Pulse Shape Analysis with Quad Coplanar Grid CdZnTe Detectors of the COBRA Experiment

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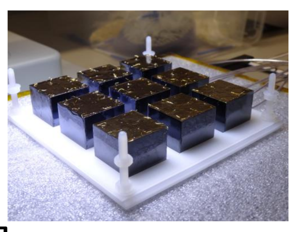
Abstract

The COBRA experiment searches for double beta decays using CdZnTe room temperature semiconductor detectors operating at the Gran Sasso underground laboratory. The setup was upgraded in 2018 with nine large CdZnTe detectors using the novel electrode layout - a quad coplanar grid surrounded by a guard ring - which can veto surface contaminations intrinsically. Although the prominent surface α backgrounds identified in the previous setup are reduced with the new CdZnTe detectors, nonphysical events and other background events are present in the ββ region of interest (ROI). Therefore, pulse shape discriminations are evaluated to identify the noise, distorted pulses, and multi-hit events, which enables further background suppression.

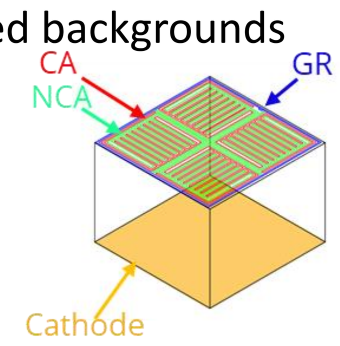
COBRA Experiment

- **C**admium-Zinc-Telluride **0**-Neutrino Double-**B**eta **R**esearch **A**pparatus [1]
  → searching for rare processes that give information about the neutrino mass
- Using "detector = source" approach
  → most promising $^{116}_{48}\mathrm{Cd} \rightarrow\, ^{116}_{48}\mathrm{Sn} + 2e^{-}$, Q value at 2814 keV
  → high efficiency
- New CdZnTe detector array installed to increase the sensitivity [2]



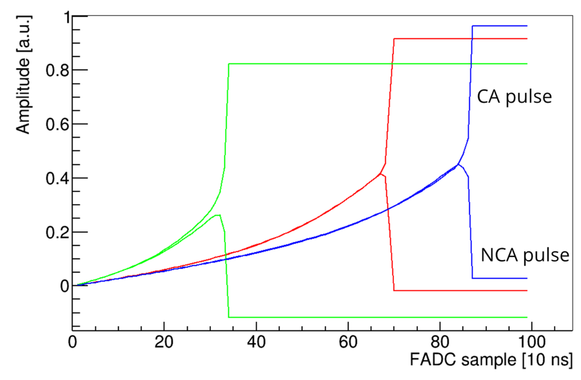
CdZnTe Detector Design

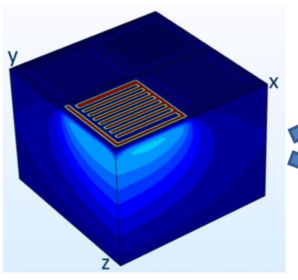
- CdZnTe detector has the advantages of room temperature operation, pure materials, high atomic number
- Aim: improve detection efficiency and minimize surface related backgrounds
- Novel readout for (20×20×15) mm^3 detector: quad coplanar grid (q-CPG) and a guard ring (GR)
- Each CPG consists of two interleaving anodes: collecting anode (CA) and non-collecting anode (NCA)



