Search for Neutrinoless Double Beta Decay with CdZnTe Semiconductor Detectors

Tobias Koettig

technische universität dortmund

Physik E-IV

tobias.koettig@tu-dortmund.de

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The COBRA Experiment

- Idea: Build 3D array with CdZnTe room temperature semiconductor detectors
  - Available as Coplanar Grid (CPG) and pixelated detectors
  - Room temperature: simplifies operation and allows options like active veto surrounding the detectors

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  - Available as Coplanar Grid (CPG) and pixelated detectors
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- CdZnTe contains 9 $0\nu\beta\beta$ candidates, the most important:
  - $^{116}\mathrm{Cd}$: Very high Q-value (2 813 keV, above 2615 keV $^{208}\mathrm{Tl}$ line, large phase space) and good Matrix element
  - $^{130}\mathrm{Te}$: High Q-value (2 527 keV), good Matrix element, very high natural abundance (33.8%)
  - $^{106}\mathrm{Cd}$: One of the most promising $\beta+$ decay candidates, very high Q-value (2 770 keV) $\rightarrow$ all $\beta^+\beta^+$ decay modes possible

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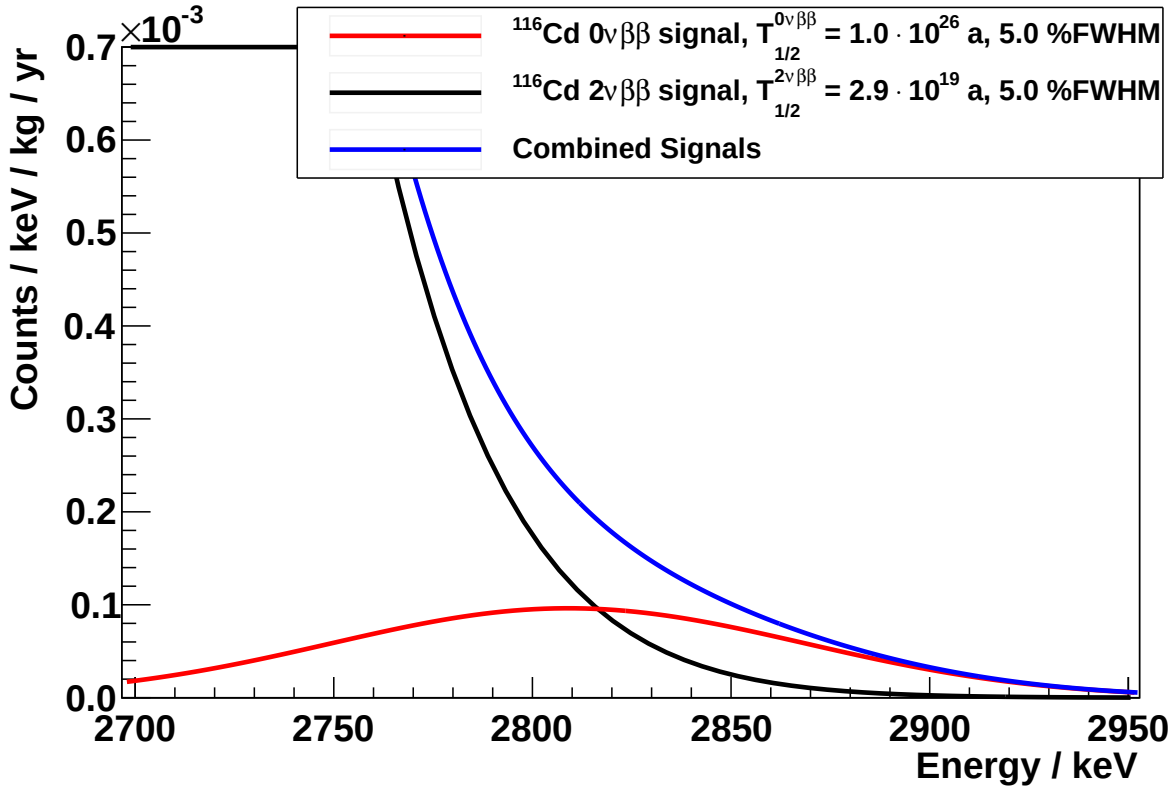
The COBRA Experiment

- Semiconductor detectors $\rightarrow$ good energy resolution (crucial due to low 2ν HLT of $^{116}\mathrm{Cd}$), intrinsically clean material



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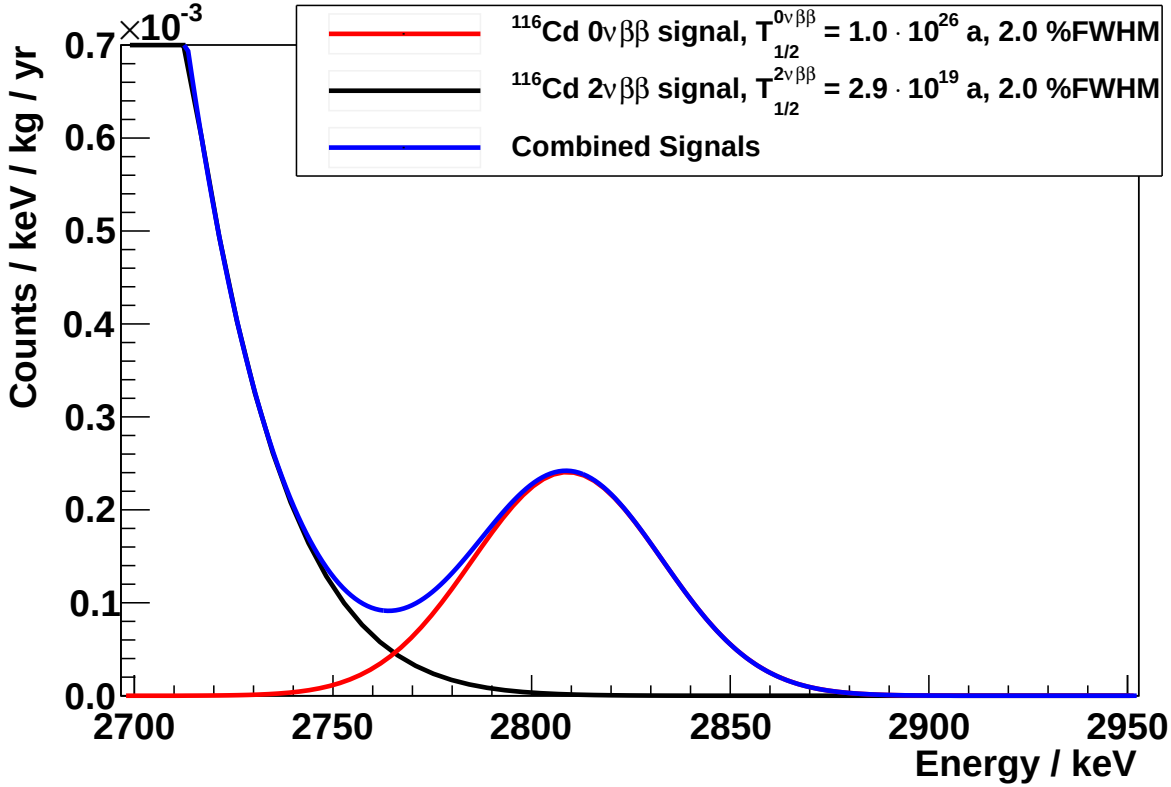

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  - to reduce background, e.g. $^{214}\mathrm{Bi} \xrightarrow{\beta} {}^{214}\mathrm{Po} \xrightarrow{\alpha} {}^{210}\mathrm{Pb}$ coincidence, multi hit events from neutron induced γ's etc.
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- R&D for a large scale experiment with $\sim 400\,\mathrm{kg}$ CdZnTe to provide sensitivity on half-lives $> 10^{26}$ years

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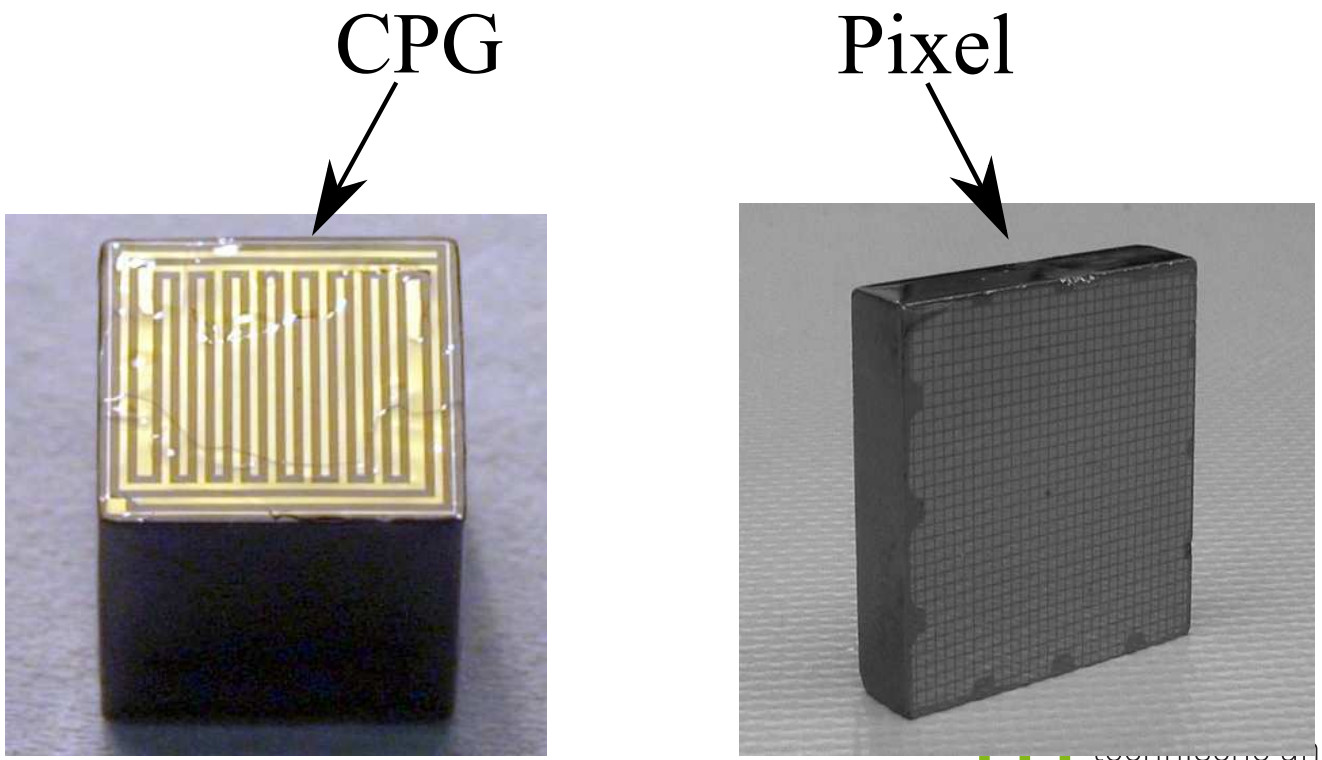
CdZnTe/CdTe Semiconductor Detectors

- Electron and hole mobility differ strongly in CdZnTe / CdTe
  $\rightarrow$ have to restrict signal readout to only electron contribution
  - Small Pixel Effect (Pixelated detectors)
  - Frisch-Grid like readout (CPG)



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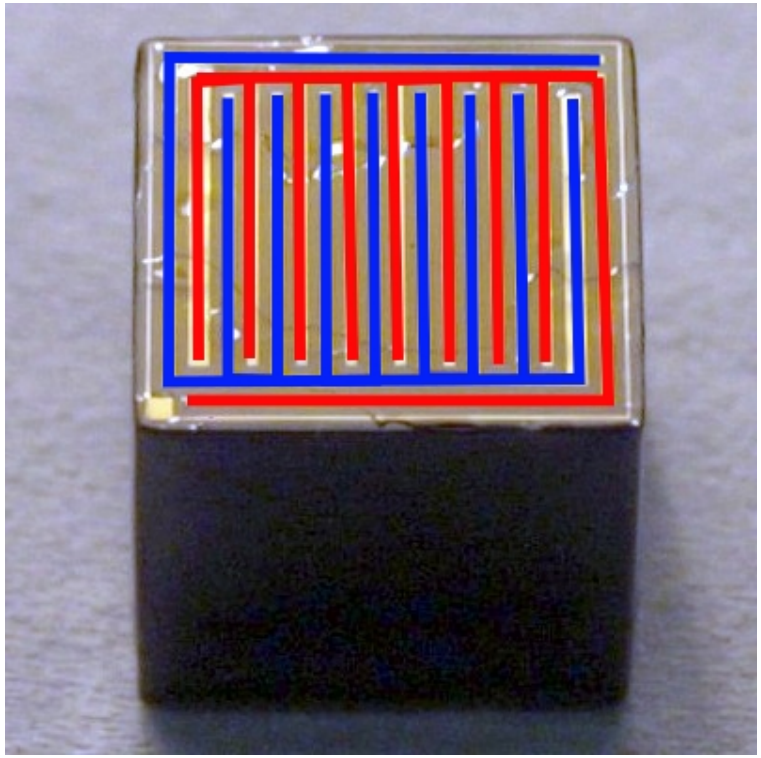

