The COBRA Double Beta Decay Experiment

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on behalf of the COBRA collaboration

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NDM12, June 5th, 2012

The COBRA Experiment

- Study of ultra-rare radioactive decays, in particular neutrinoless double-beta ($0\nu\beta\beta$) decays
- Goal: Array of 64000 enriched CdZnTe Detectors, massing about 400kg,
  sensitive to decays with half lives exceeding 10^{26} years
- Primary Focus: $0\nu\beta\beta$-decay of $^{116}\mathrm{Cd}$

Collaboration Members

TU Dortmund

TU Dresden

Freiburg Materials Research Center

University of Hamburg

University of Erlangen

Czech Technical University in Prague

Laboratori Nazionali del Gran Sasso

Washington University at St. Louis

University of Bratislava

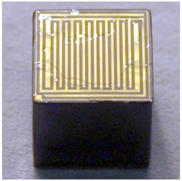
University of Jyvaskyla

University of La Plata

JINR Dubna

Supporting Institutes: Jagellonian University(Poland), University of Michigan (USA)

Why use CdZnTe?

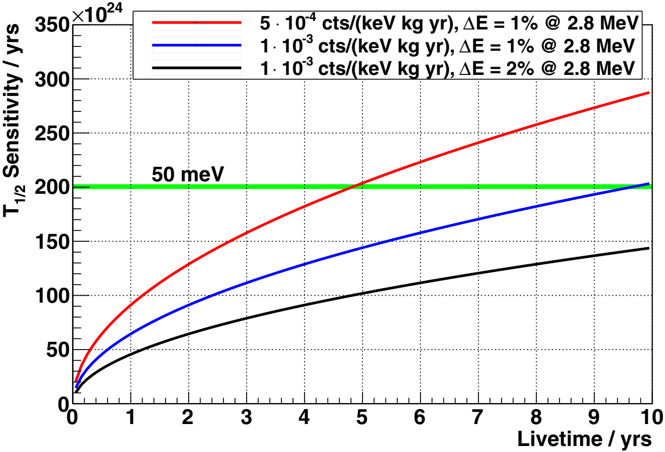


- Source = Detector
- Contains 9 $0\nu\beta\beta$ candidate isotopes
  Most interesting: ^{116}Cd, ^{106}Cd, ^{130}Te
- High Q-values (^{116}Cd above 2615 keV)
- Semiconductor → Good energy resolution, intrinsically pure
- Operation at room temperature → easy handling

Isotope	Nat. Abund. (%)	Q (keV)	Decay Mode
^{106}Cd	1.21	2771	$\beta+\beta+$
^{116}Cd	7.5	2814	$\beta-\beta-$
^{130}Te	33.8	2527	$\beta-\beta-$

COBRA Sensitivity

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



Cobra Setup at LNGS

- COBRA experimental setup located at Laboratori Nazionali del Gran Sasso (LNGS), Italy (1400 m under Gran-Sasso massif, 3700 m water equivalent)
- Past: Ran different setups, installed arrays with up to 64 CdZnTe coplanar-grid detector crystals, tested different pixelized detector prototypes
- Currently: Array of 32 background-improved CPG detectors

Construction and Shielding

- Copper holder for 4 Delrin (POM) crystal layers, with 16 detectors each (for 1 cm^3 CPG)
- Lead shielding with clean lead in inner layers and copper core
- Pb-shield enclosed in Rn-tight foil
- 70 mm borated PE plates as Neutron shield
- Tight Faraday-Cage (EMI shield)

Recent Progress

- Moved within LNGS to former HdM-Building in spring 2011
  - Better facilities
  - New Faraday cage
  - Improved Radon-shielding and Nitrogen-flushing
- New DAQ chain
  - Switched to fully digital readout in winter 2010/11 (Amanda, thanks for the ADCs!)
  - New amplifiers in fall 2011 (differential signal transmission to DAQ rack)
- New Detectors
  - New detectors (16x CPG) installed in fall 2011
  - Second layer (16x CPG) installed in spring 2012
  - Next two layers will follow soon $\rightarrow$ 64 CPG detectors

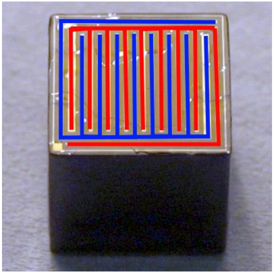
CdZnTe Detector Types

- Energy resolution and identification of BG-Events depends on choice of detector type
- Two options for CdZnTe:
  - Coplanar-Grid detectors (CPG)
  - Pixelized detectors