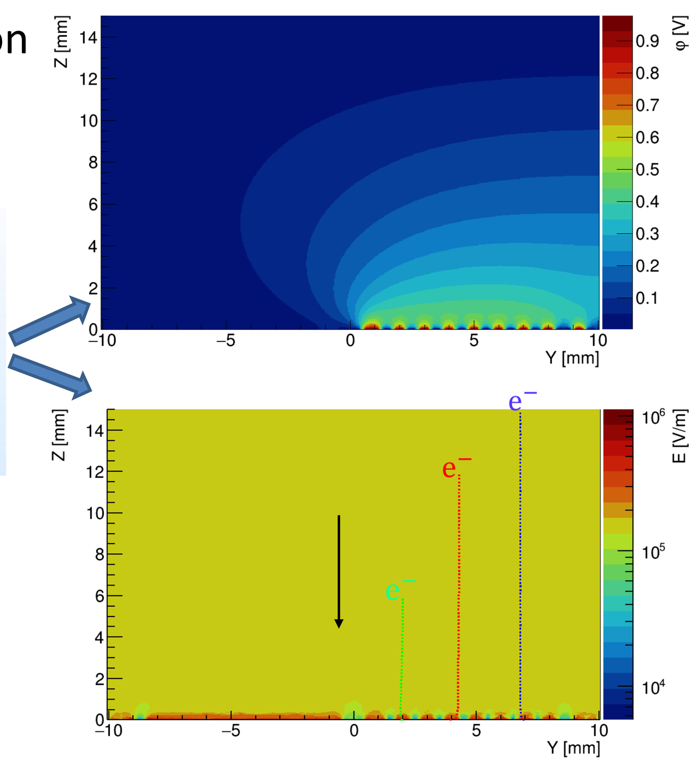
Pulse Shape Simulation

- Give insights of how the new readout affects the detector
- The induced signal can be calculated based on the Shockley-Ramo theorem
- Simulation built on Comsol [3] and Geant4
- Electrons drift paths turn into waveforms



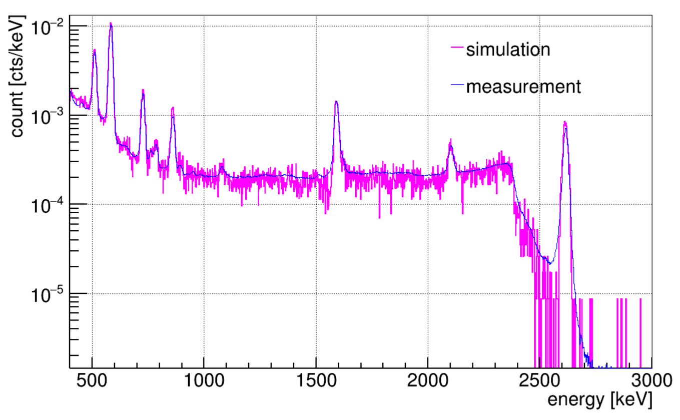


$q \cdot \Delta\varphi$



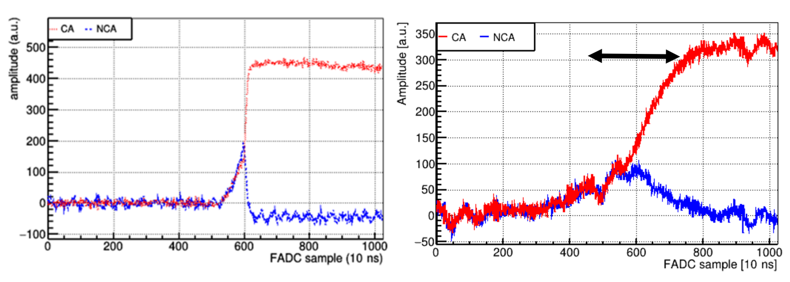
Event Reconstruction and Performance

- Energy reconstruction
  → average energy resolution **(1.1446±0.0387)%** at 2614 keV
  → simulated and measured ^{228}Th spectra show good agreement
- Interaction depth reconstruction
  → normalized distance between anodes and cathode
  → together with the guard ring, veto surface related contaminations

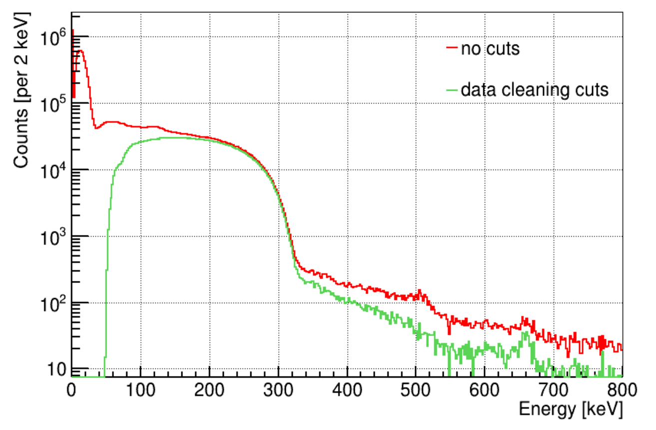


Data Cleaning Cuts

- Non-physical and distorted signal pulses identification
- Cuts criteria are defined based on pulse height, <u>rising slope</u>, maximum change