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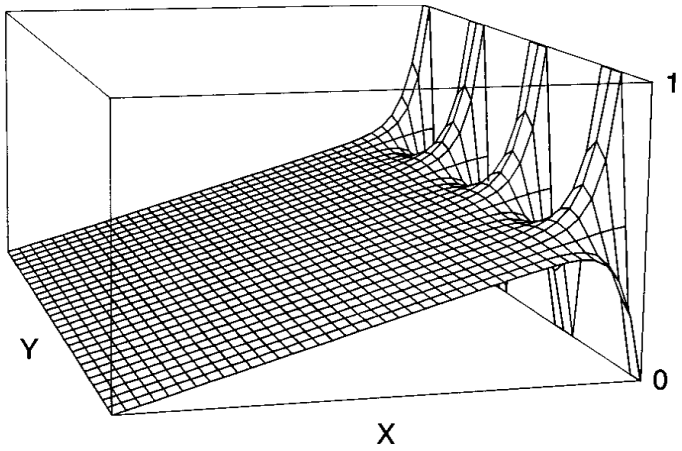

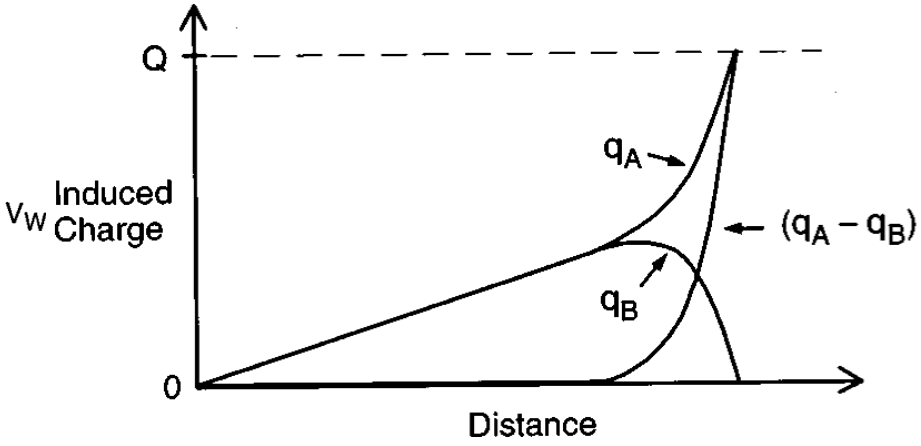

[Luke(1994), Appl. Phys. Lett. 65]

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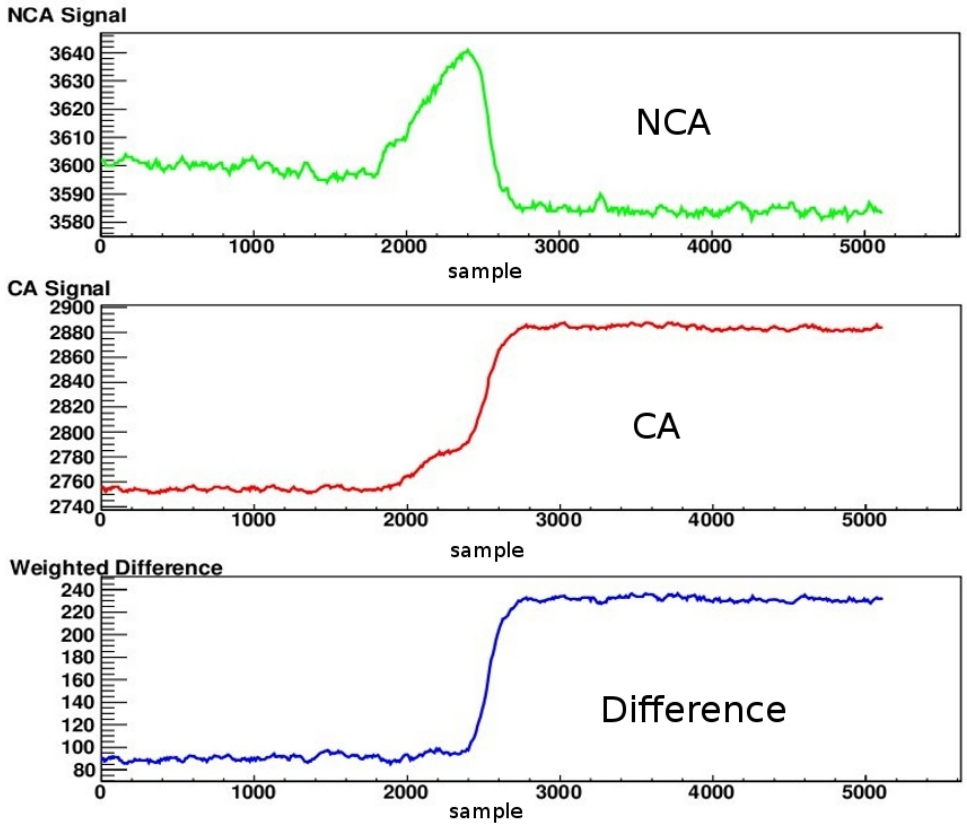

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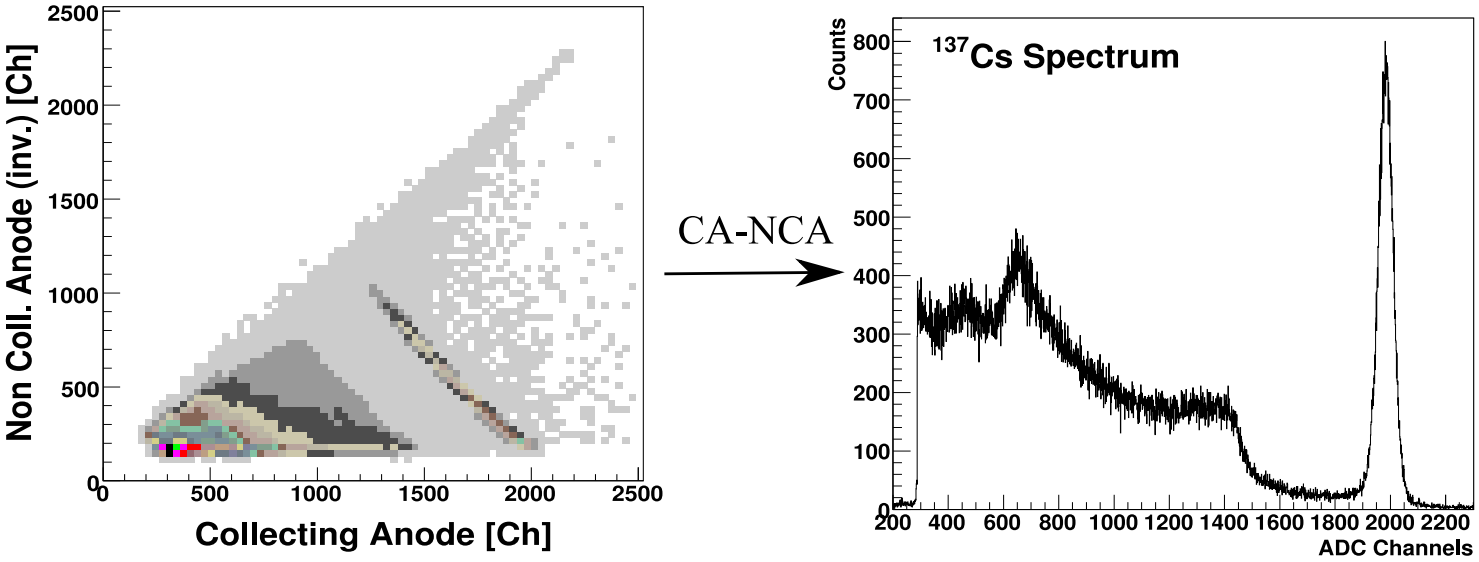

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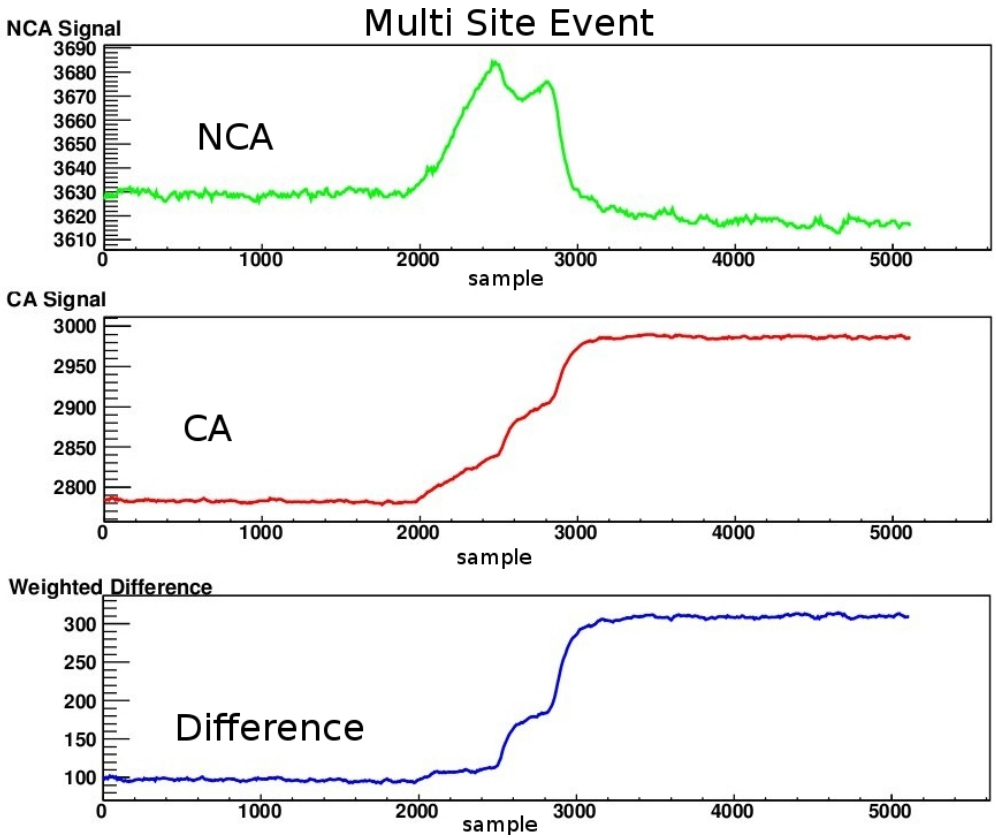

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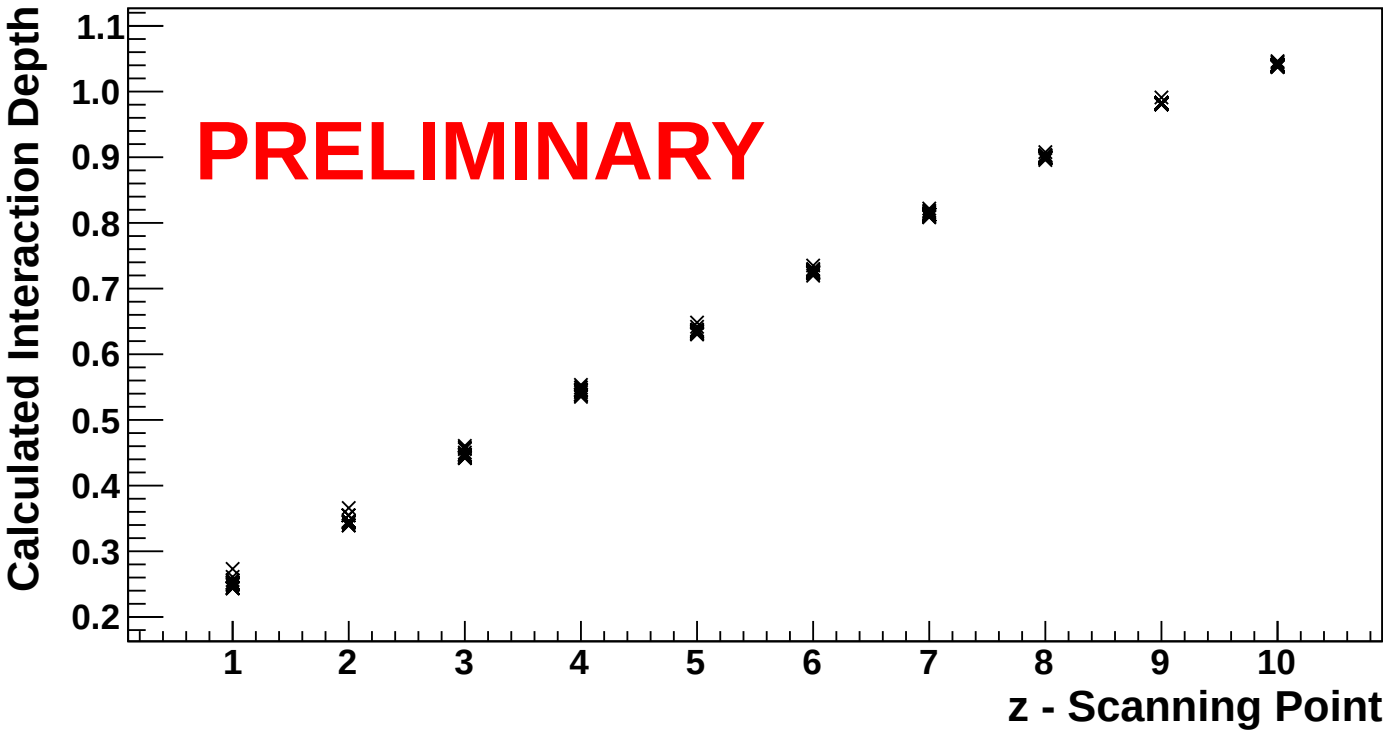