CdZnTe Crystal with Coplanar Grid

- CPG: Two comb-shaped, differently biased anode grids create virtual "small pixel effect"
- Advantages: Simple, low background compatible
- Disadvantages: Less detailed information about events:
  - Energy and interaction depth
  - Limited event topology: Single- vs. multi-site (under dev.)
- Currently deployed at LNGS

CdZnTe Crystal with Coplanar Grid



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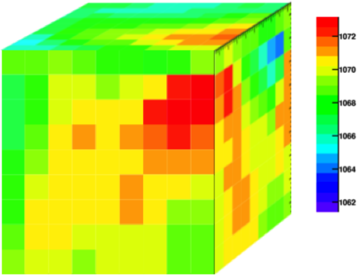
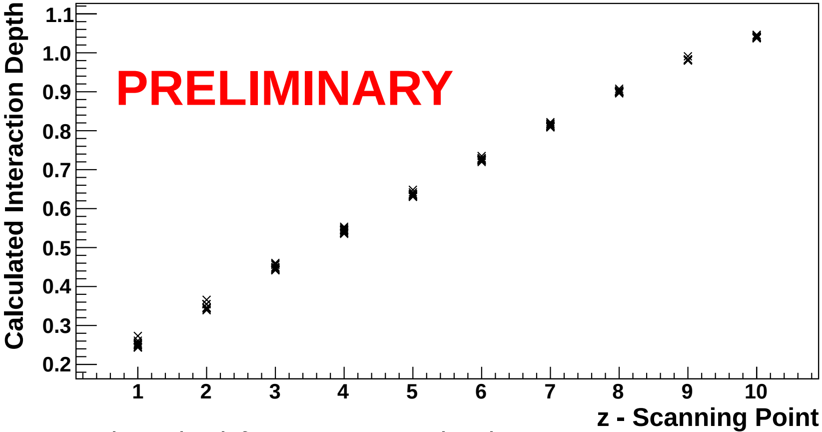
Detector Characterization



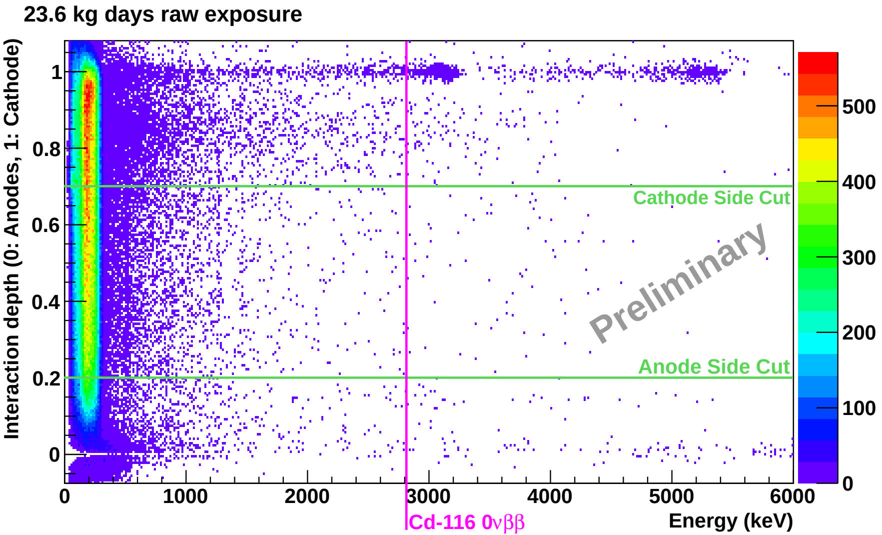
- 3-side raster-scanning of all new detectors with collimated $^{137}\mathrm{Cs}$ source
- Determination of local and global detector efficiency
- Reference data to check pulse shape processing