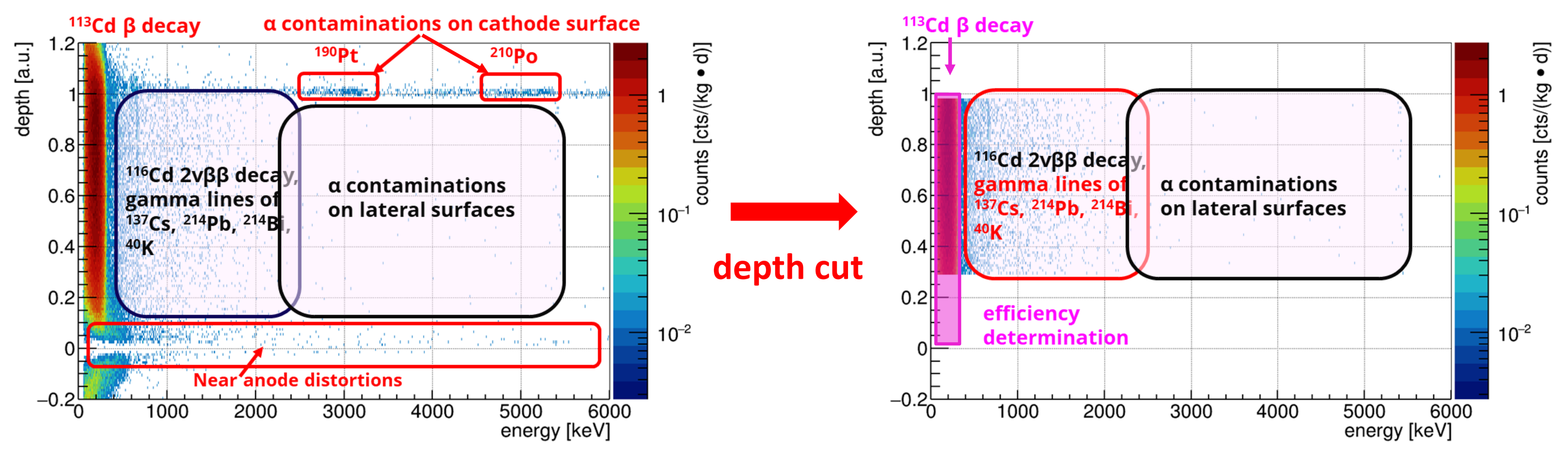


- After applying the cuts,
  → Low energy events reduced with known efficiency [4]
  → (99.80±0.18)% noise events discarded
  → high energy events not affected



Interaction Depth Cut

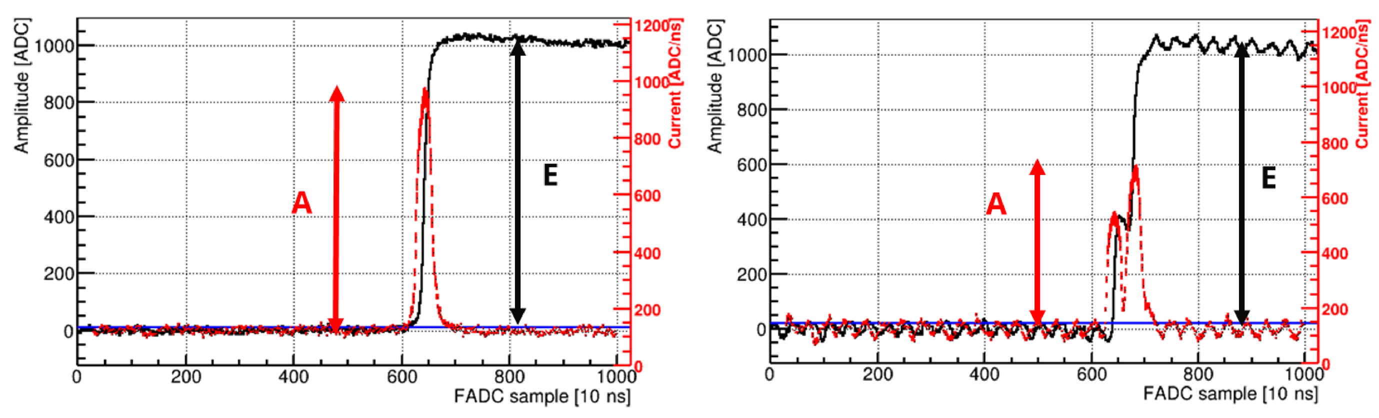
- Events identified via the depth versus energy plot
- A fiducial cut removes surface contaminations (mostly α emitters) and reconstruction artifacts (intrinsic to CPG readout) near the electrodes



