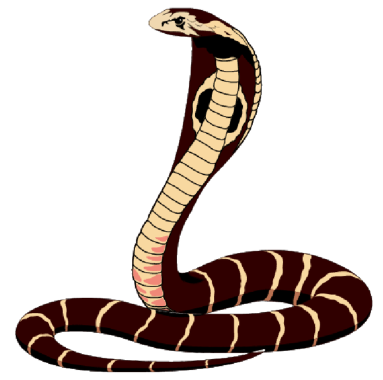
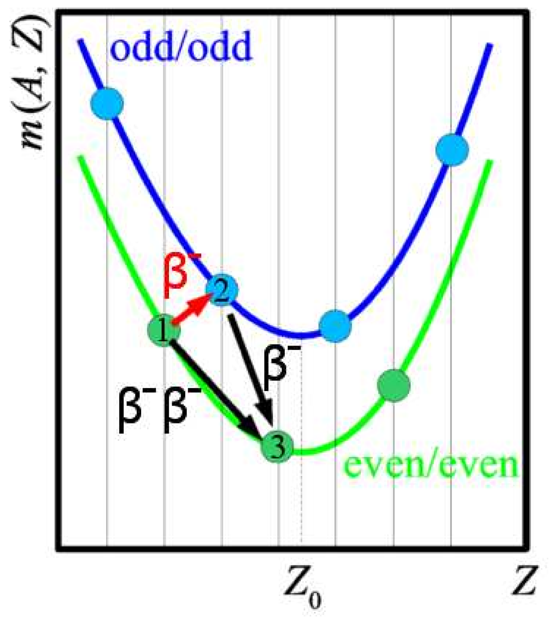
The COBRA Experiment

Cadmium-Zinc-Telluride 0-neutrino double-Beta Research Apparatus



Neutrinoless Double Beta Decay

Double β^-–decay is possible for some unstable nuclei, if decay via a single β-decay is energetically forbidden.



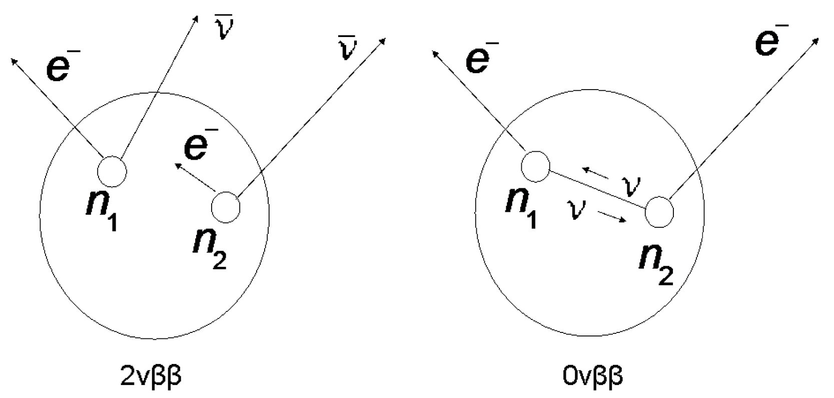
Two different modes are possible:

- $2\nu\beta\beta$: 2 simultaneous single β-decays
  $(Z,A) \rightarrow (Z+2,A) + 2e^- + 2\overline{\nu}_e$
- $0\nu\beta\beta$: Emission and absorption of an neutrino
  $(Z,A) \rightarrow (Z+2,A) + 2e^-$

For the second mode, at least two conditions have to be fulfilled:

- The neutrino is a Majorana particle, i.e. its own anti particle
- The neutrino's helicity has to change

For the helicity change, the neutrino has to have a rest mass, which has been shown by several neutrino experiments in the past years.



Beside the double β^-–decay, there are three other (neutrinoless) double beta decay processes:

- Double β^+–decay: $(Z,A) \rightarrow (Z-2,A) + 2e^+$ $(+\,2\nu_e)$
- β^+ + Electron Capture (EC): $(Z,A) + e^- \rightarrow (Z-2,A) + e^+$ $(+\,2\nu_e)$
- Double Electron Capture: $(Z,A) + 2e^- \rightarrow (Z-2,A)$ $(+\,2\nu_e)$

