmic ray flux is reduced by six orders of magnitude and the neutron flux by three orders of magnitude compared to the earth's surface. In addition, 7 cm boron loaded polyethylene shields against neutrons. A Faraday cage protects against electromagnetic interference.

The inner shielding consists of about 2 t of lead and a high purity copper core. It is permanently flushed with nitrogen to suppress radon background from the air. With this test set-up a background rate of less than 8 counts/keV/kg/year in the main region of interest has been achieved so far.



Current Results

With the LNGS test set-up limits on $T_{1/2} \geq 9.4 \cdot 10^{19}$ years for ^{116}Cd, $T_{1/2} \geq 5.0 \cdot 10^{20}$ years for ^{130}Te and a record limit for $0\nu\beta^+$EC decay to g.s. for ^{120}Te with $T_{1/2} \geq 4.1 \cdot 10^{17}$ years [2] were obtained. Furthermore the fourfold forbidden β-decay of ^{113}Cd with a half-life of $T_{1/2} = 8.0 \cdot 10^{15}$ years was investigated [3].

Large-Scale Experiment

The idea for a large scale experiment is a set-up with a total mass of more than 400 kg CdZnTe, isotopically enriched in ^{116}Cd. One option is a three dimensional array of $40 \times 40 \times 40$ 1 cm^3 CPG CdZnTe detectors, but also the use of pixelated detectors is under investigation.

With such a large scale set-up the COBRA experiment will be sensitive to half-lives $> 10^{26}$ years which corresponds to $\langle m_{\nu_e}\rangle < 50$ meV.

Coplanar Grid Detectors

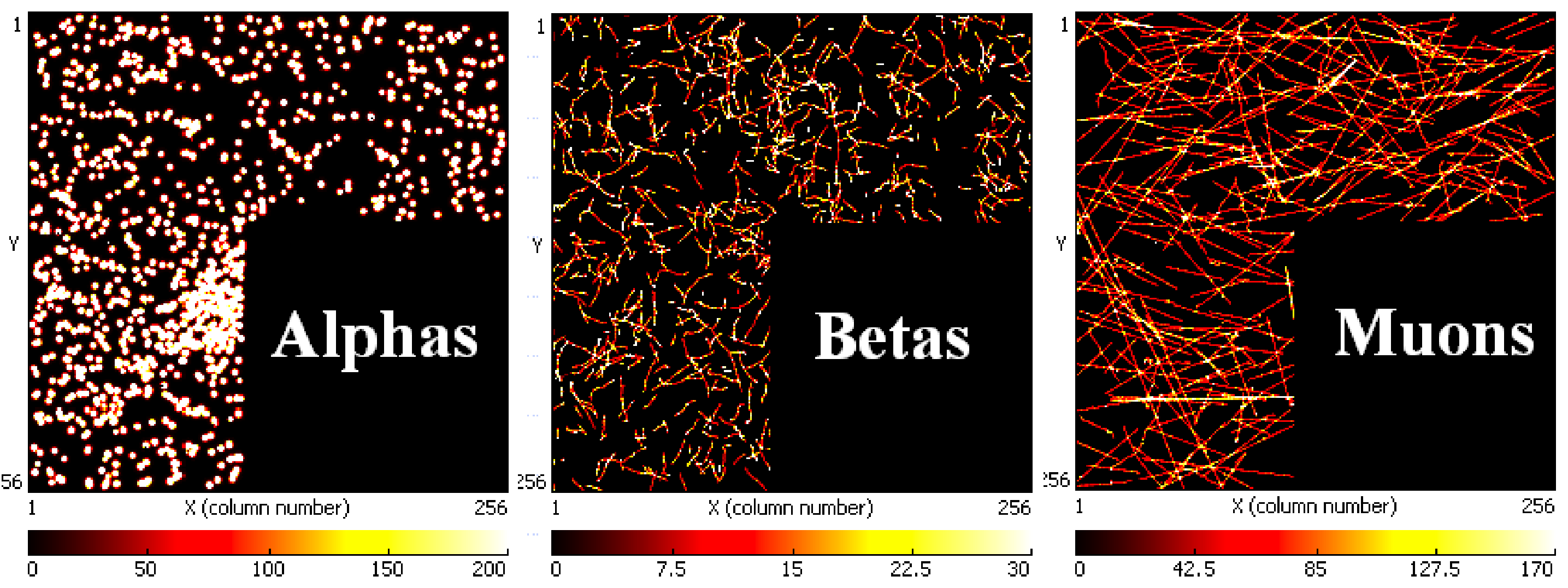
The hole-collection characteristic of CdZnTe is comparatively poor. To compensate for the interaction-depth dependent contribution of the hole signal two comb shaped anodes, a so-called Coplanar Grid (CPG) design, and a special signal processing technique are required [4]. Such detectors are commercially available with volumes of more than 2 cm^2. First detectors were grown also by the COBRA collaboration. CPG detectors offer the possibility of a set-up with a large mass and only few readout channels. Even with cost effective detectors a resolution of 2% in the ROI was achieved in the underground test set-up.

