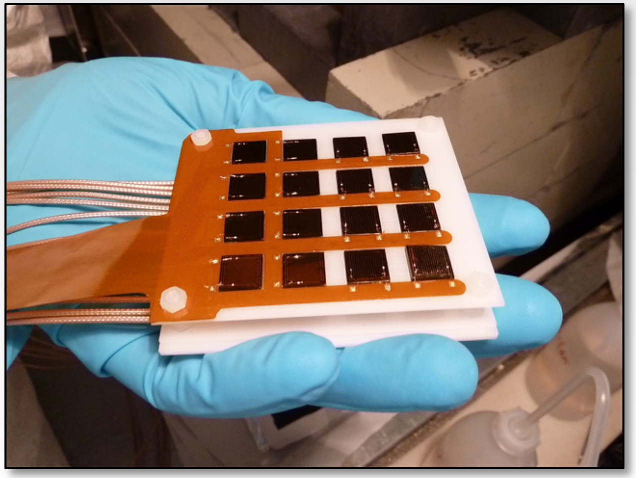
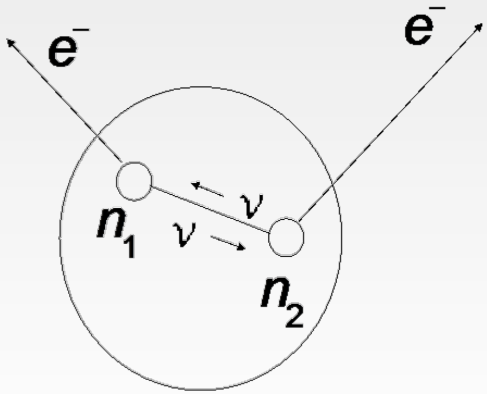
Gadmium-Zinc-Telluride 0-Neutrino Double-Beta Research Apparatus

