Recent Progress of the COBRA Experiment

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Outline

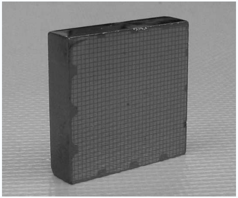
1. The COBRA Experiment
2. Coplanar Grid Detectors
    - The LNGS Test Set–up
    - Detector Scanning
    - Pulse Shape Analysis
    - Detector Operation in Liquid Scintillator
3. Pixelated Detectors
    - Large Volume Detectors
    - Detectors with small Pixel Sizes
4. Conclusion

The COBRA Experiment

Cadmium–Zinc–Telluride **0**–neutrino double–**B**eta **R**esearch **A**pparatus

The idea: A large array of CdZnTe semiconductor detectors

- Total mass of 420 kg, enriched in ^{116}Cd
- Sensitivity: $T_{1/2}^{0\nu\beta\beta} > 10^{26}$ yr ($m_{\beta\beta} \approx 50$ meV)
- Technical Design Report 2012/2013



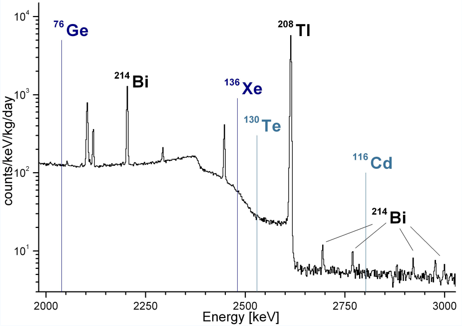
Advantages of CdZnTe

- Semiconductor detector
  - ➥ Good energy resolution, intrinsically clean material
- Source = Detector approach
  - ➥ Big mass and high detection efficiency
- Room temperature
  - ➥ No cooling needed
- Modular design
  - ➥ Coincidence analysis
- Industrial development of CdZnTe detectors
  - ➥ Maturing technology

Isotopes

CdZnTe contains 9 $0\nu\beta\beta$ candidates, the most important:

	Q (keV)	Mode	nat. abundance
^{116}Cd	**2814**	$\beta^-\beta^-$	7.5 %
^{106}Cd	2771	$\beta^+\beta^+$	1.2 %
^{130}Te	2527	$\beta^-\beta^-$	**33.8 %**



The COBRA Collaboration

Technical University of Dresden
Technical University of Dortmund
Freiburg Materials Research Center
University of Hamburg
University of Erlangen–Nürnberg

Technical University Prague

Washington University at St.Louis

Laboratori Nazionali
del Gran Sasso

University of Bratislava

University of Jyväskylä

University of La Plata

JINR Dubna

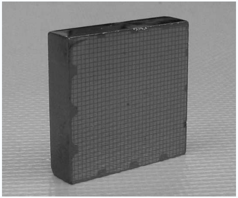
Detector Technologies

Coplanar Grid Detectors (CPG):

- ✔ Good energy resolution ($<2\%$)
- ✔ Simple readout (2 anodes, 1 cathode)
- ✗ Little “location of interaction“ information

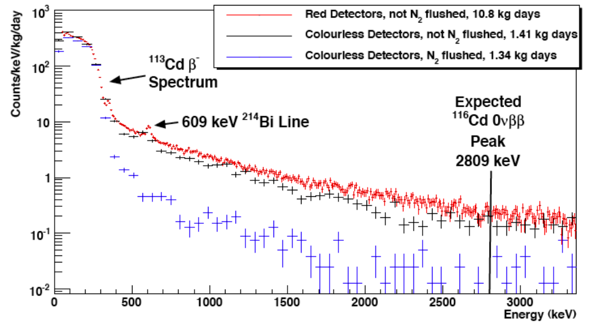
Pixelated Detectors:

- ✔ Very good energy resolution ($<1\%$)
- ✔ 3D “location of interaction“ information
- ✔ With small pixel sizes: Particle identification
- ✗ Complex readout: 1 channel/pixel



Data Taking at LNGS

- Finished data taking with red passivated CPGs (18 kg·d)
  - Red passivation and radon identified as major background
- New colorless passivated detectors and nitrogen flushing



➥ Background reduced to ∼5 counts/keV/kg/yr at 2.8 MeV!