Interaction-Depth Estimation

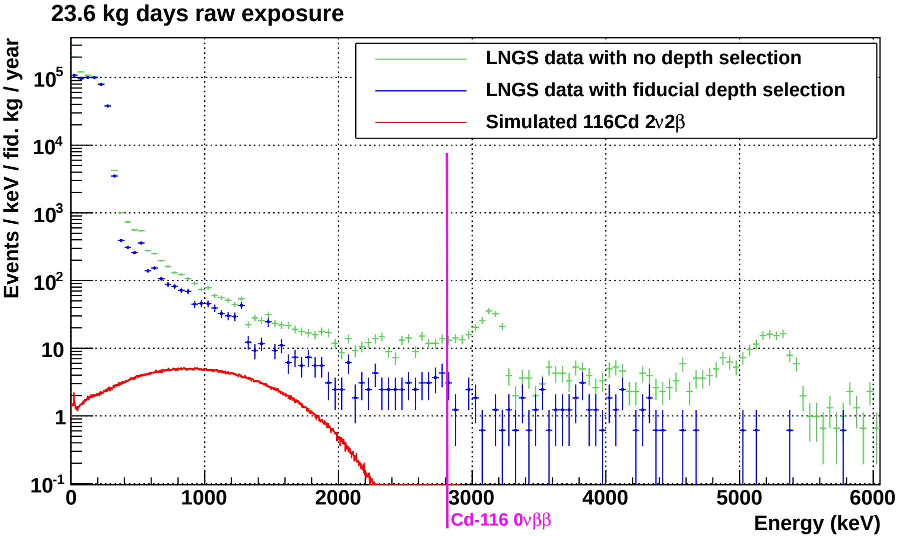


- Novel method for interaction depth estimation
- Confirmed by detector scans, resolution < 0.05 mm (probably better, verification limited by collimator aperture)

LNGS Background and Interaction Depth



Current LNGS Background Spectrum

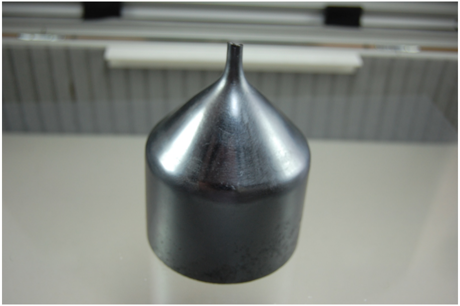


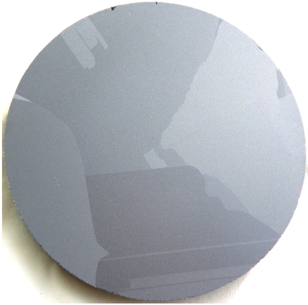
Current ROI background index: 2 events / keV / kg / year with fiducial cuts at anodes and cathode

Challenges

- Scale up isotope mass
  $\rightarrow$ produce detectors enriched to 90% $^{116}\mathrm{Cd}$ content
- Further reduce background
- Improve energy resolution
- Veto background events

CdZnTe Crytal and Detector Production



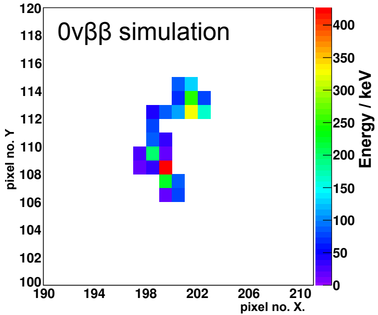


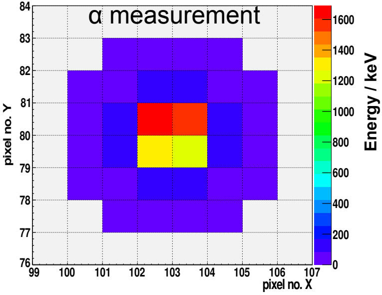
- CdZnTe crystal growth research at FMF Freiburg
- Working CdTe and CdZnTe detectors produced
- Acquired new patent,
  advanced CdZnTe detector growth technique

Further background reduction

- Dedicated HPGe material pre-screening facility
- Working on future layer designs.
- Monte Carlo campaign for large-scale experiment shielding: Multi-Layer passive designs with high neutron shielding effectiveness
- Shielding option: Active core with liquid scintillator
  - CZT detectors run well in liquid scintillator
  - High background suppression potential

CdZnTe Pixel detectors





- Better energy resolution than CPG
- Very detailed information about events → TPC-like
- Massive background reduction due to particle identification
- But: Low-Background compatibility of frontend electronics still unknown
- Tested three systems at LNGS (not radiopure yet)