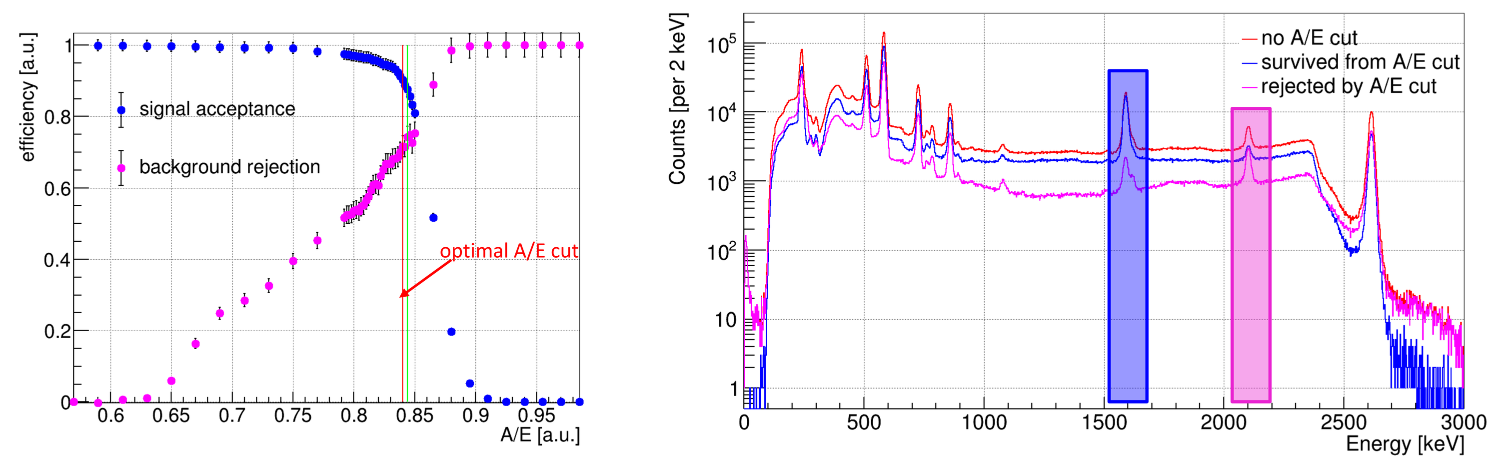
- Selection efficiency using the non-unique single β-decay of ^{113}Cd

Multi-site Events Cut

- Signal expected to be single-site events, while multi-site events mostly caused by multiple scattered photons
- Defining a parameter ***A/E***
  → A: the maximum amplitude of the derivative of charge pulses
  → E: the height of the charge pulse
- A/E value for the single-site event is smaller than that for the multi-site event at certain energies



- The ^{208}Tl double escape peak (1592 keV) used as the signal, events in the single escape peak at 2103 keV used to quantify the background rejection
- Optimal A/E cut value is set at 90% signal acceptance



Summary and Outlook

- Pulse shape discriminations are developed for q-CPG CdZnTe detectors and the corresponding efficiencies are evaluated
- With the cuts applied, the background level in the signal ROI has improved by two orders of magnitude compared to the previous setup
- Simulations are ongoing to verify the cut efficiencies

References

[1] K. Zuber, Phys. Lett. B, 2001, 519(1-2): 1-7.
[2] J.H. Arling et al., Nucl. Instrum. Methods Phys. Res. A, 2021, 1010: 165524.
[3] https://www.comsol.com/
[4] S. Zatschler, Pulse-shape studies with coplanar grid CdZnTe detectors and searches for rare nuclear decays with the COBRA experiment, PhD Thesis, 2020.

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