Oct, 29th, 2013

On the Search for the Neutrinoless Double Beta Decay with the COBRA-Experiment

D. Gehre for the COBRA-Collaboration

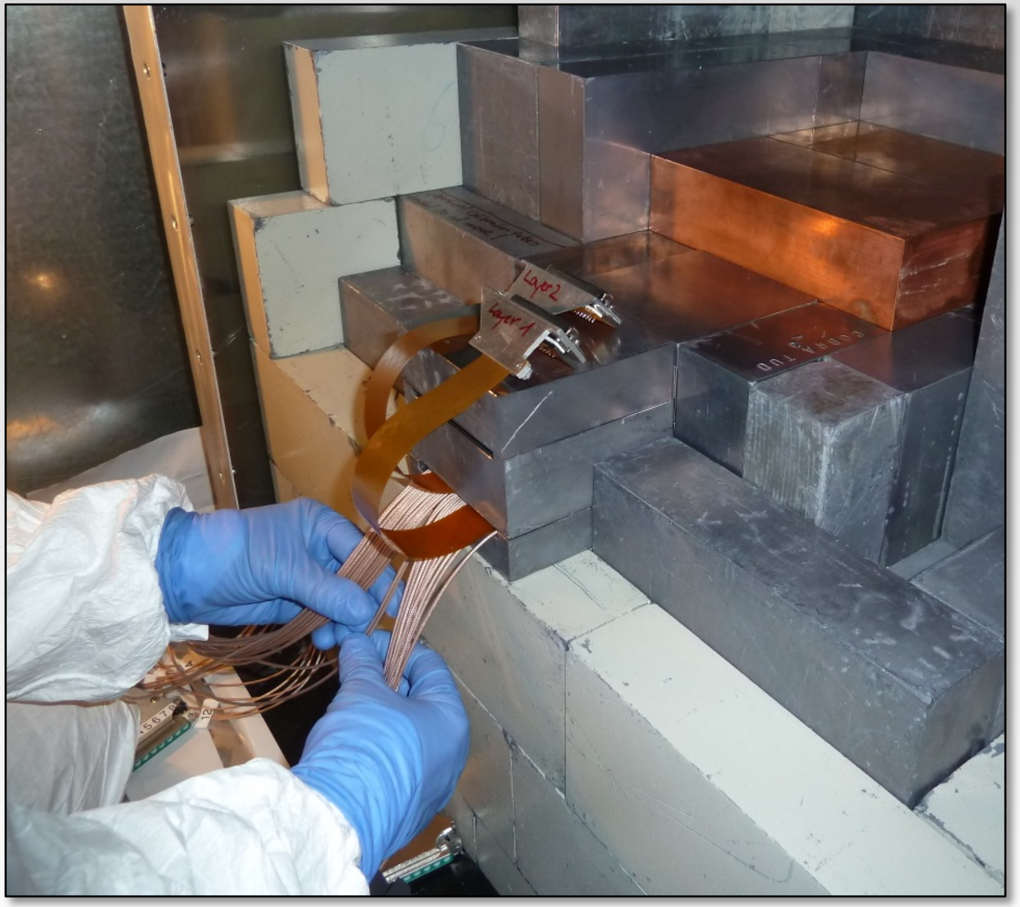




What is COBRA?

Cadmium – Zinc – Telluride – 0ν - 2Beta – Research - Apparatus

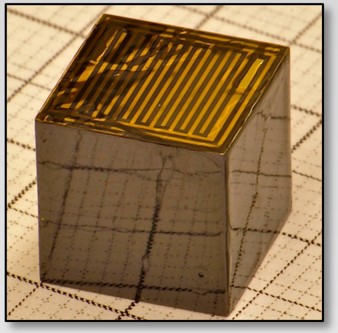
- Collaboration of 11 institutions from 7 countries
- Search for the existence of the neutrinoless double beta decay (0ν2β-decay) in ^{116}Cd and other candidates
- Deduction of the electron-neutrino-mass from the measured half-life