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- With pulse shape readout achieved better resolution than specification of manufacturer

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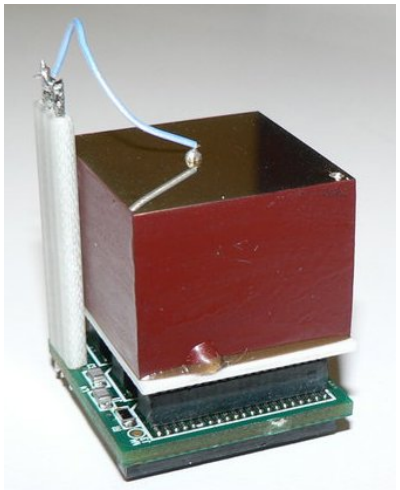
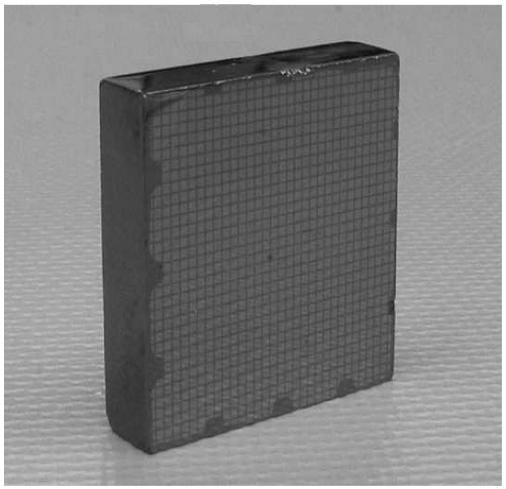
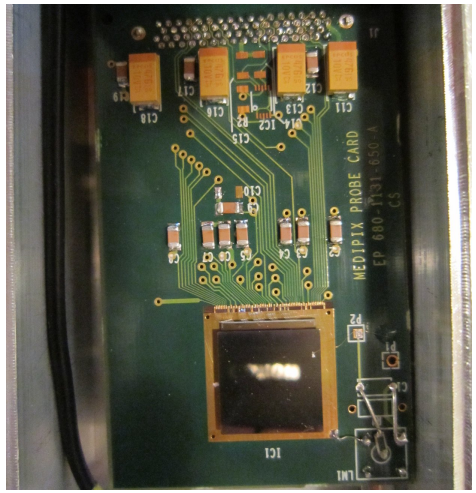
Pixelated Detectors

- Two types of pixelated detectors tested by COBRA:
  - Large volume detectors (up to $2 \times 2 \times 1.5\,\mathrm{cm}^3$) with larger pixel pitch ($\sim 1\,\mathrm{mm}$) (Polaris System, WUStL System)
  - Thinner detectors (several mm) with small pixel size ($\sim 100\,\mu\mathrm{m}$) (Timepix detector developed by the Medipix2 Collaboration)







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COBRA

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- 11×11 pixel $\rightarrow$ pixel pitch of $\sim 1.8\,\mathrm{mm}$

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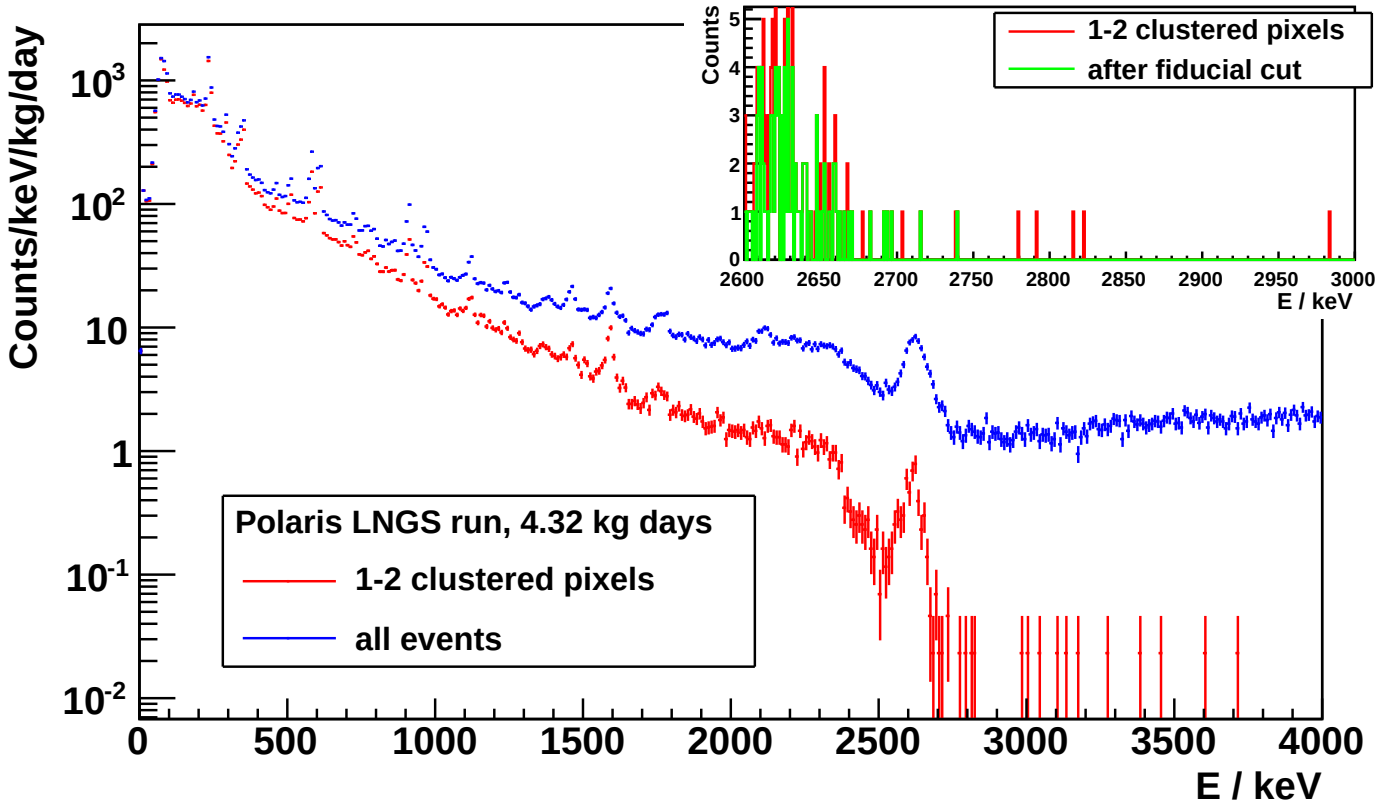
- Pixel size too large for tracking, but cuts to number & location of hit pixels demonstrates the power of background reduction



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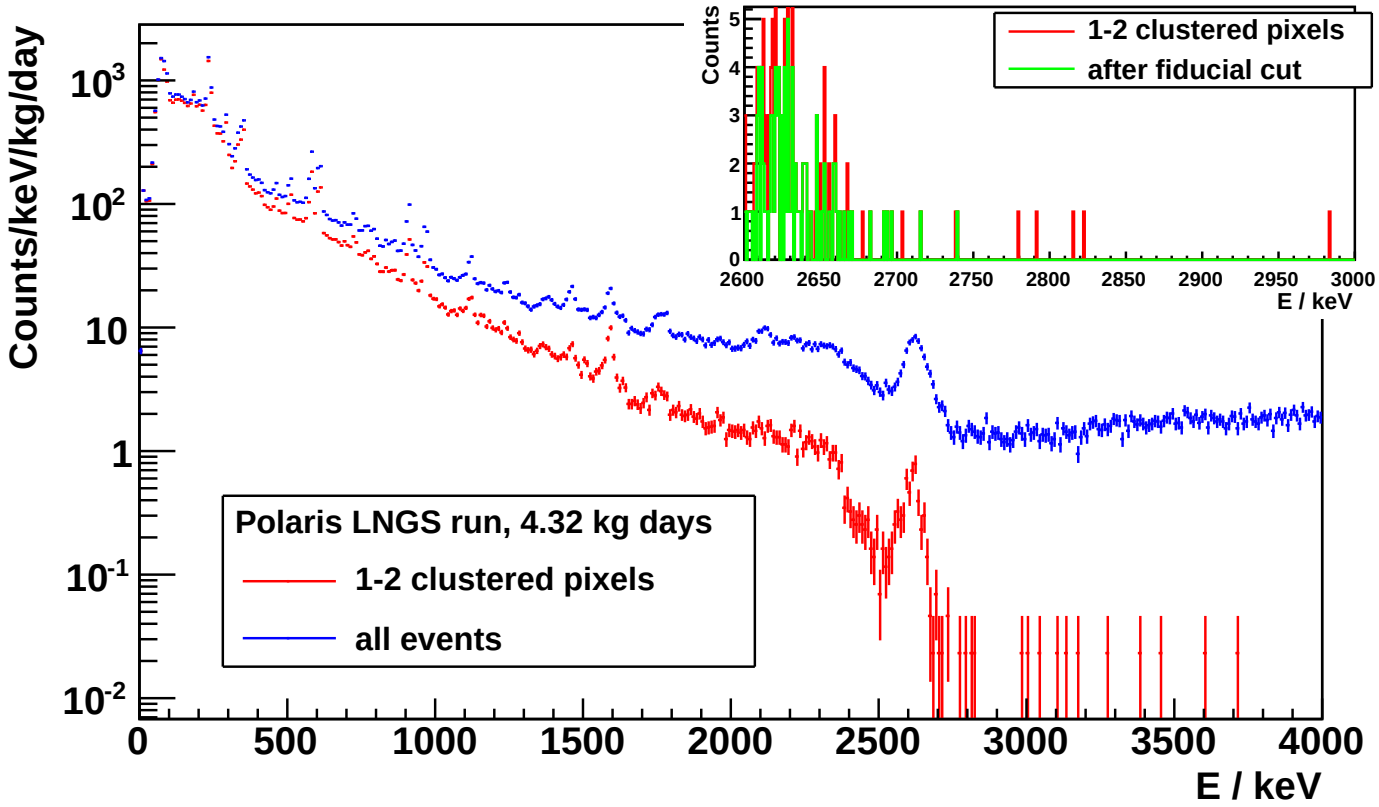

- With fiducial cut reduction to 0 cts in ROI in 3 months of measurement ($\sim$2 cts/keV/kg/yr)

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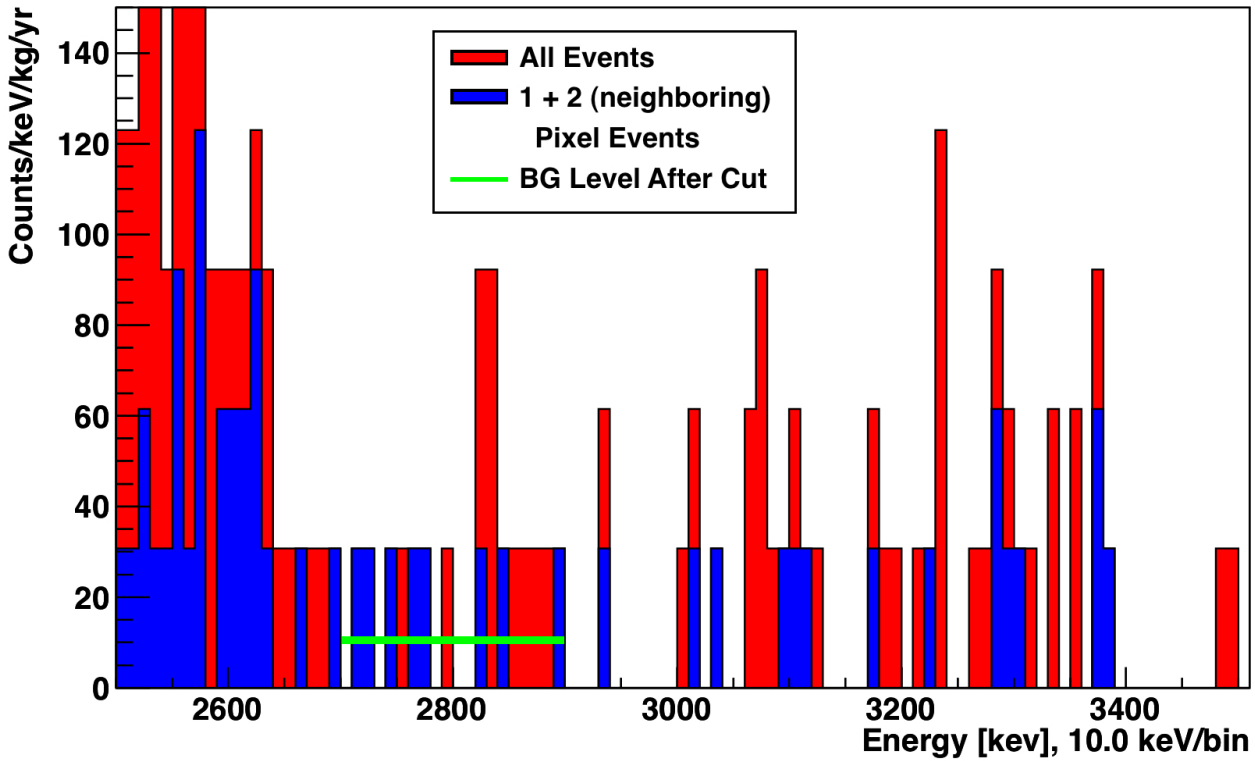
COBRA