Recent Results from LNGS Data

Isotope and Decay	Fit Range (MeV)	$T_{1/2}$ limit (years)	
		This work	Previous [14]
^{116}Cd to gs	2.2–3.2	9.4×10^{19}	3.14×10^{19}
^{130}Te to gs	2.2–3.2	5.0×10^{20}	9.92×10^{19}
^{130}Te to 536 keV	1.7–2.3	3.5×10^{20}	3.73×10^{19}
^{116}Cd to 1294 keV	1.2–1.8	5.0×10^{19}	4.92×10^{18}
^{116}Cd to 1757 keV	0.9–1.3	4.2×10^{19}	9.13×10^{18}
^{128}Te to gs	0.6–1.3	1.7×10^{20}	5.38×10^{19}
^{116}Cd to 2027 keV	0.5–1.2	2.8×10^{19}	1.37×10^{19}
^{116}Cd to 2112 keV	0.5–1.0	4.7×10^{19}	1.08×10^{19}
^{116}Cd to 2225 keV	0.5–1.0	2.1×10^{19}	9.46×10^{18}
^{130}Te to 1794 keV	0.5–1.2	1.9×10^{20}	3.1×10^{18} [15]
^{130}Te to 1122 keV	1.1–1.7	1.2×10^{20}	1.4×10^{19} [15]
^{114}Cd to gs	0.4–1.0	2.0×10^{20}	6.4×10^{18} [15]

Isotope and Decay	Fit Range (MeV)	$T_{1/2}$ limit (years)	
		This work	Previous [14]
^{64}Zn β^+EC to gs	0.5–1.3	1.1×10^{18}	2.78×10^{17}
^{120}Te β^+EC to gs	1.0–2.0	4.1×10^{17}	1.21×10^{17}
^{120}Te 2EC	0.8–2.0	2.4×10^{16}	2.68×10^{15}
^{120}Te 2EC to 1171 keV	0.6–2.0	1.8×10^{16}	9.72×10^{15}
^{106}Cd $\beta^+\beta^+$ to gs.	0.5–2.0	2.7×10^{18}	4.50×10^{17}
^{106}Cd β^+EC to gs	1.5–3.0	4.7×10^{18}	7.31×10^{18}
^{106}Cd 2 EC to gs	2.0–3.0	1.6×10^{17}	5.7×10^{16}
^{106}Cd $\beta^+\beta^+$ to 512 keV	0.6–1.5	9.4×10^{17}	1.81×10^{17}
^{106}Cd β^+EC to 512 keV	0.8–2.0	4.6×10^{18}	9.86×10^{17}

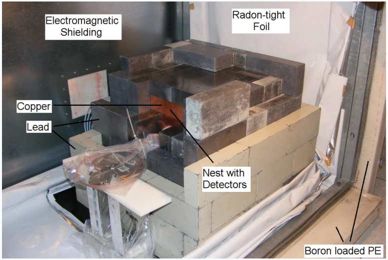
J.V. Dawson et al., Phys. Rev. C 80, 025502 (2009)

- Six half-life limits above 10^{20} years
- Seven limits within factor 3 of world best

New Setup at LNGS

Activities in 2011:

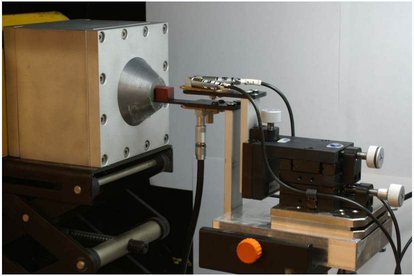
- Move of the set–up to the former Heidelberg–Moscow hut
- Completely new electromagnetic shielding
- New ultra low background lead
- New FADC readout
- 8 Detectors running, full 64 array will be installed soon

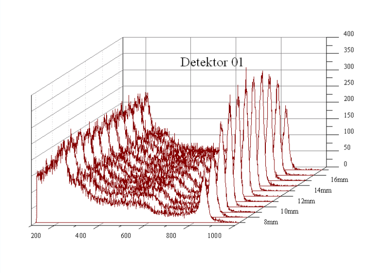


Shielding:

- 7 cm boron loaded PE
- EMI shielding
- Rn tight foil and N_2 flushing
- 2 t lead
- High purity copper

Detector Scanning



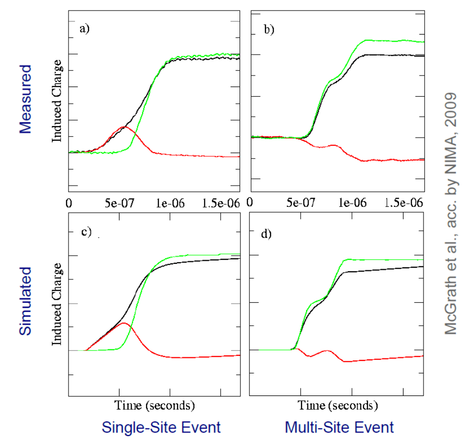


- 3D scan with a collimated beam (^{137}Cs, 100 MBq) to determine charge collection efficiency and energy resolution
- Detectors with best perfomance will be installed in the center of LNGS set–up

Pulse Shape Analysis

Pulse Shape with FADC readout:

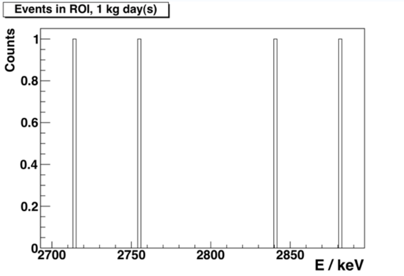
- Distinguish between single site ($0\nu\beta\beta$) and multi site events (γ–background)
- Depth–sensing allows rejection of background from surface contamination
- Identify noise events

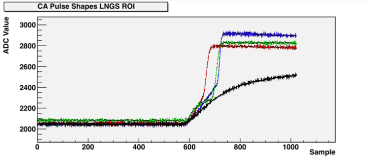


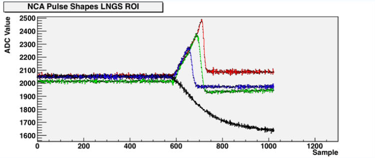
Black & red: Signals of the two anodes
Green: Substracted anode signals

Pulse Shape Analysis

- Results from 8 detectors at LNGS with FADC readout
- About 1 kg·d data



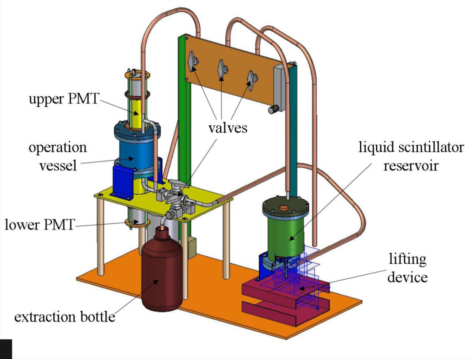




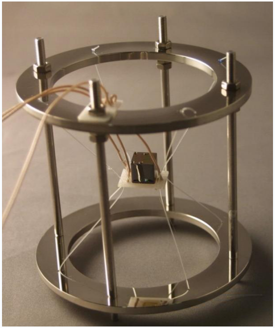
CdZnTe in Liquid Scintillator

Operation of unpassivated CPGs in liquid scintillator:

- Clean environment, good shielding
- Active veto
- Maximize detection efficiency



1 cm^3 CdZnTe, no passivation:



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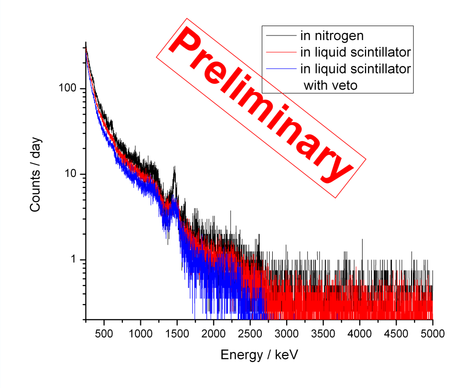
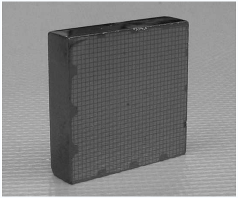