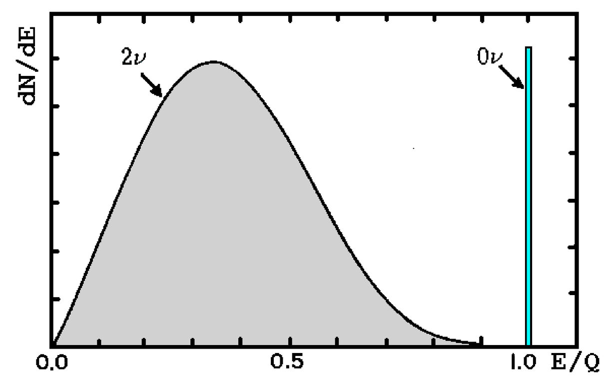
Neutrino mass

The neutrino mass $\langle m_{\nu_e}\rangle$ is directly connectet to the $0\nu\beta\beta$ half life $T_{1/2}^{0\nu}$:

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

with the phase space $G^{0\nu}(Q,Z)$ and the nuclear matrix element $\left|M_{GT}^{0\nu} - M_F^{0\nu}\right|^2$. $G^{0\nu}(Q,Z)$ scales with the fifth power of the decay energy (Q-value), so that high Q-values result in lower half–lives.

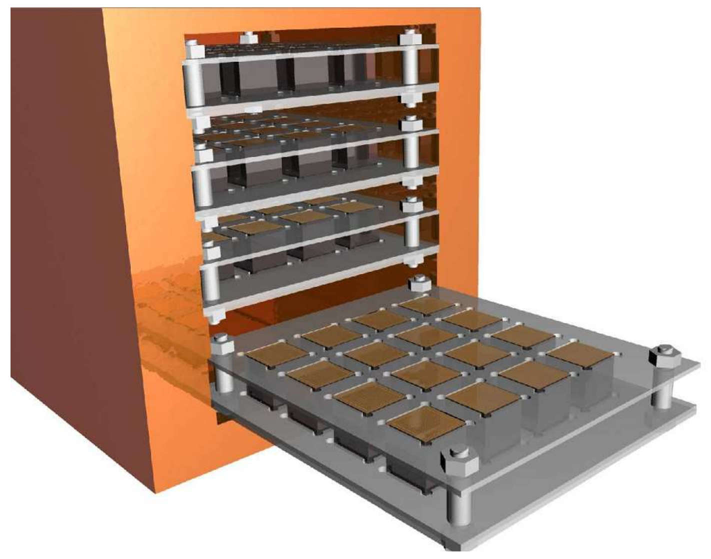
Detection principle



Unlike the distribution of the e^- energies of the $2\nu\beta\beta$ decay, the $0\nu\beta\beta$ energy spectrum has a peak at the Q-value of the nuclear transition. To detect the rare $0\nu\beta\beta$ events, a high energy resolution and a good background suppression is needed.

The COBRA Set–Up

- Central detector consisting of 64.000 CdZnTe crystals
- ~ 400 kg source material
- Crystals of 1 cm^3 are commercially available
- Central detector surrounded by an optimized shielding



$\beta\beta$–isotopes in CdZnTe

Isotope	decay–mode	Q-value
^{70}Zn	$2\beta^-$	1001 keV
^{114}Cd	$2\beta^-$	534 keV
^{116}Cd	$2\beta^-$	2809 keV
^{128}Te	$2\beta^-$	868 keV
^{130}Te	$2\beta^-$	2529 keV
^{106}Cd	$2\beta^+$	2771 keV
^{64}Zn	β^+/EC	1096 keV
^{120}Te	β^+/EC	1722 keV
^{108}Cd	EC/EC	231 keV

Due to its high possible enrichment and high Q-value, ^{116}Cd is the most important isotope for COBRA. Also ^{130}Te and ^{106}Cd are very interesting for the discovery of $0\nu\beta\beta$.

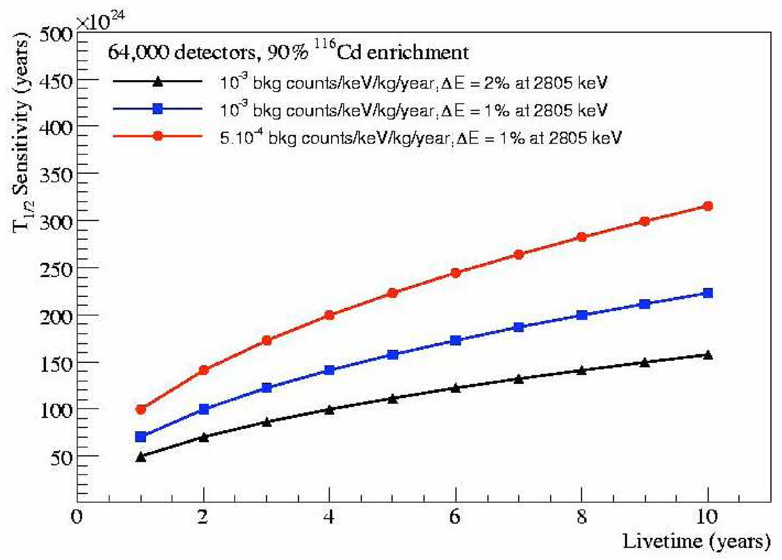
Advantages of COBRA

- Source = detector
- CdZnTe semiconductors have a good energy resolution
- ^{116}Cd has a higher Q-value than ^{76}Ge and therefore a lower half life
- Analysis of nine different isotops
- Room temperature operation → no cryostat needed
- Modular Design allows coincidence measurements and future upgrades