Large Volume Pixel, WUStL System

- $1 \times 2 \times 2\,\mathrm{cm}^3$ CZT sensor, 8×8 pixels $\rightarrow$ 2.5 mm pixel pitch
- Prototype (not low BG opt., 1.6% @ 583 keV) operated at LNGS
- With single pixel cut BG level of 12 cts/keV/kg/yr achieved



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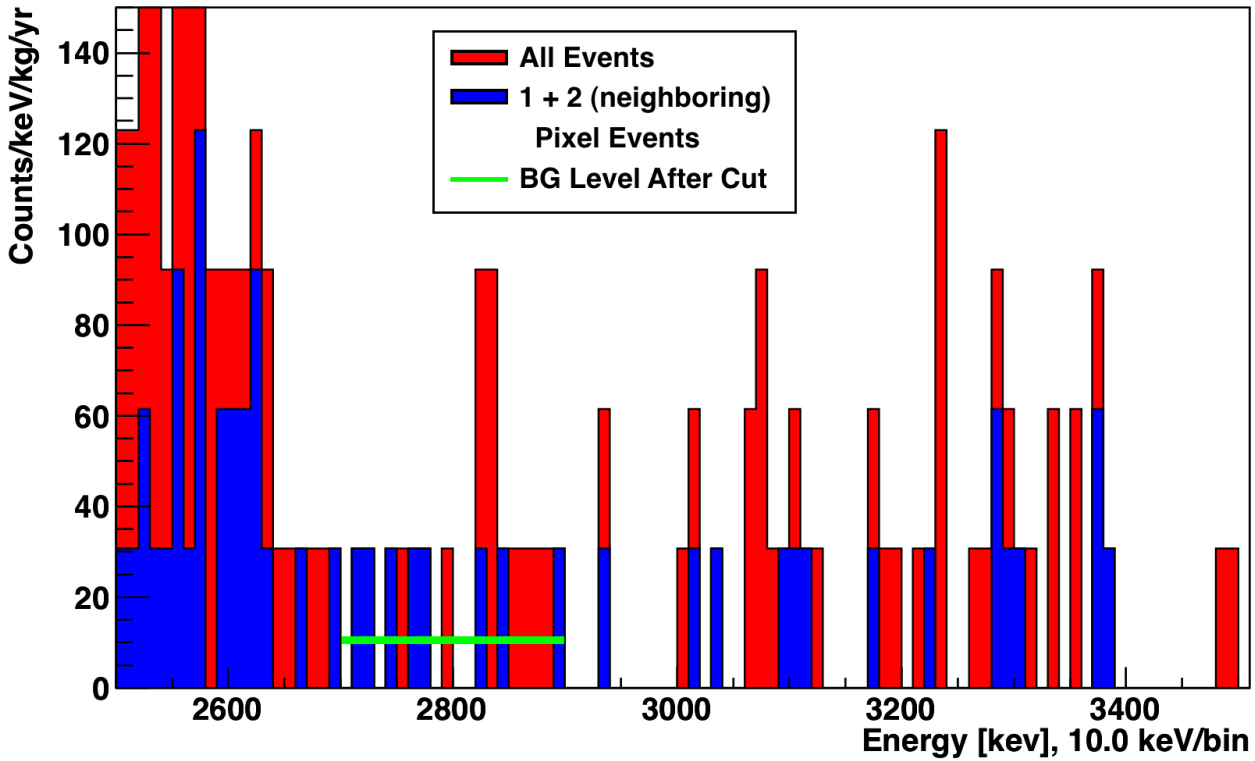

- Low BG optimised system (incl. pixel design optimisation) under development

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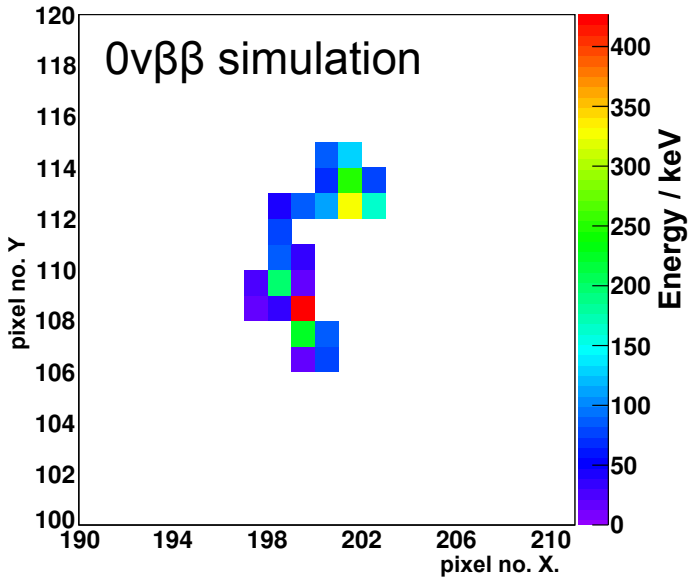

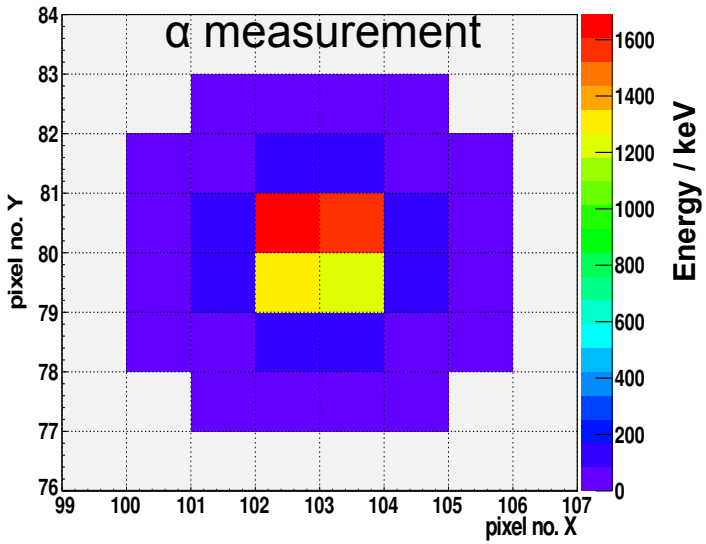

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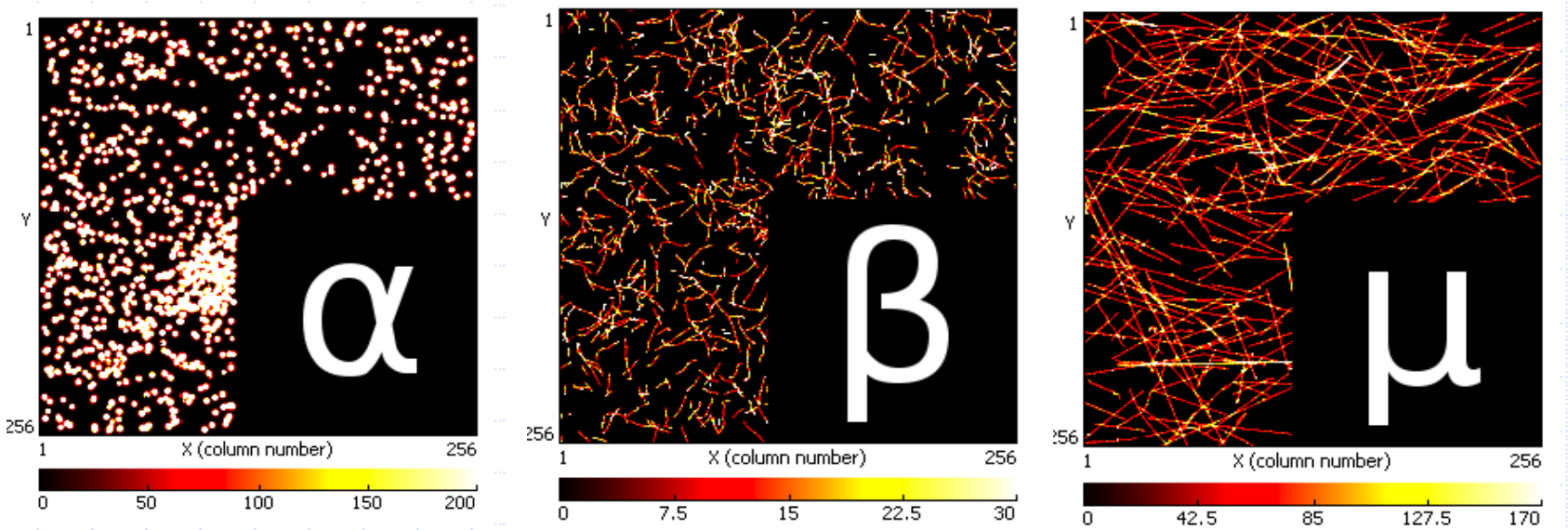

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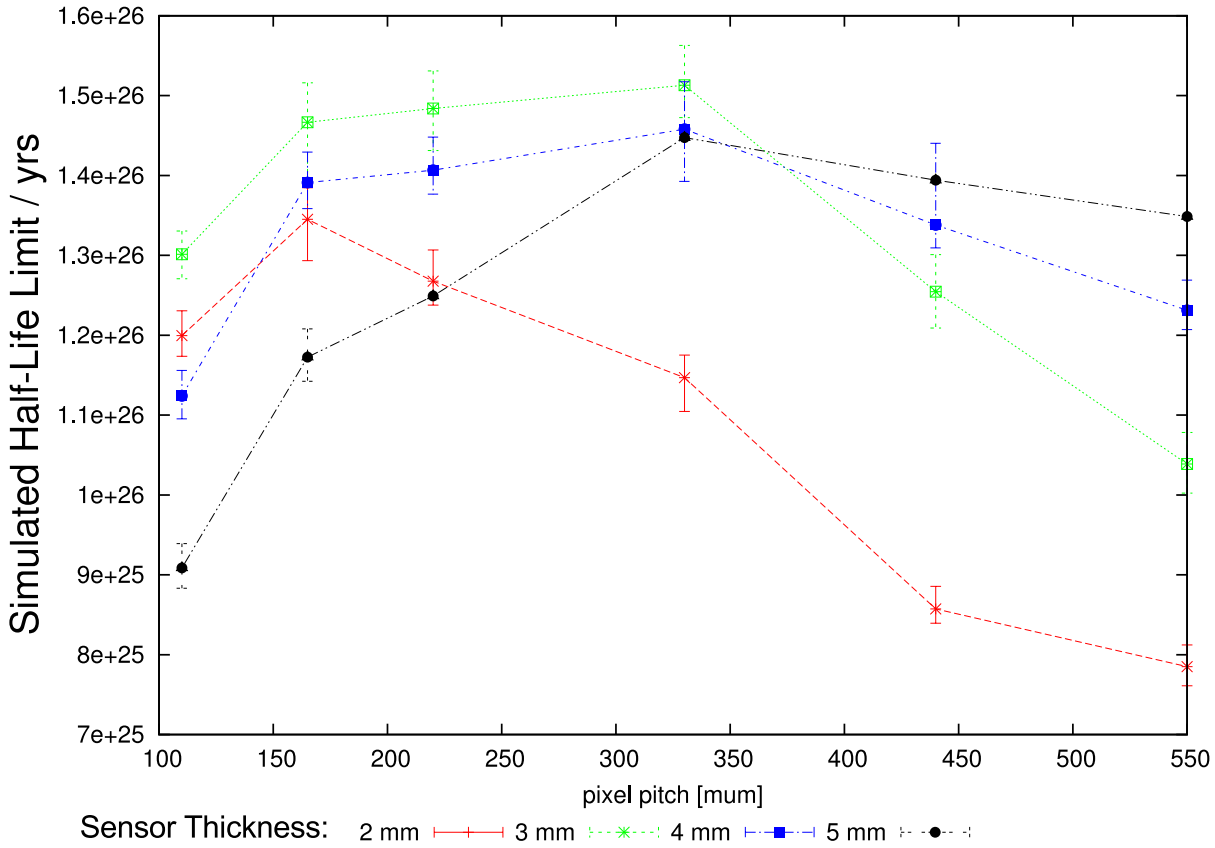
Small Pixel Detector, Sensitivity Studies

- Extensive studies for parameter optimisation (pixel pitch, voltage, thickness)