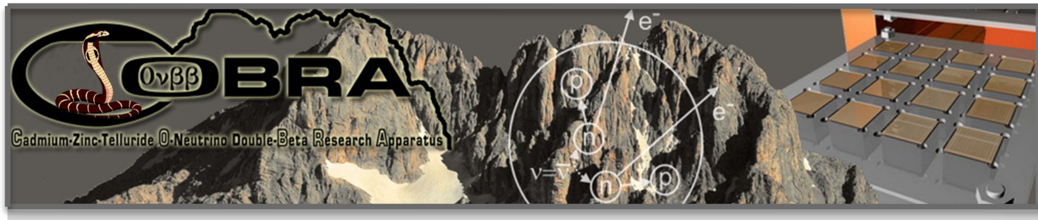


What is COBRA?

Cadmium – Zinc – Telluride – 0ν - 2Beta – Research - Apparatus

- Intrinsic, room-temperature semiconductor
- High density (5.9 g/cm^3) and high atomic number (Z~50)
- Moderate mob. lifetime product for electrons (1x10^{-2} cm^2/V)
- Low mobility lifetime product for holes (1x10^{-4} cm^2/V)
- Commercially available material





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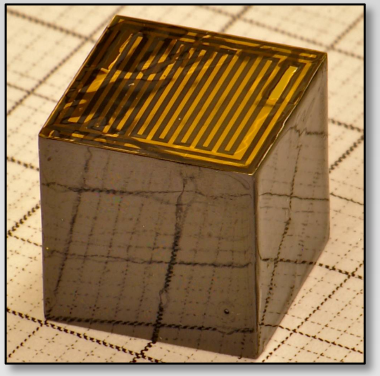
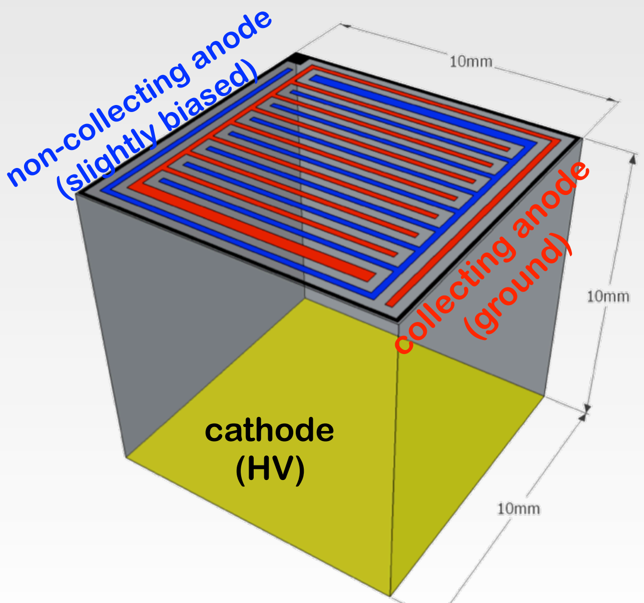
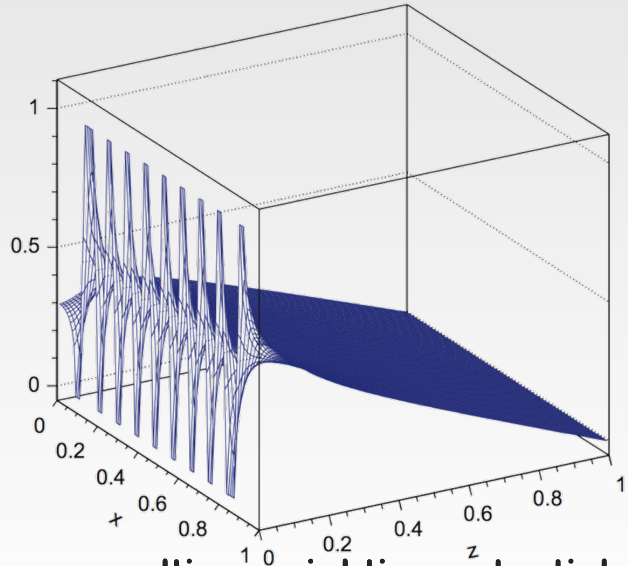