Pixel Detectors

In addition to the CPG technique pixelated CdZnTe detectors are also available. Beside the energy information they can also provide tracking capabilities. Detailed simulations have shown that with ∼200 µm pixel size background can be reduced significantly, α-background even by three orders of magnitude [5]. Pixelated CdZnTe detectors offer the unique possibility of combining the advantages and high detection efficiency of semiconductor detectors with the possibility of particle identification. The COBRA Collaboration is currently investigating three types of pixelated detectors:

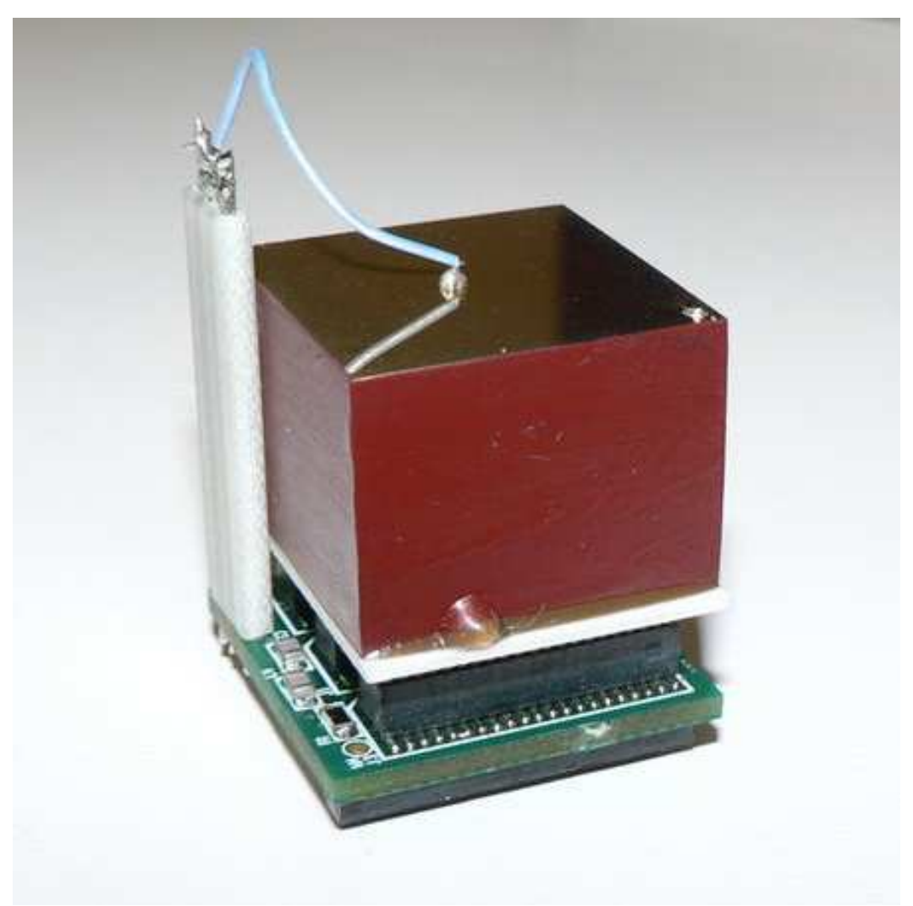
CdTe TimePix Detector

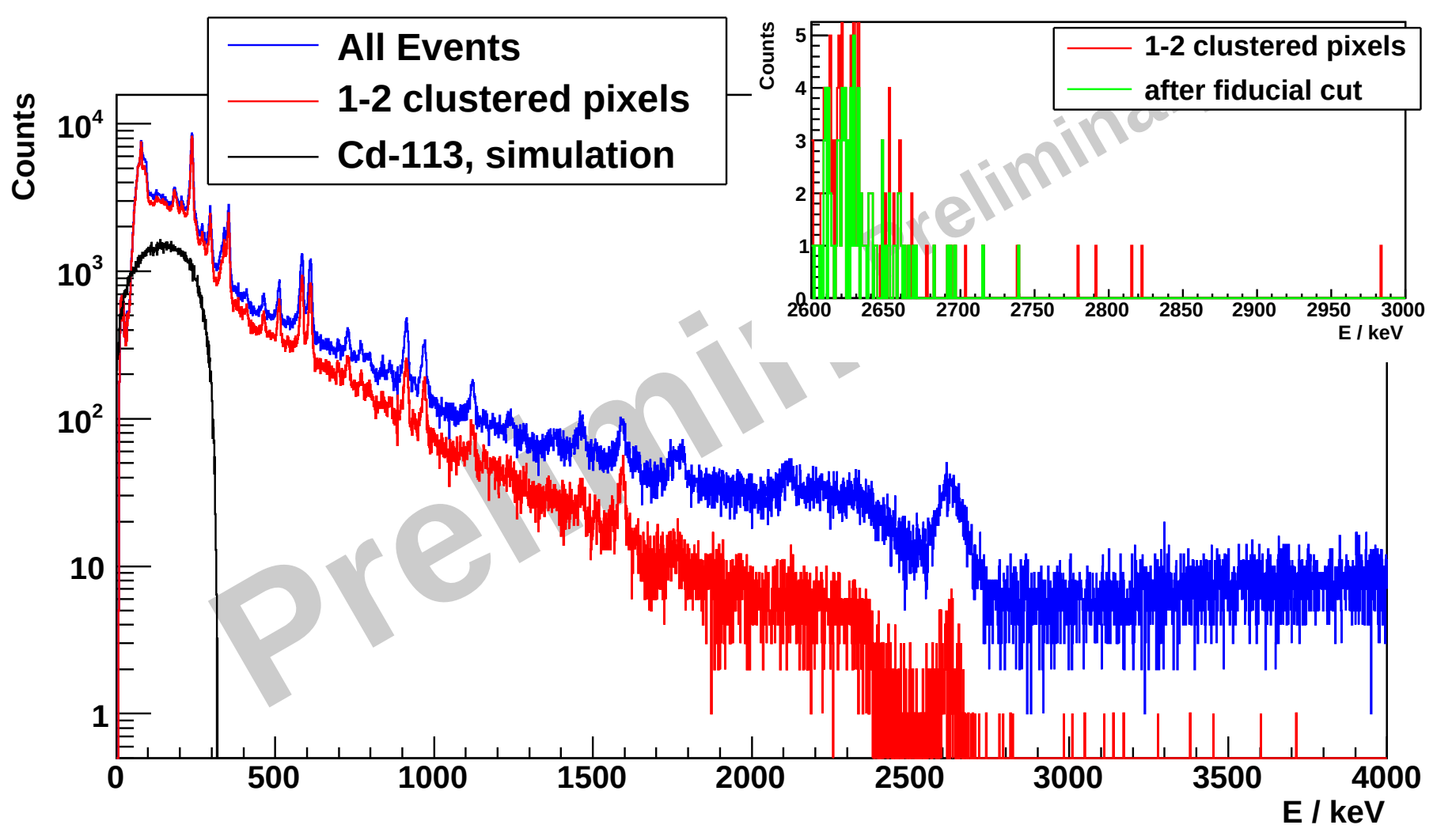
The TimePix chip, developed by the MediPix2 collaboration, has 65 000 readout channels allowing for 55 µm, 110 µm and 220 µm pixel size. A 1 mm thick CdTe system with 110 µm pixel size from the Technical University of Prague is running underground and performing background measurements at LNGS since May 2010. First results are expected soon. Measurements with a 300 µm thick Si–TimePix detector show the potential to identify the different patterns of alpha particles, electrons and muons:



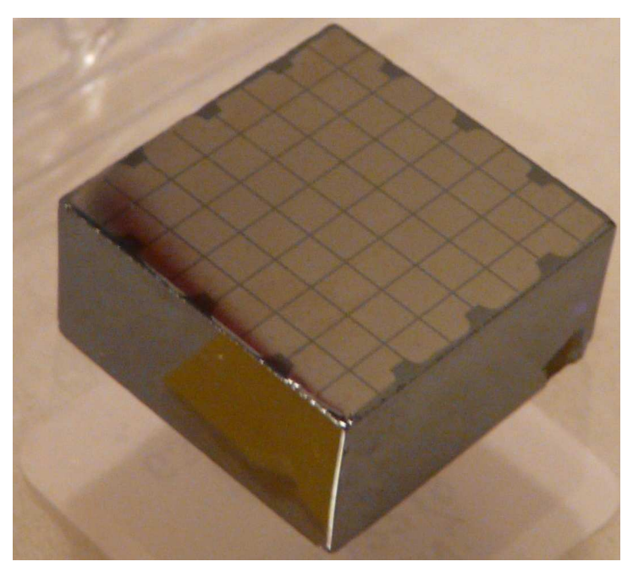
Polaris System

With a prototype of the Polaris system, provided by the group of Zhong He from the University of Michigan, background measurements were performed at LNGS from September 2009 until January 2010. The CdZnTe crystal has a volume of $2 \times 2 \times 1.5$ cm^3 and a mass of 36 g. The Polaris system has 11×11 pixel with a size of 2000 µm and allows even for 3D hit information. After applying an appropriate fiducial cut no events remained in the peak region of ^{116}Cd in the entire data set of 4.3 kg days. Although the pixel size of this system is too large for particle identification, the power of pixelated detectors regarding background suppression was demonstrated clearly.





St. Louis Pixel Detector



A CdZnTe detector system from the Washington University at St.Louis performed background measurements from January until May 2010 at LNGS. The crystal has a volume of $2 \times 2 \times 1$ cm^3 with 8×8 pixels. The energy resolution of this system is 1−2% at 662 keV. The analysis of the data taken is currently ongoing.

Improvements in Progress

- Dortmund Low Background Facility: A low background facility for a germanium detector was set up at TU Dortmund to examine the radiopurity of construction materials.
- Active Veto Studies: An active veto directly surrounding the detectors can be used to decrease background and increase the detection efficiency. Applying a scintillating crystal veto to the experimental setup is examined at TU Dresden. The operation of CdZnTe detectors in liquid scintillator is studied at the University of Hamburg.
- Monte–Carlo Studies: Proper shielding is crucial for the reduction of background events in a large scale experiment. The CTU Prague and the University of Hamburg are studying different types of shielding with Monte–Carlo simulations. Furthermore detector properties including charge transport for the TimePix detector are investigated and simulated at the University of Erlangen.
- Crystal Growth and Enrichment: A crystal growth facility was commissioned at FMF Freiburg. CPG detectors have already been grown. In future this facility will allow the growth of isotopically enriched CdZnTe detectors.

References

[1] K. Zuber, Phys. Lett. B **519** (2001) 1.
[2] J. V. Dawson *et al.*, Phys. Rev. C **80** (2009) 025502.
[3] J. V. Dawson *et al.*, Nucl. Phys. A **818** (2009) 264
[4] P. Luke, IEEE Trans. Nucl. Sci. **42** (1995) 207.
[5] T. R. Bloxham and M. Freer, Nucl. Instrum. Meth. A **572** (2007) 722.

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