T=3 a, $3\,\sigma$, $2\nu\beta\beta$ BG only, 400 kg

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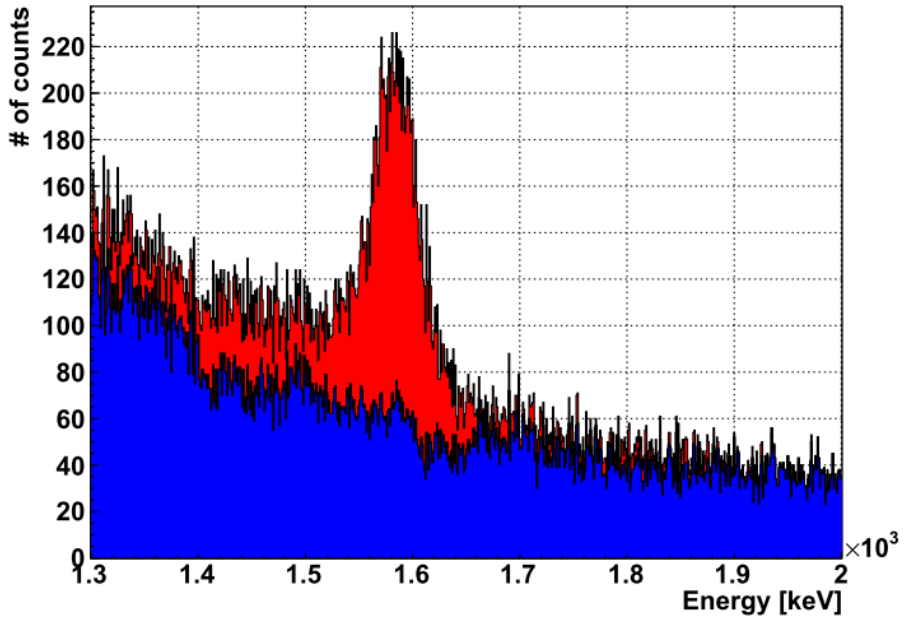
Small Pixel Detector, Sensitivity Studies

- Extensive studies for parameter optimisation (pixel pitch, voltage, thickness)
- Studies on particle identification:
  - α's comparatively easy
  - $\beta\beta \leftrightarrow \beta$ rather challenging $\rightarrow$ neuronal network, test with double escape events from ^{208}Tl 2.6 MeV line



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Small Pixel Detector, Low BG Studies, CTU Prague

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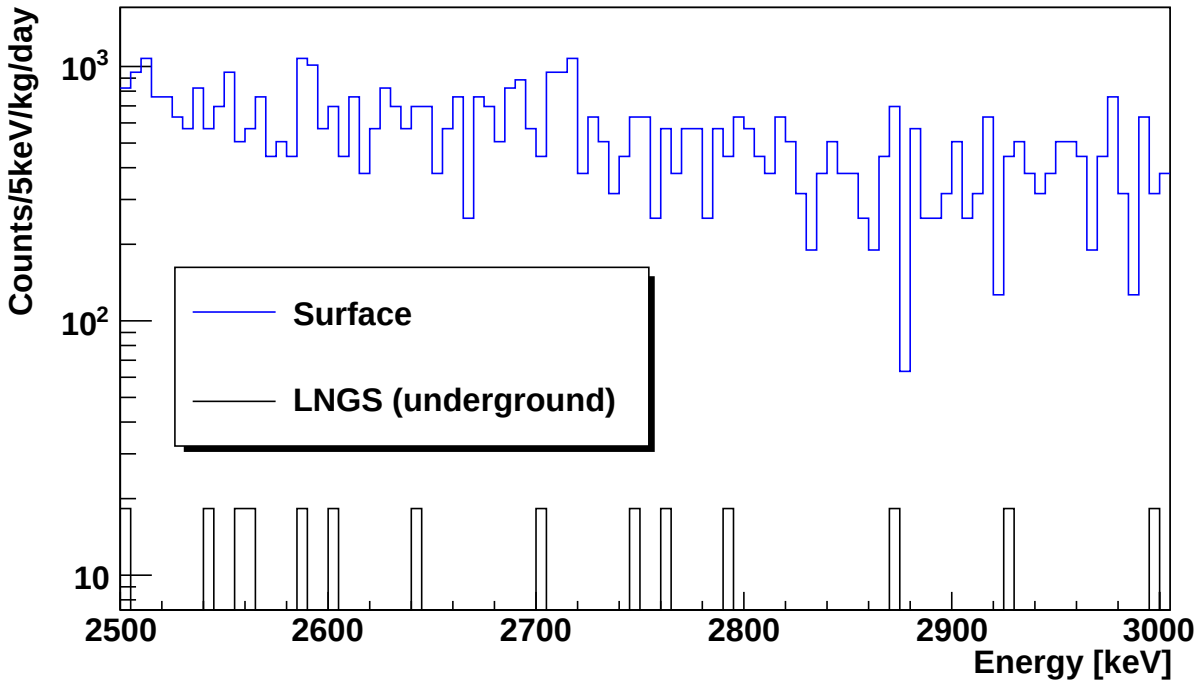
- 14 events between 2.5 MeV - 3 MeV in 45 days of measurement



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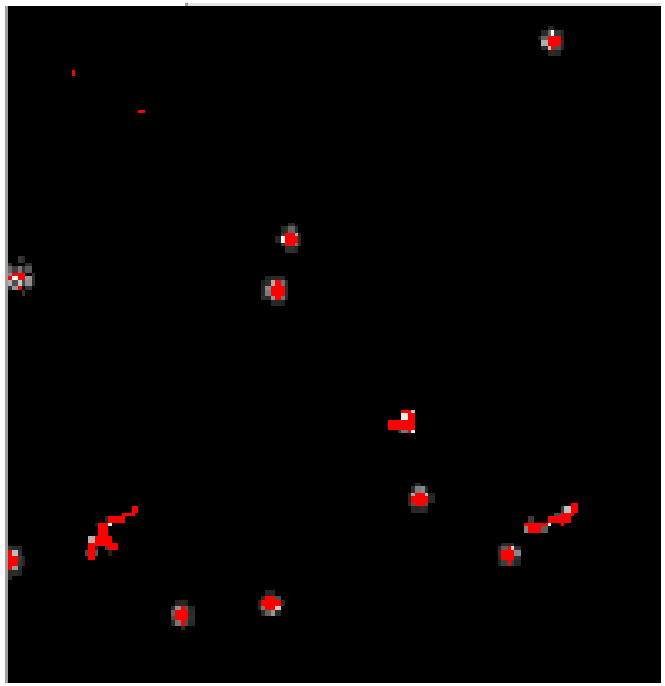

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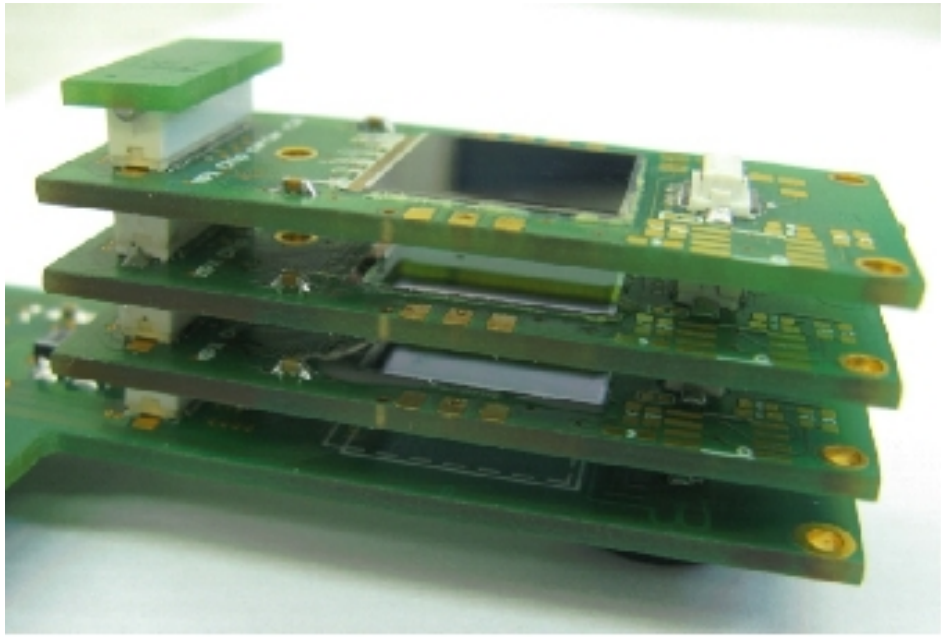

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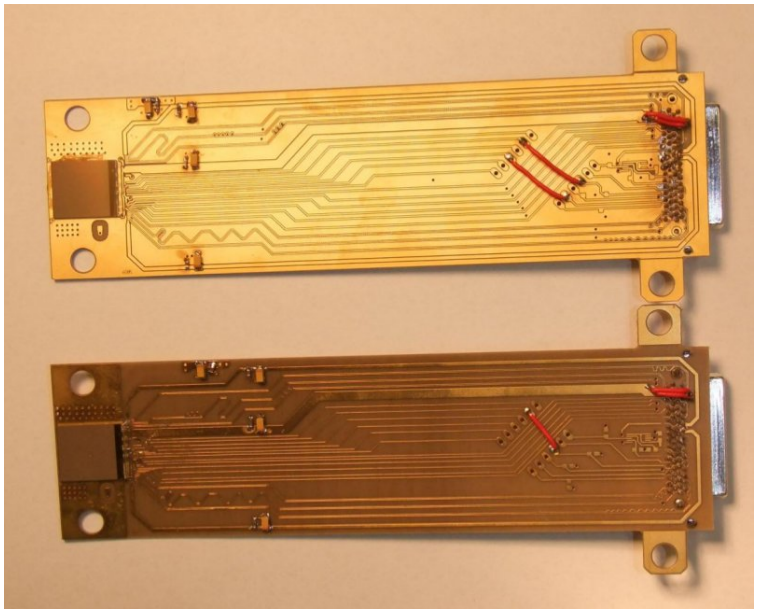
- As PCB boards known to be dirty $\rightarrow$ work on board with radiopure materials



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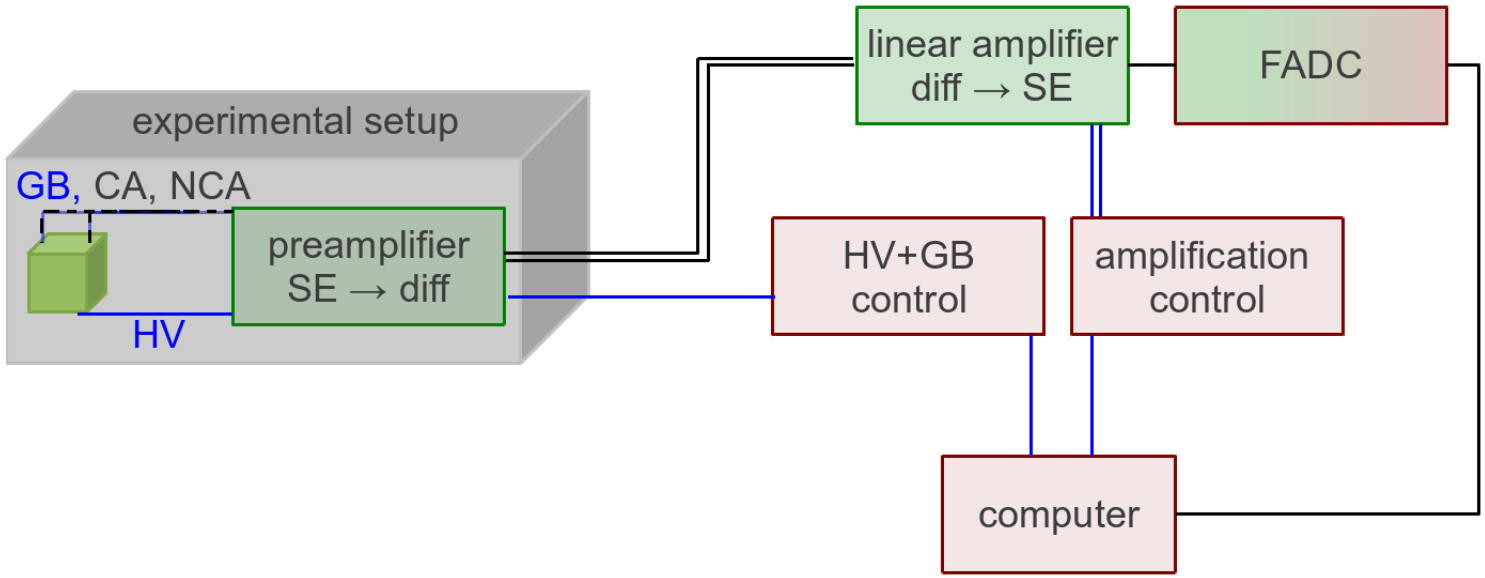
COBRA

LNGS Electronics Upgrade

- In 2010 start of change to pulse shape based readout
- DAQ-software, readout electronics & evaluation methods had to be redone from scratch, including differential signal transmission and fast differential linear amplifiers



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LNGS New Location

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- Upgrades during move:

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  - Installation of radon tight foil
- Other features
  - 7 cm of Boron loaded PE
  - 20 cm of lead, 5 cm of Copper
  - Constantly flushed with evaporated and filtered N_2
  - Can house up to 64 CPG detectors
  - Space for pixel detector test set-ups

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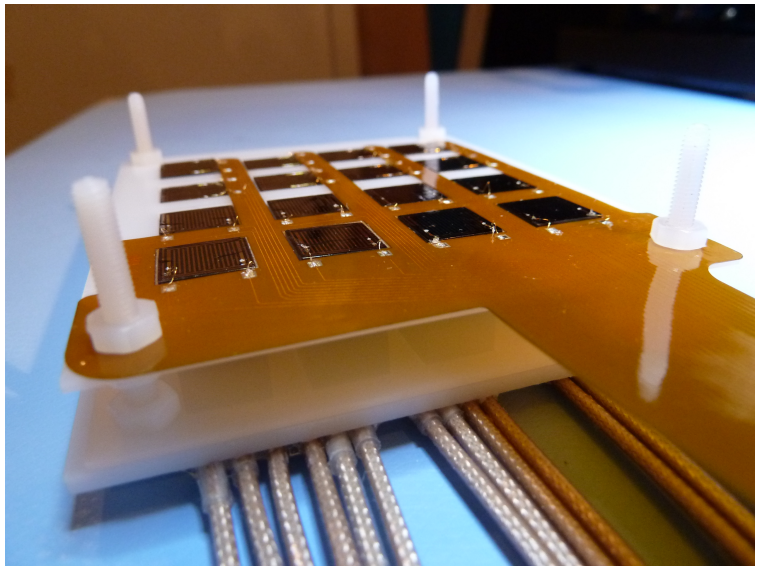
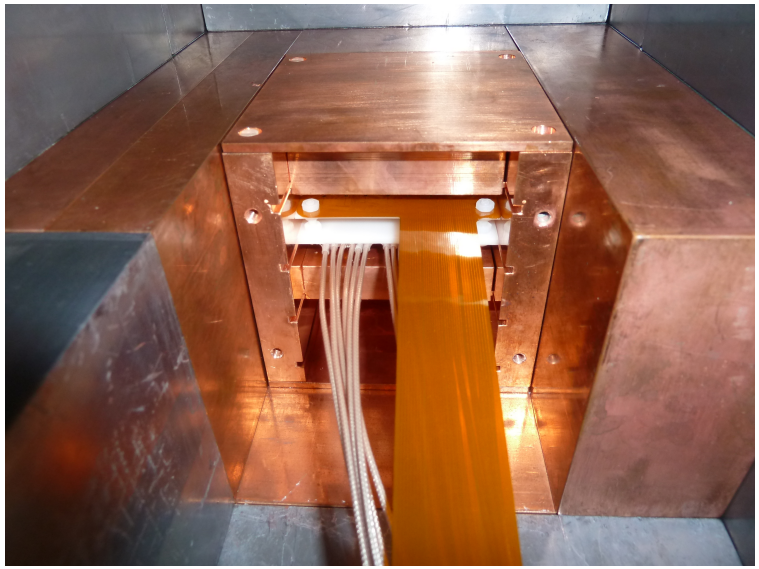
LNGS New Location

- Recently installation of 16 detectors with clear passivation.
  Aim: Installation of 64 detectors (all available)





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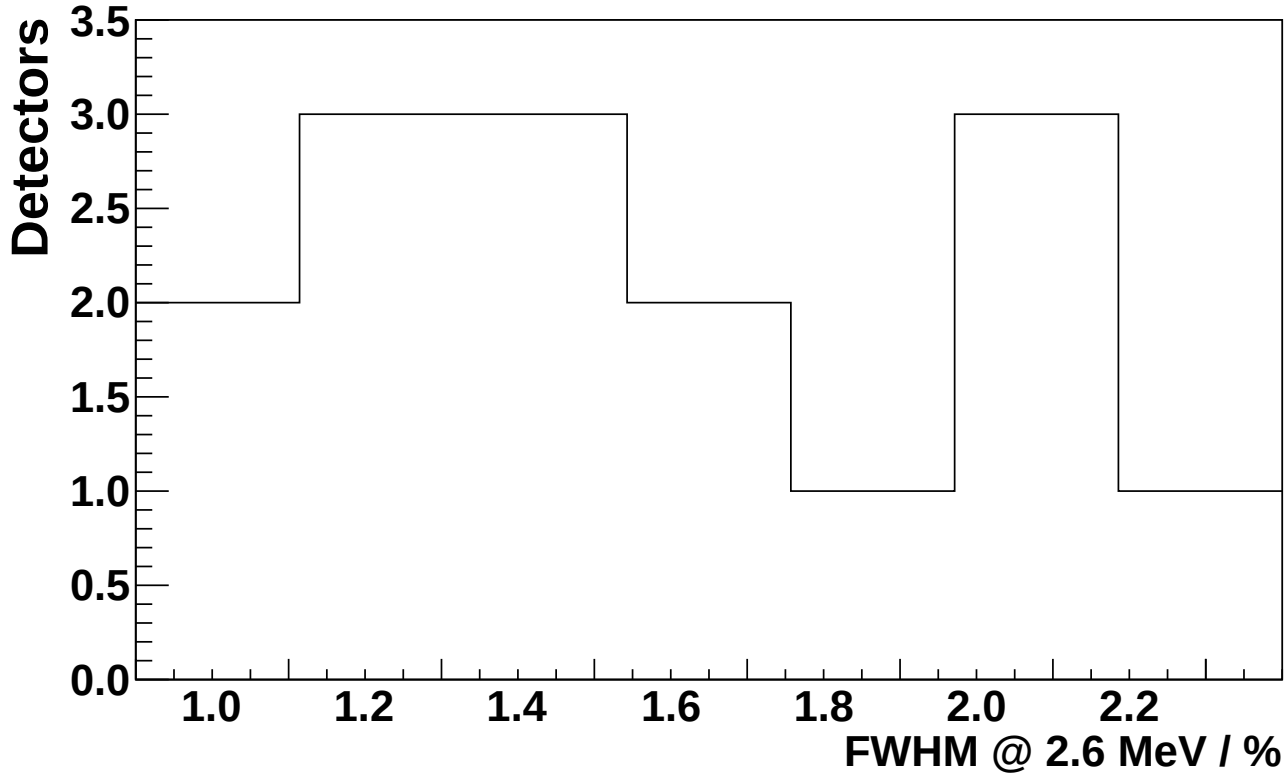

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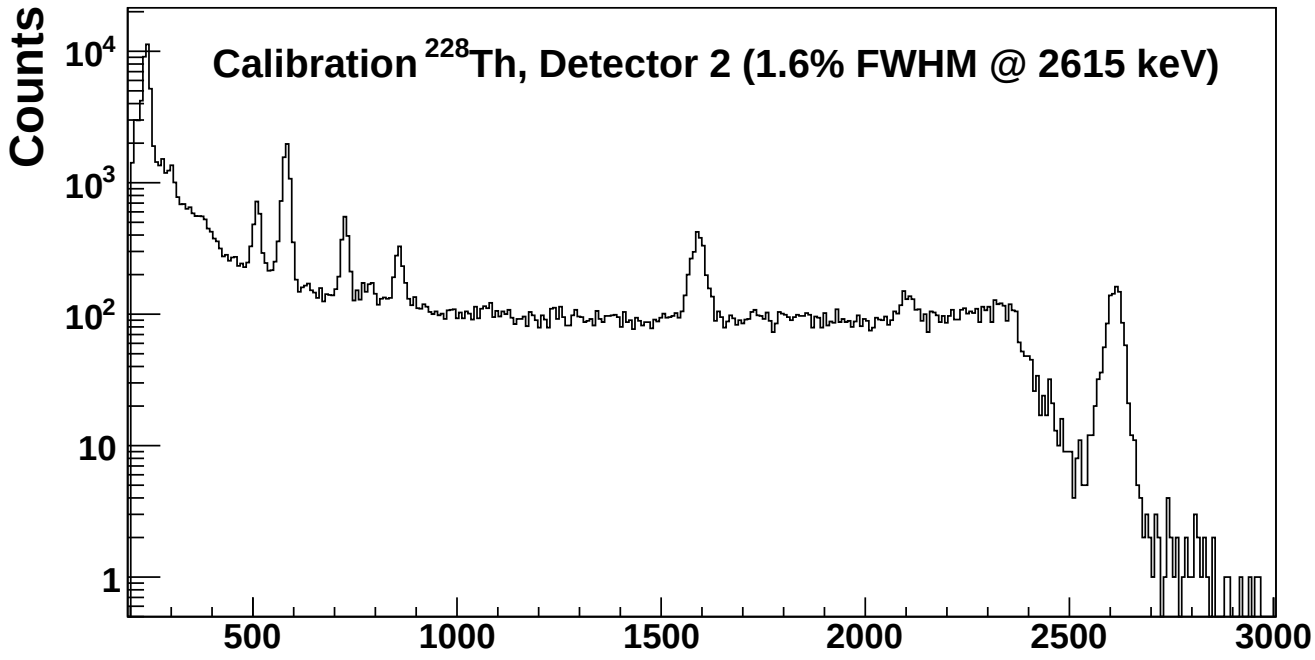

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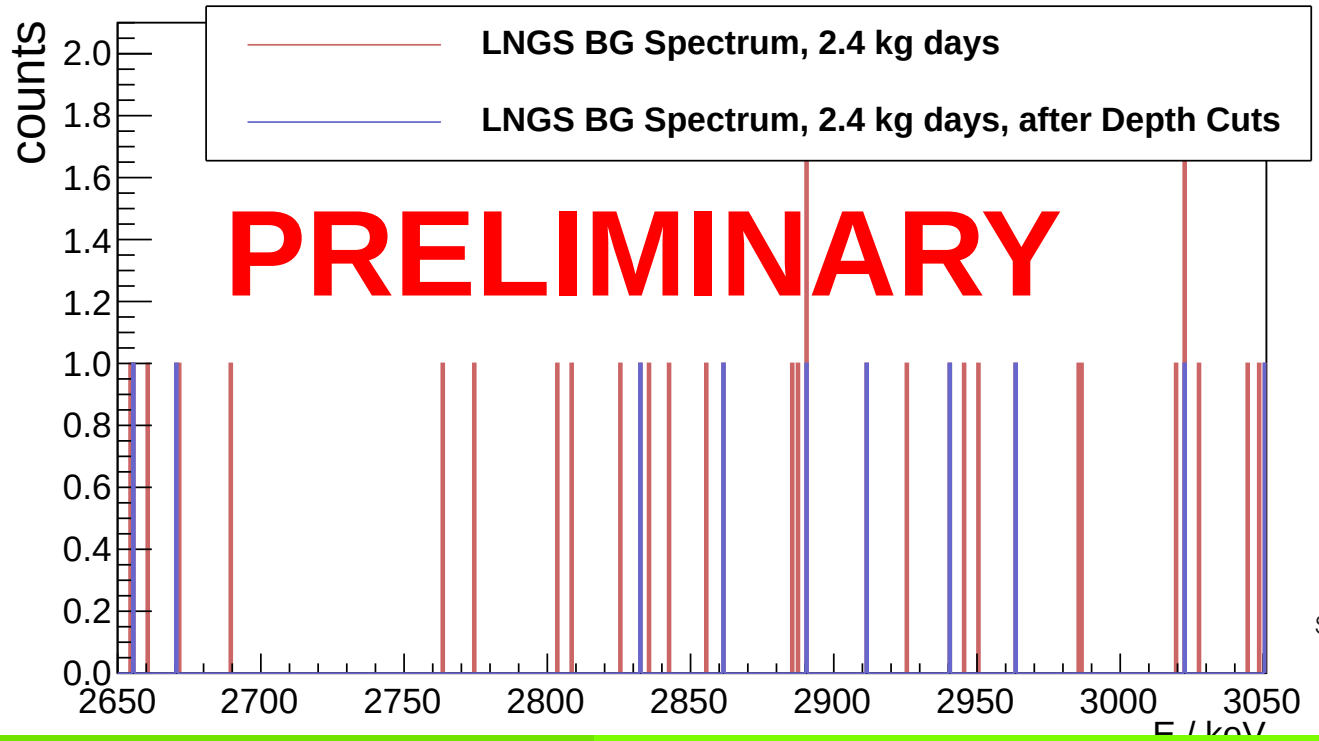
- Still in comissioning phase, but preliminary results promissing