- Intrinsic, room-temperature semiconductor
- High density (5.9 g/cm^3) and high atomic number (Z~50)
- Moderate mob. lifetime product for electrons (1x10^{-2} cm^2/V)
- Low mobility lifetime product for holes (1x10^{-4} cm^2/V)
- Requires single polarity charge sensing devices (CPG)
- Two instrumented electrodes (collecting & non-collecting anode; CA& NCA)

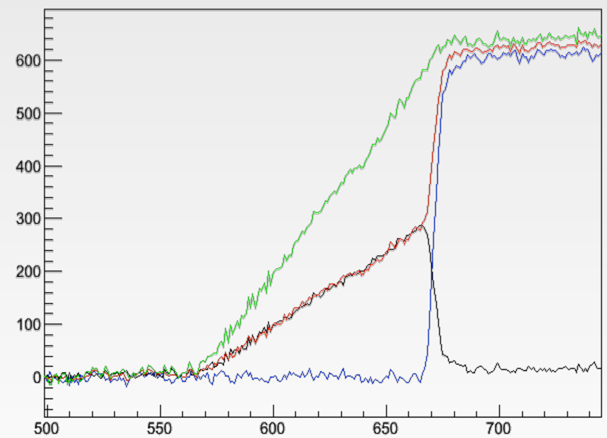


CoplanarGrid electrode layout

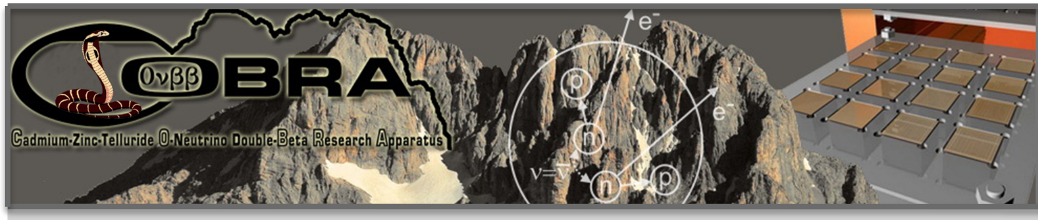


resulting weighting potential
(here non-collecting anode)