Half life sensitivity and background

The half live sensitivity scales with the enrichment a, efficiency ϵ, source mass M, measurement time t, energy resolution ΔE and the number of background events B:

$$T_{1/2} \propto a\cdot\epsilon\cdot\sqrt{\frac{M\cdot t}{\Delta E\cdot B}}$$



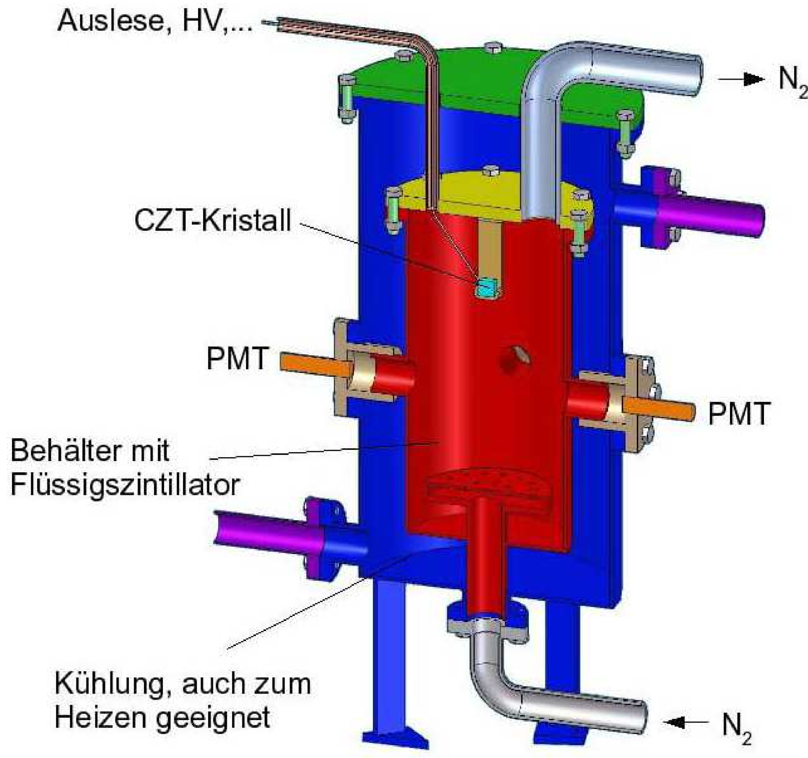
Main background sources:

- α and γ radiations from decay chains
- thermal neutrons
- neutrons produced by fast muons
- cosmogenic radionuclides
- all sources for α, β and γ radiation
- $2\nu\beta\beta$ decay

The decay energy of ^{116}Cd lies above the highest naturally occurring γ–background (^{208}Tl, 2614 keV). For all other background sources an adequate shielding is needed. To shield against high energetic cosmic radiation, the COBRA detector will be located in the LNGS underground laboratory in Italy.

Hamburg's involvement

Operation in liquid scintillator



One of the most important experimental challenges of COBRA is the identification of background events. The main background sources at the current set–up are the contamination of a red passivation lacquer of the crystals and radon from the air. These two background sources could be eliminated by operating the crystals in liquid scintillator. As the future shielding design will contain an active veto, the operation of CdZnTe semiconductors in liquid scintillator has to be tested thoroughly.

Monte Carlo simulations

To reduce the background at the COBRA experiment, an optimzed shielding has to be found. With Monte Carlo simulation the University of Hamburg examines different shielding designs to diminish the neutron flux at the LNGS underground laboratory.

Open Positions

The neutrino physics group offers bachelor, diploma and master positions at any time. The main focus is on these topics:

- Monte Carlo simulations
- Detector development and operation

If you are interested in further information, please contact Prof. Dr. Caren Hagner or Dr. Raoul Zimmermann via E-Mail.

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- Technical University Prague
- University of Bratislava
- University of Jyvaskyla
- University of La Plata
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