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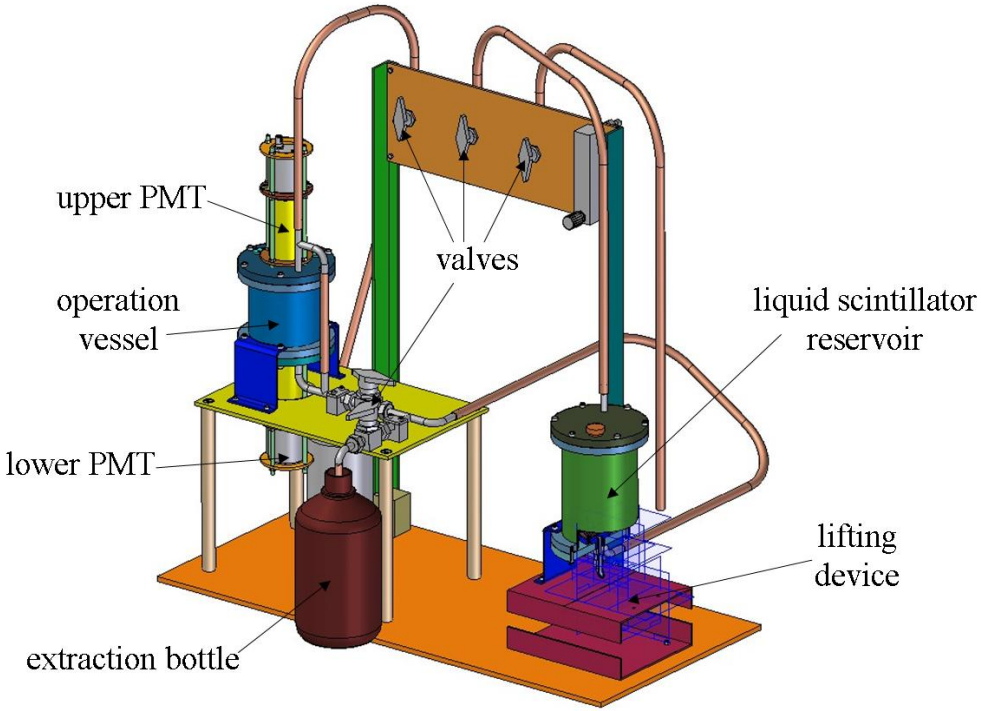
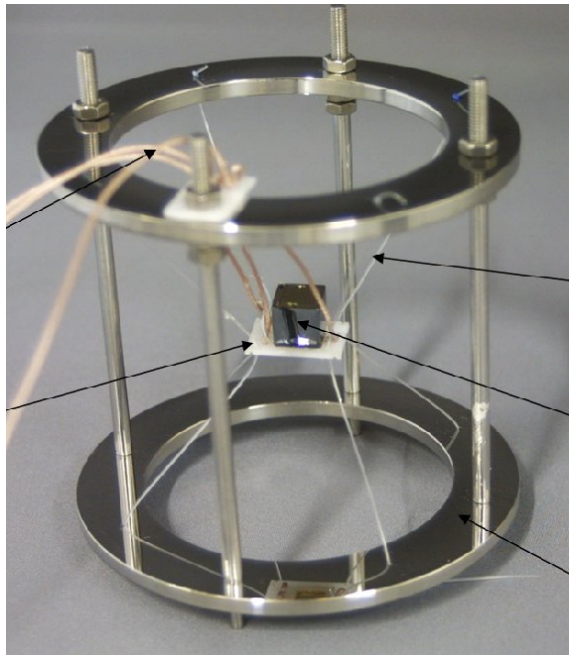
Shielding Option Liquid Scintillator

- LSc as shielding, veto system and to maximise detection efficiency





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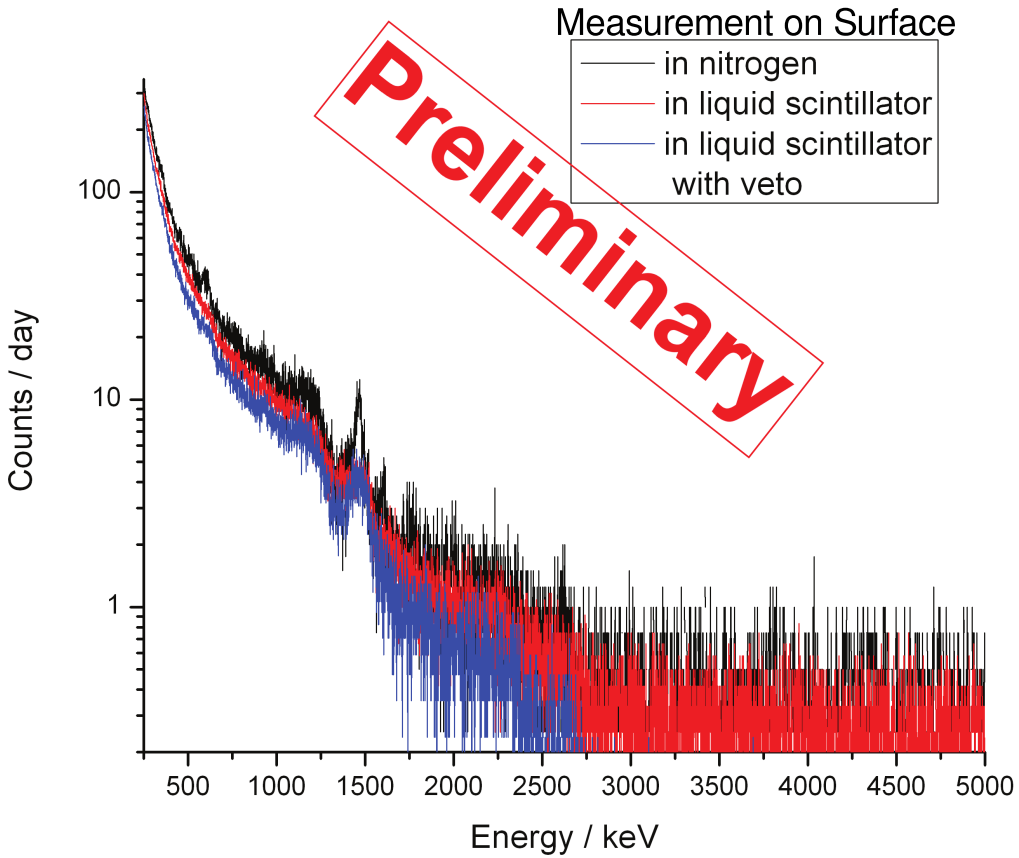

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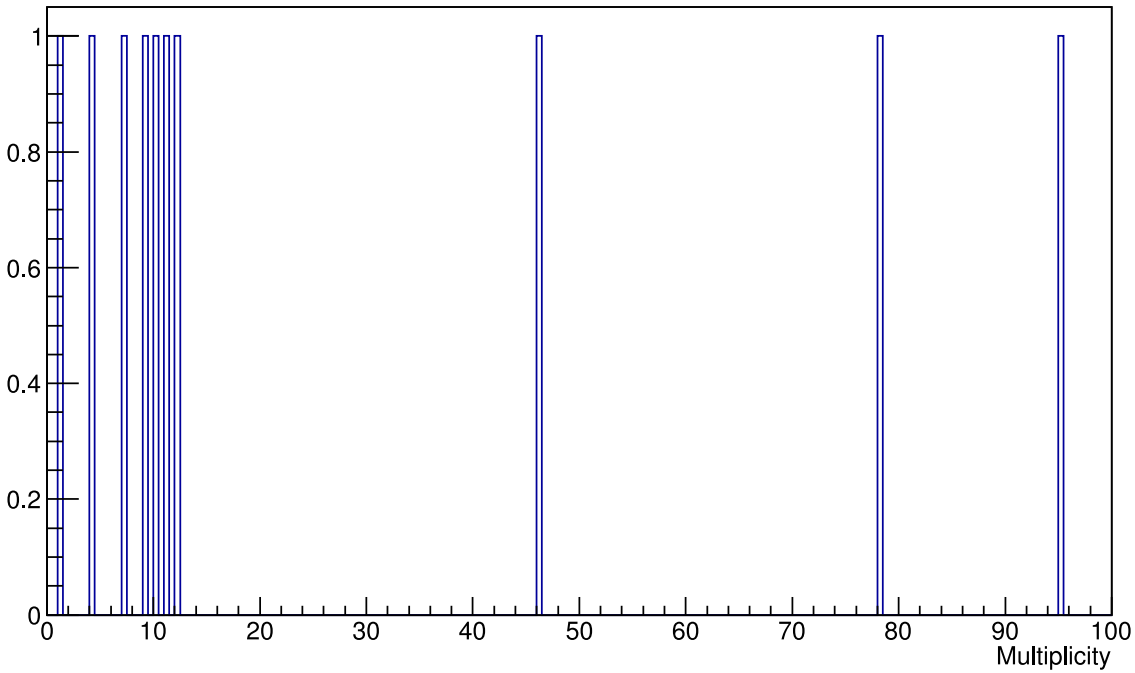
Simulation Studies

- Intensive studies to find optimal shielding for large scale set-up
- Initial focus on shielding compositions to suppress neutron BG
- Simulations show mainly multiple detector events for neutrons in ROI



- Simulations of various materials in many layer configurations
- Plans for experimental verifications of best rated shieldings

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Crystal Growth

- Aim: Produce enriched detectors
- Developed new synthesis method (for Cd, Zn, Te)

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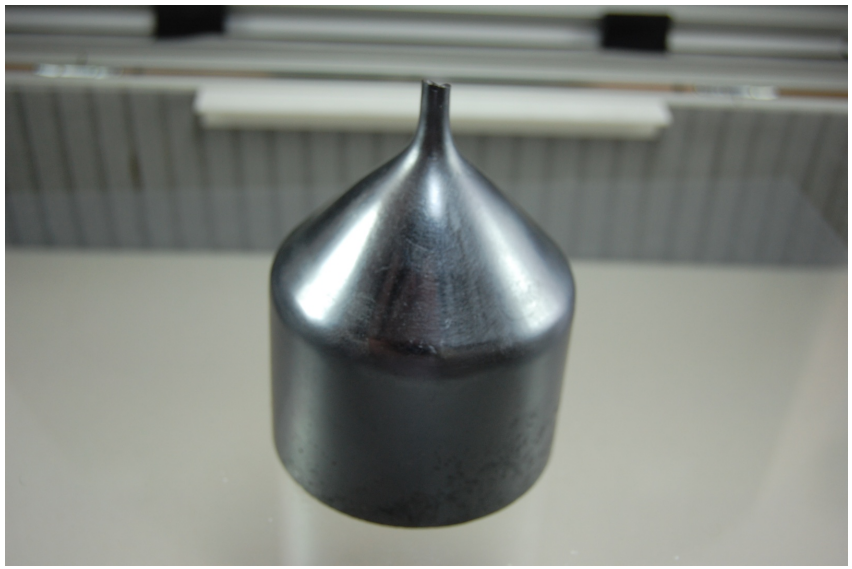
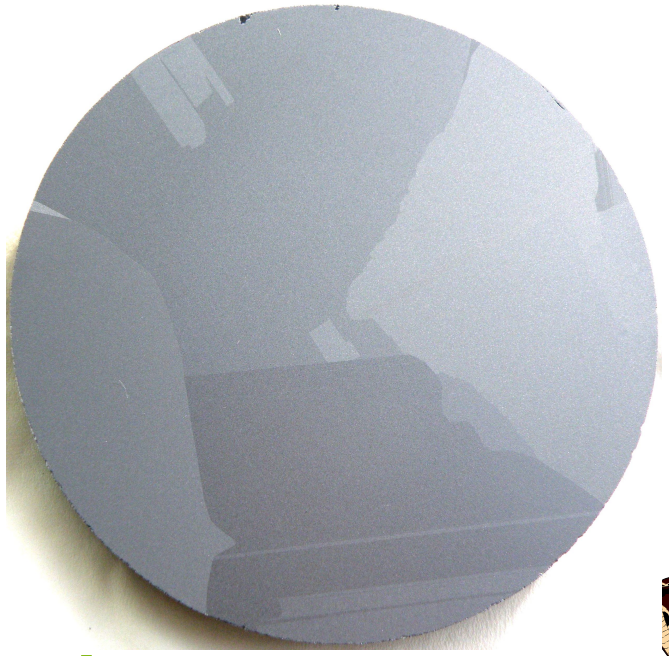
Crystal Growth

- Aim: Produce enriched detectors
- Developed new synthesis method (for Cd, Zn, Te)
- Already growth of CdTe ($\rightarrow$ TimePix) and preparation of detectors within the collaboration
- Also successful growth of CdZnTe detector material





- Further work on growth procedure

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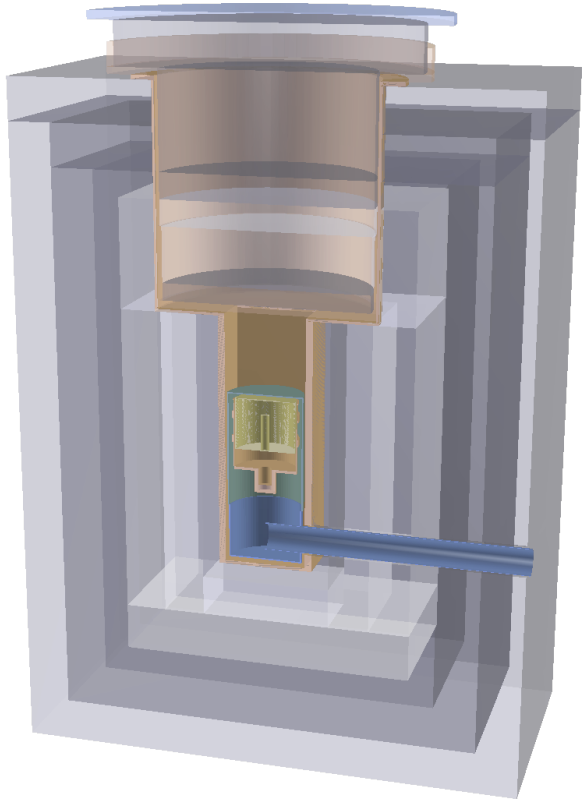
COBRA