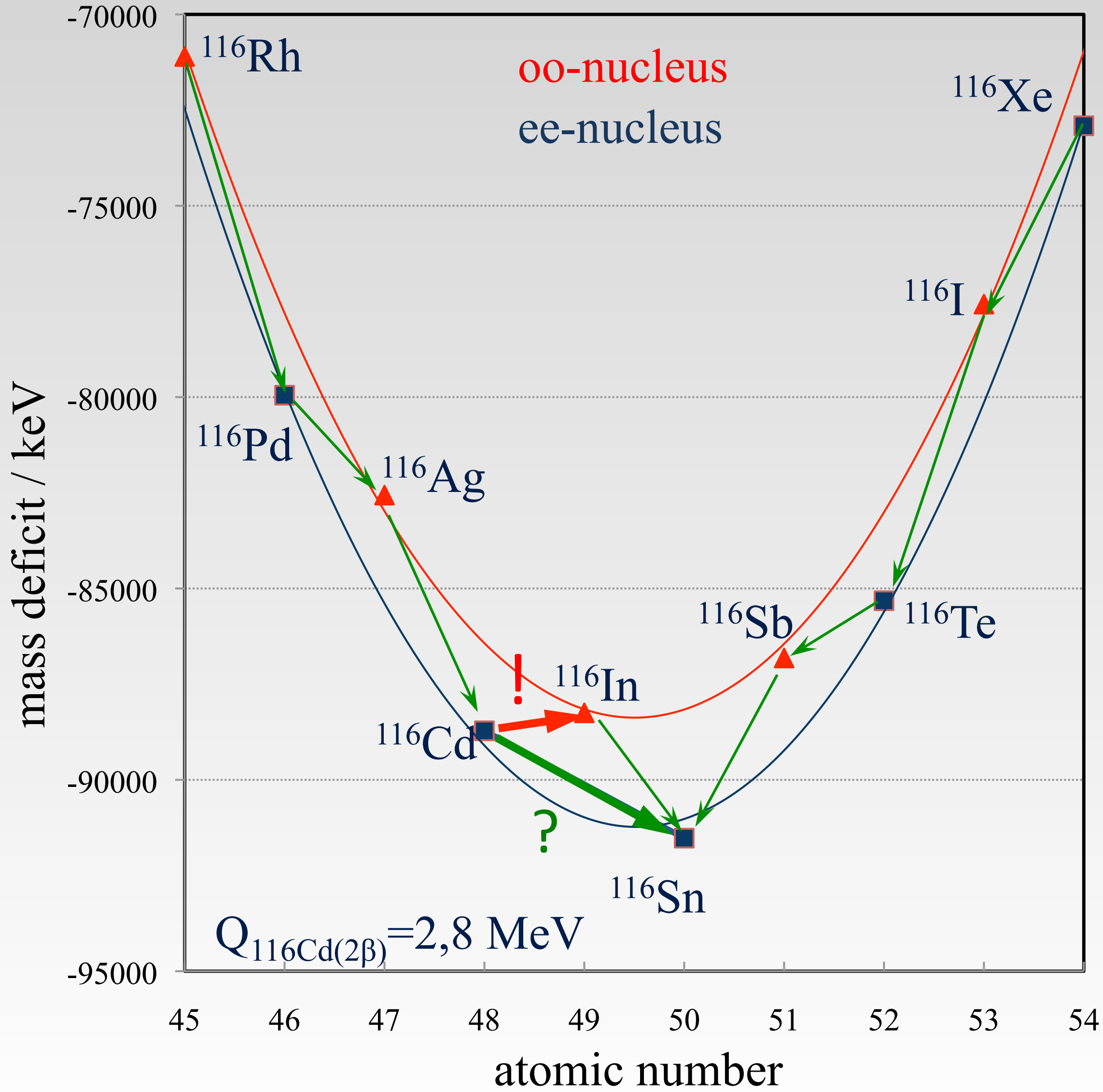
pulse shape sampling



nca-signal, ca-signal
cathode equiv.: ca+nca
energy equiv.: ca-nca

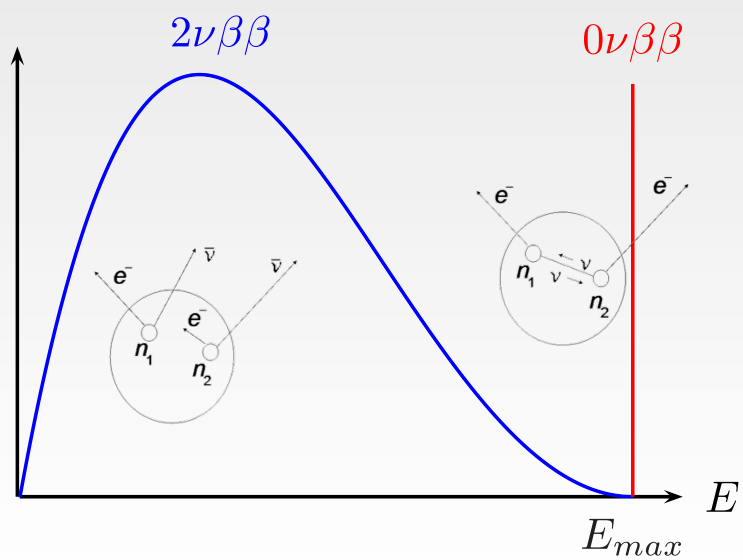


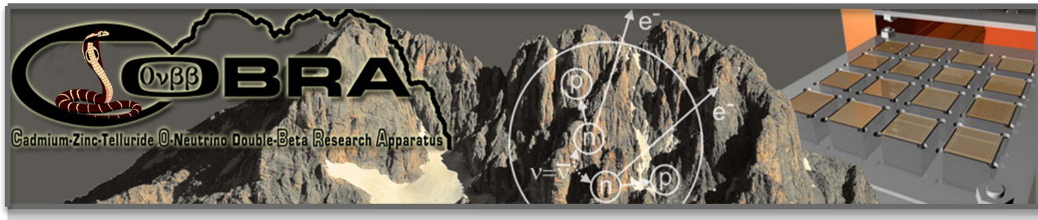
2β-decay



Properties of the 2β-decay:

- possible only for isotopes in ee-configuration
- single beta decay is energetically forbidden
- 0ν2β-decay: full Q-value is transfered to the two emitted electrons & neutrino is a Majorana particle



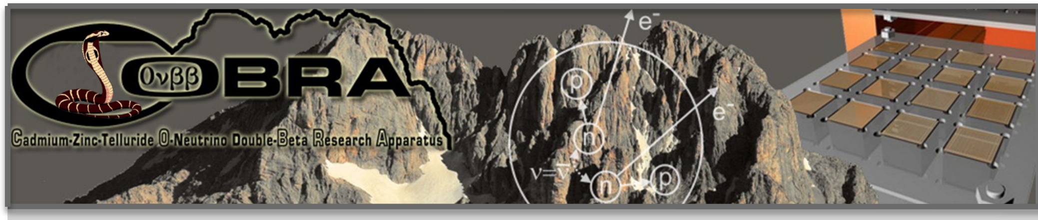


Why CZT?

- The detector is the source of the decay – high detection efficiency
- CZT contains nine double-beta isotopes (different decay modes)

isotope	decay mode	Q-value / keV	natural abundance / %	lower limit for half- life [g.s.] / y
^{64}Zn	$\beta^+/EC; EC/EC$	1096	48.6	$4.3\text{x}10^{20}$ [1]
^{70}Zn	$\beta^-\beta^-$	1001	0.6	$1.8\text{x}10^{19}$ [1]