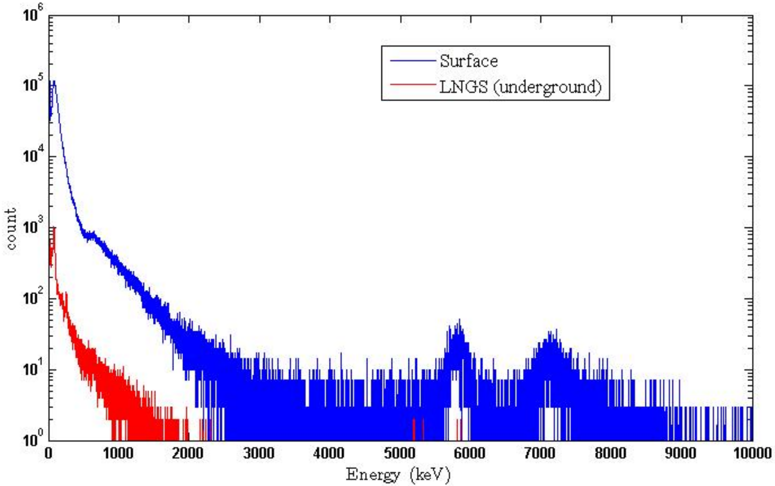
Pixel Pitch

- Tracking and maximum thickness depend on pixel size
- Small pixels
  - Detailed tracking
  - Limited thickness $\rightarrow$ smaller volume
  - Lower energy resolution
- Large pixels
  - Limited tracking
  - Increased thickness $\rightarrow$ larger volume
  - Higher energy resolution
- Simulation of charge deposition and transport necessary to determine optimum pixel size $\rightarrow$ ongoing

Pixel Detector Frontend Electronics

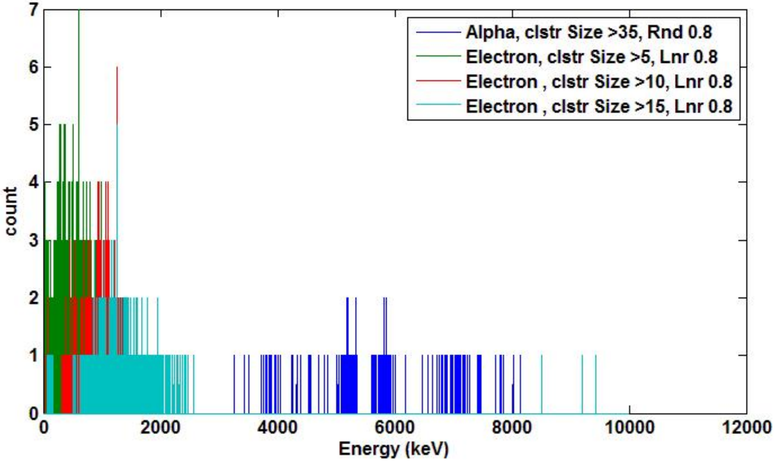
- Frontend ASIC development very expensive
  $\rightarrow$ Evaluating three existing systems:
- Polaris System, Univ. Michigan
  - Large pixels, large volume
  - Not low-background optimized yet
- CZT Pixel, Univ. St. Louis
  - Large pixels, large volume
  - Not low-background optimized yet
- Medipix/Timepix
  - Small pixels, small volume
  - Not low-background optimized yet

Timepix Run at LNGS



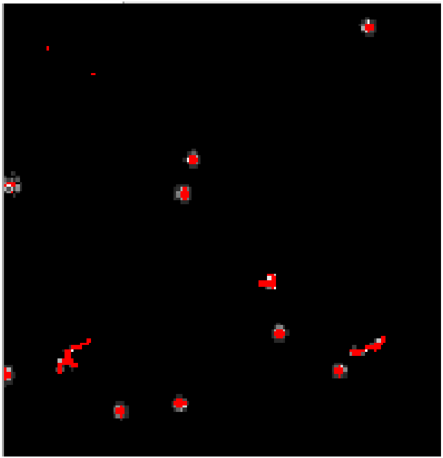
45 days of data (underground setup flushed with LN_2)

Timepix Particle Identification



- Excellent background reduction potential confirmed by underground data

Timepix Events in ROI



- Clear visible distinction of event topologies

Conclusion

- COBRA: A new innovative approach for the $0\nu\beta\beta$-decay search, especially in $^{116}\mathrm{Cd}$.
- Significant improvements to LNGS setup, working to double number of detectors
- Deeper understanding of our detectors, $\rightarrow$ deeper understanding of background
- Demonstrated potential of CdZnTe pixel detectors for low-background applications, currently developing radiopure small-pixel system
- Next physics goal: $2\nu\beta\beta^{116}\mathrm{Cd}$ decay