Dortmund Low Background Facility

- Preselection of materials necessary
- Built a low BG Germanium facility
- Multi-layer shielding with neutron moderator



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Dortmund Low Background Facility

- Preselection of materials necessary
- Built a low BG Germanium facility
- Multi-layer shielding with neutron moderator
- Heavy shielding to achieve overburden of ~ 10 mwe
- Integral countrate (40 - 2700 keV) 4 cts/kg/min
- Detection limits < 100 mBq/kg

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COBRA

Summary

- Usage of CdZnTe semiconductor detectors, either CPG or Pixel technology to build a 3D detector array

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- Under intense R&D to explore full potential (CPG, Pulse-Shape Readout, Pixel, LSc...)
- Expected sensitivity for large scale set-up $> 10^{26}$ yrs

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Collaborators

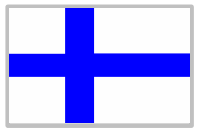
TU Dortmund
TU Dresden
FMF Freiburg
University of Hamburg
University of Erlangen

Czech Technical University in Prague

Laboratori Nazionali del Gran Sasso

Washington University in St. Louis

University of Bratislava



University of Jyvaskyla

University of La Plata

JINR Dubna

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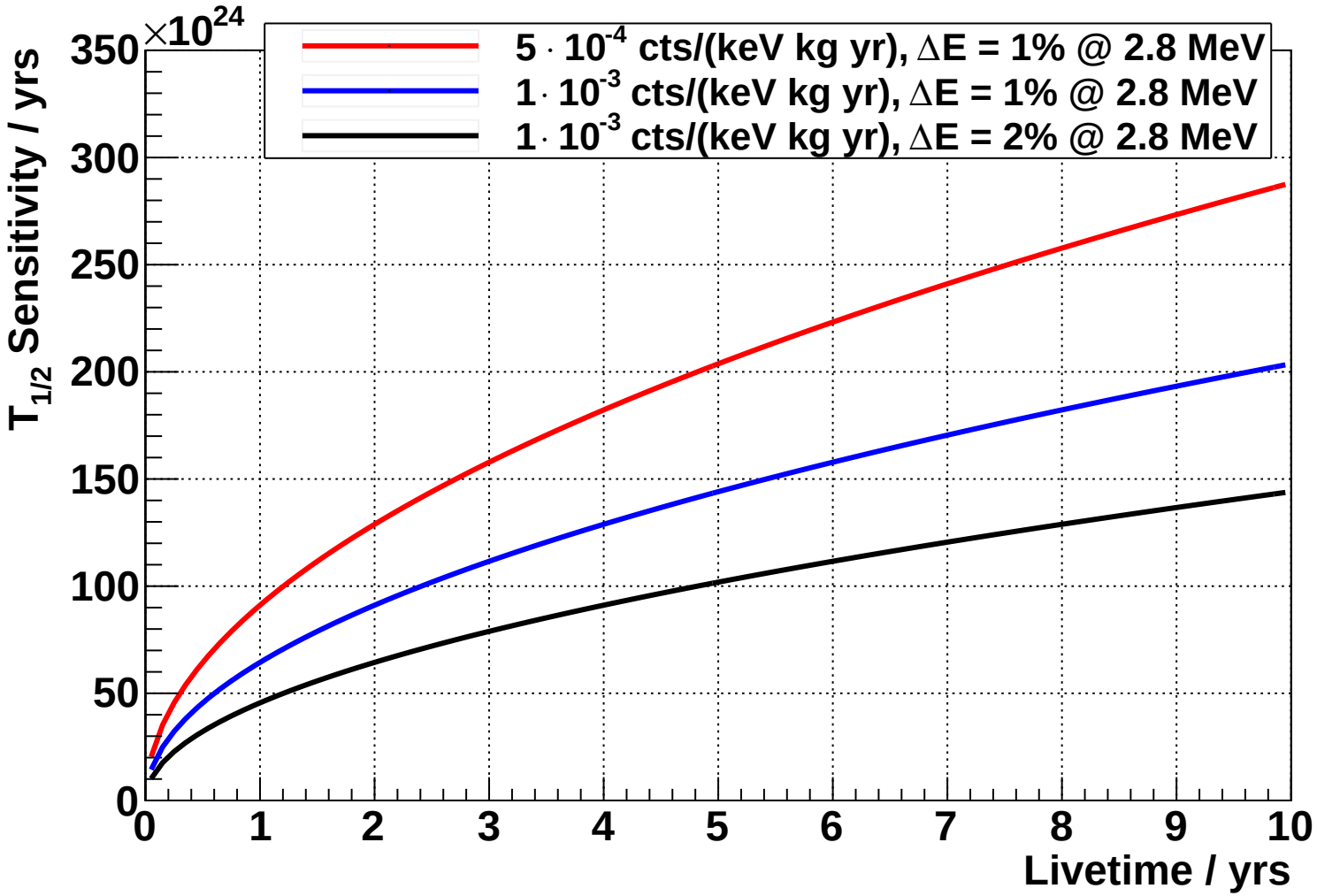
Expected COBRA Sensitivity



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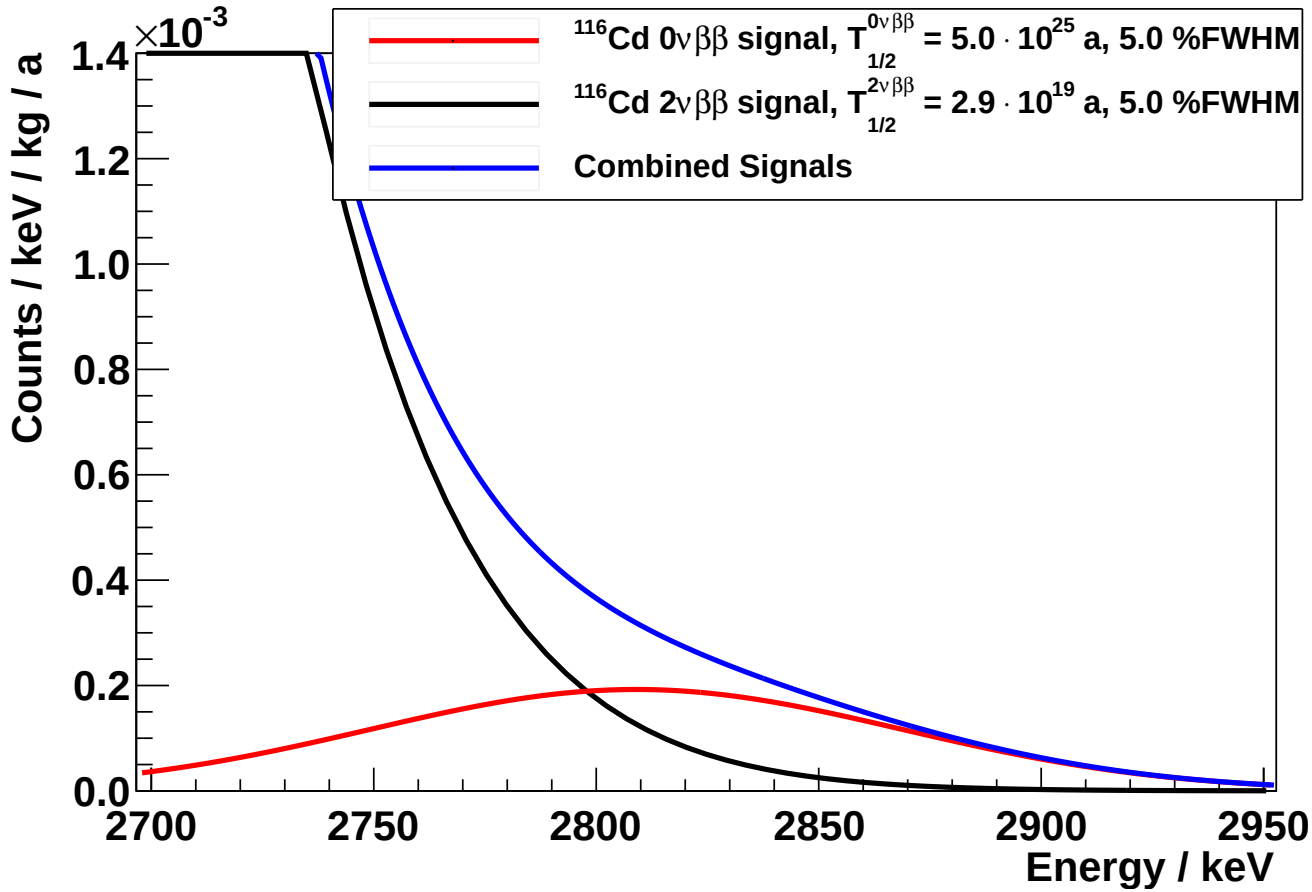
COBRA

$0\nu\beta\beta$ and $2\nu\beta\beta$



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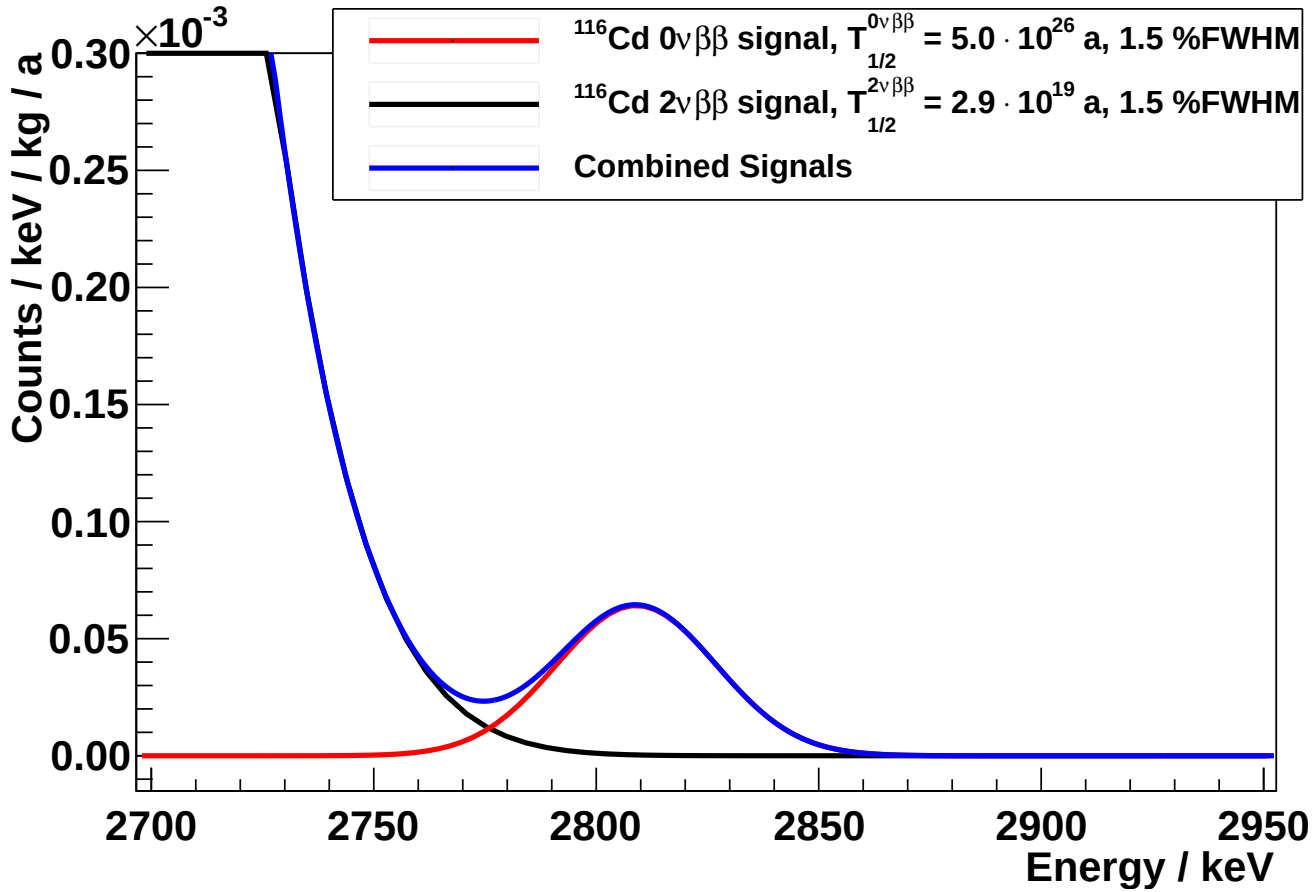

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Z. He et al. *1-D position sensitive single carrier semiconductor detectors* NIM A 380 (1996) 228–231.

P. Luke *Single-polarity charge sensing in ionization detectors using coplanar electrodes* Appl. Phys. Lett. 65 (1994) 2884.

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