^{106}Cd	$\beta^+\beta^+; \beta^+/EC; EC/EC$	2771	1.25	$2.4\text{x}10^{20}$ [2]
^{108}Cd	EC/EC	231	0.89	$1.1\text{x}10^{18}$ [3]
^{114}Cd	$\beta^-\beta^-$	534	28.72	$1.1\text{x}10^{21}$ [3]
^{116}Cd	$\beta^-\beta^-$	2814	7.74	$1.7\text{x}10^{23}$ [4]
^{120}Te	$\beta^+/EC ; EC/EC$	1722	0.096	$6.0\text{x}10^{17}$ [5]
^{128}Te	$\beta^-\beta^-$	868	31.69	$1.1\text{x}10^{23}$ [6]
^{130}Te	$\beta^-\beta^-$	2527	33.8	$3.0\text{x}10^{24}$ [7]

[1] Bernabei et.al, 2010; [2] Belli et.al, 1999; [3] Belli et.al, 2008; [4] Danevich et.al, 2005;
[5] Barabash et.al, 2008; [6] Alessandrello et.all 2000; [7] Arnaboldi et.al 2003



Why CZT?

- The detector is the source of the decay – high detection efficiency
- CZT contains nine double-beta isotopes (different decay modes)
- Focus on the five $2\beta^-$ candidates