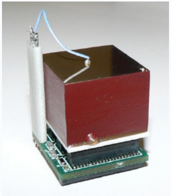
- Active veto reduces background around 2.8 MeV by $\sim$ 90 %
- Upgrade to 8 detectors and FADC readout is underway

Pixel Detector Technologies

Two types of detectors under investigation:

1. Large volume ($2-6\,cm^3$) with large pixel pitch ($\sim 1\,mm$)
   - ➥ Washington University of St. Louis and Polaris System
2. Thin detectors (0.3 - $2\,mm$) with small pixel pitch ($\sim 100\,\mu m$)
   - ➥ Timepix detector developed by the Medipix2 Collaboration

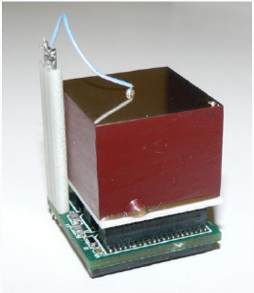


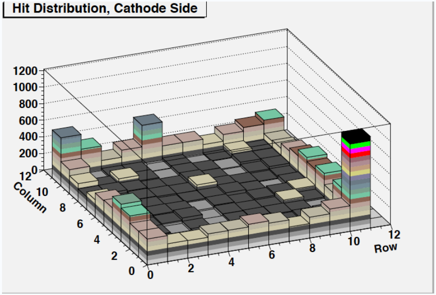


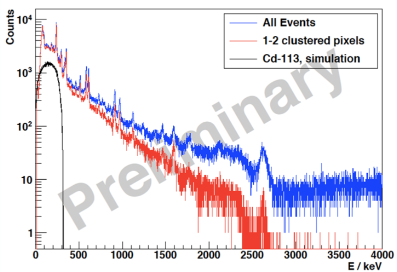
Large Volume Pixel Detectors

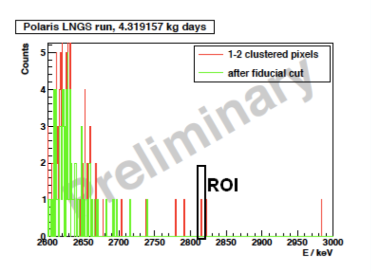
Polaris System (in collaboration with University of Michigan):

- Energy resolution: 5.16 keV FWHM at 662 keV (0.78%)
- $2 \times 2 \times 1.5\,\text{cm}^3$, 36 g
- 11×11 pixel: No particle identification due to large pixel pitch, but cuts to clustered pixels and fiducial volume demonstrate the power of background reduction









- 0 events in the region of interest after 125 days of data taking
- 0.9 counts/keV/kg/yr between 2700 - 3000 keV
- Detector was not tuned for low background application!

Detectors with small Pixel Sizes

Timepix systems:

- 2 Si systems: $14 \times 14 \times 0.3\,\mathrm{mm}^3$
- 2 CdTe systems: $14 \times 14 \times 1\,\mathrm{mm}^3$
- 256×256 pixel systems
- 128×128 pixel systems

➥ Particle tracking with a solid–state TPC

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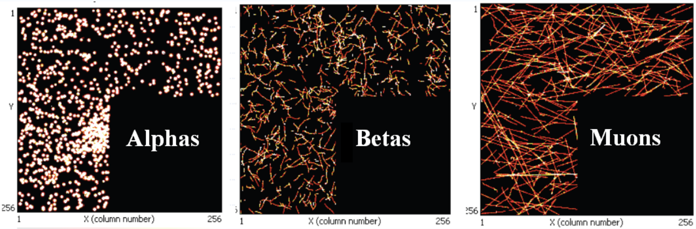
➡ Particle tracking with a solid–state TPC



➡ Particle identification as background reduction tool works!

Conclusion

- COBRA is a next generation experiment to explore $0\nu\beta\beta$
- Limits for some decay modes near to world best, even with low masses
- In 2011: New set–up, electronics and more detectors at LNGS
- Broad R&D programme underway
- Pixelised Detectors would allow particle identification
  - ➥ Solid–state TPC – a unique option in this field
- Technical Design Report within 2 years