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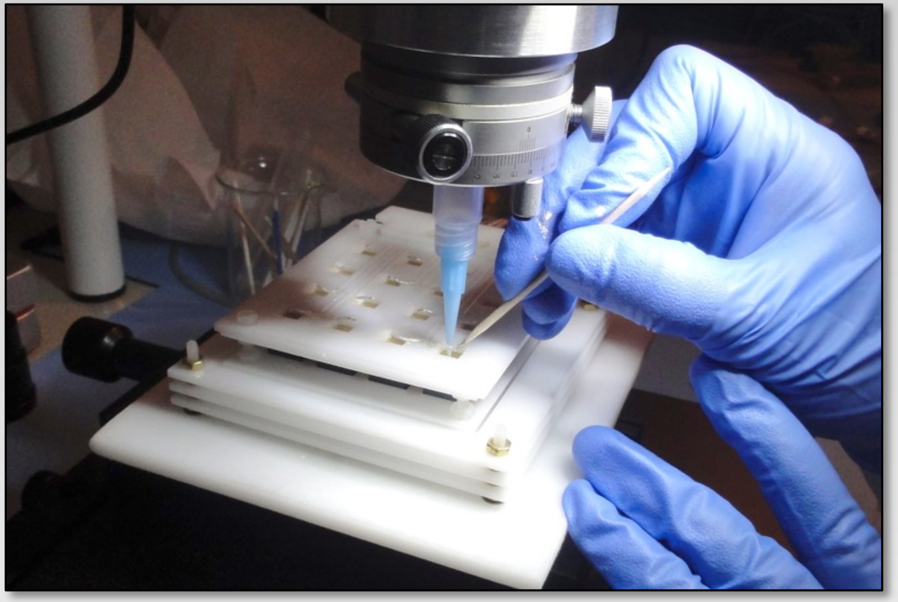
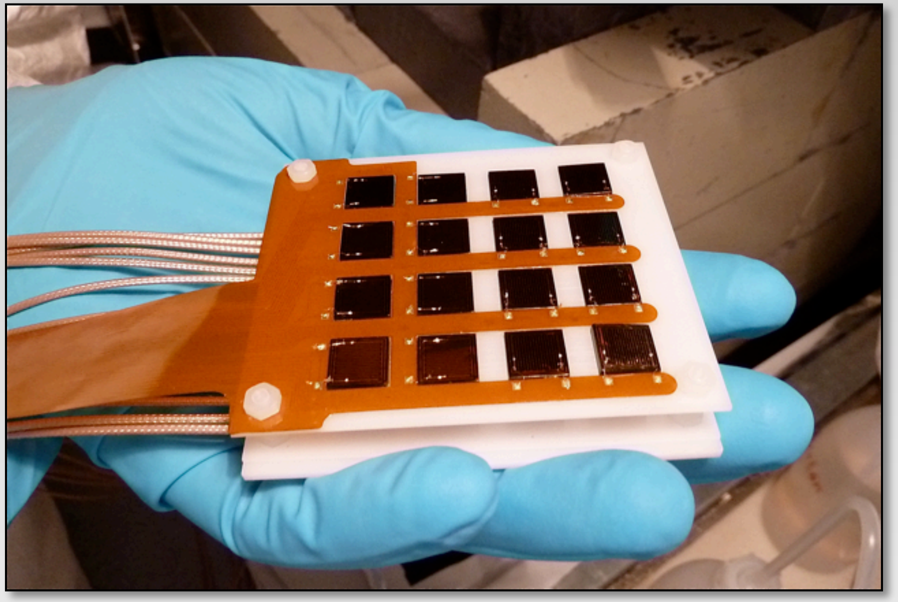
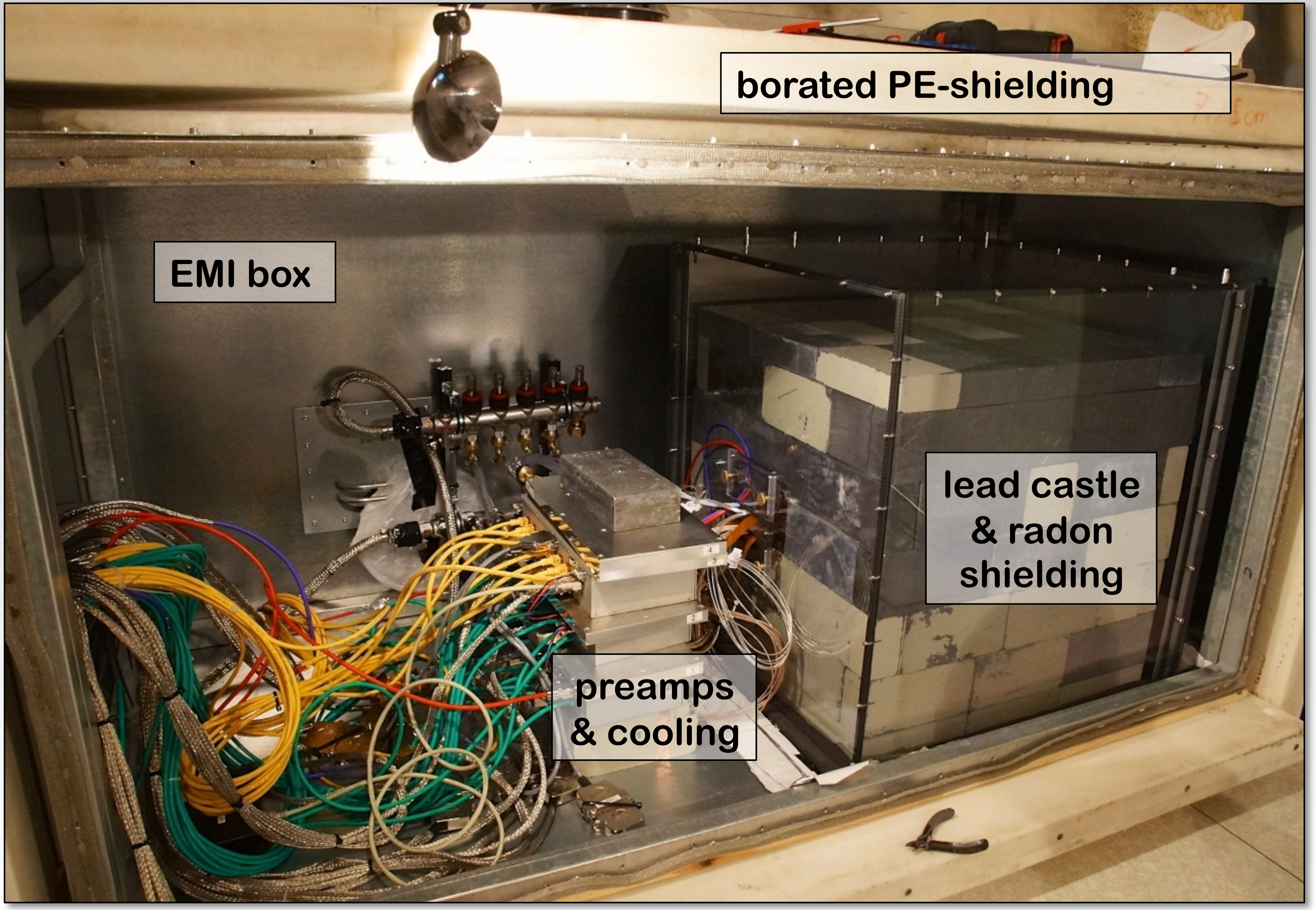
Detector layer

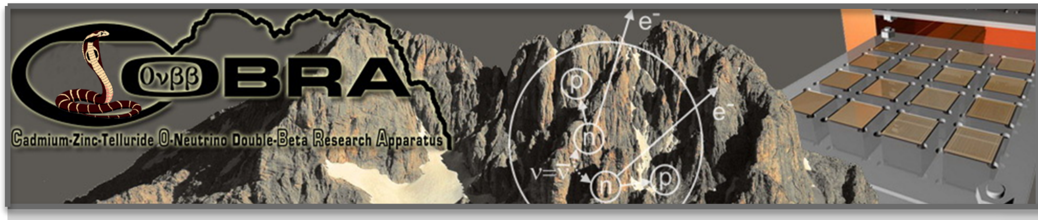




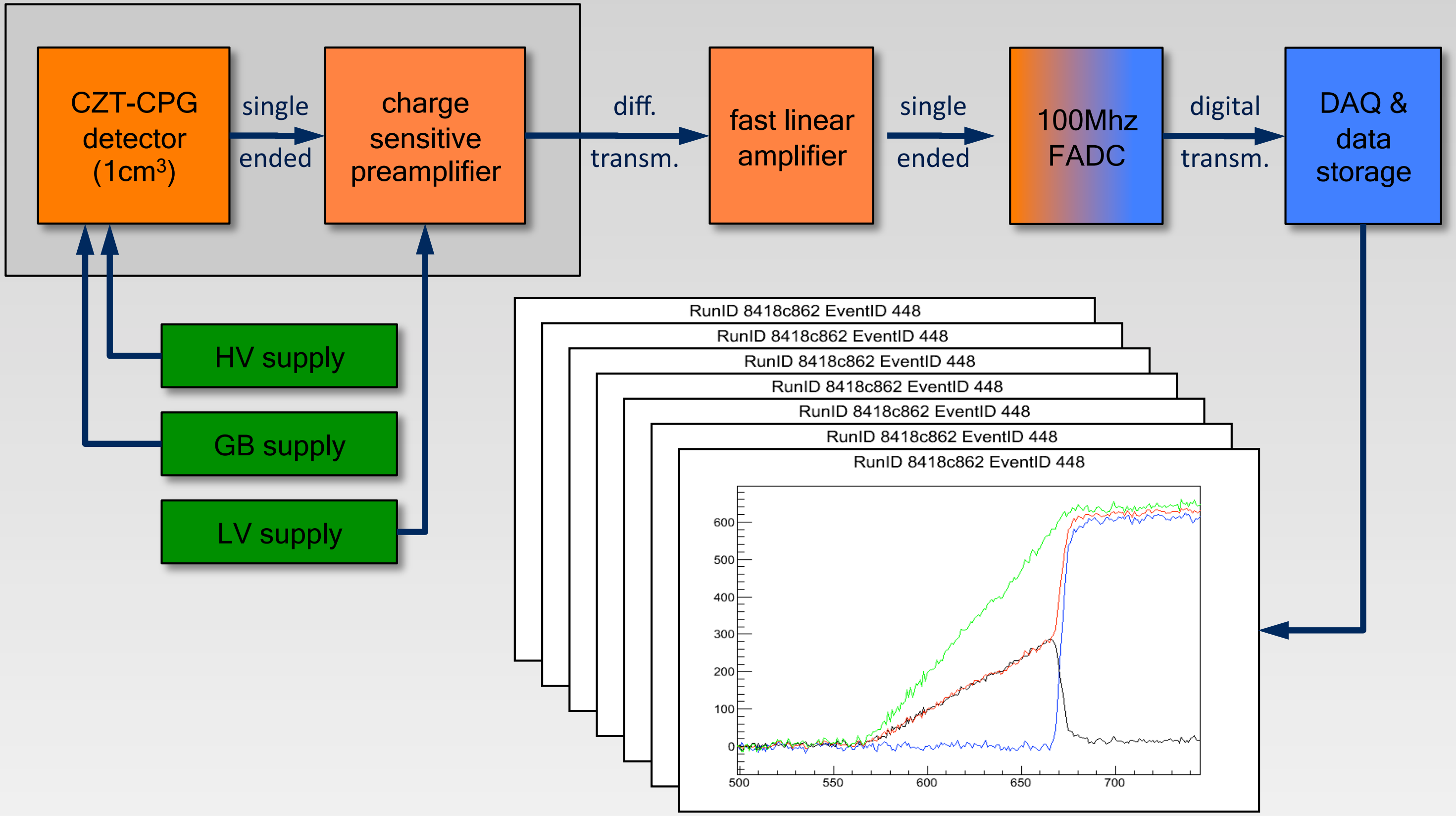
- Onsite Layer assembly under clean-room conditions
- Holder structure made of Delrin and ultra clean copper
- Inner shielding by low level alpha lead (A < 3 Bq/kg)
- Additional screening with standard lead

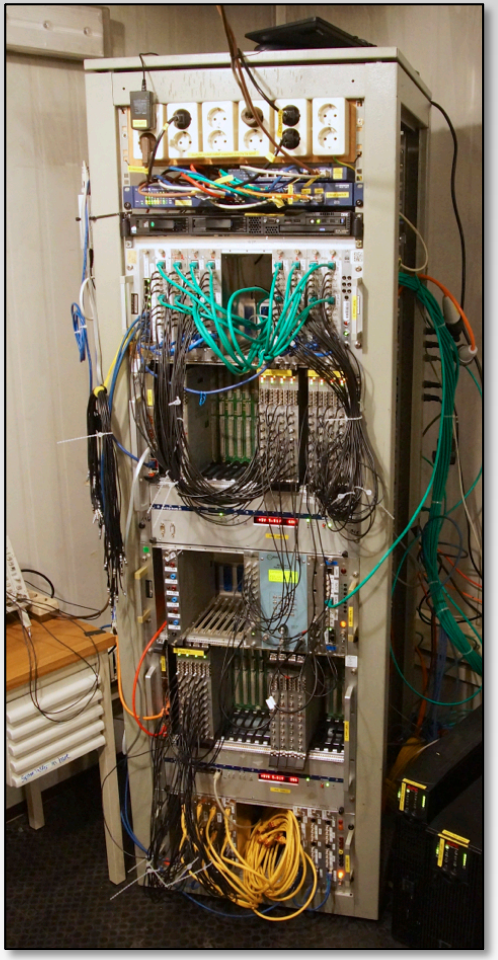
Experimental setup at the LNGS





DAQ chain & pulse sampling

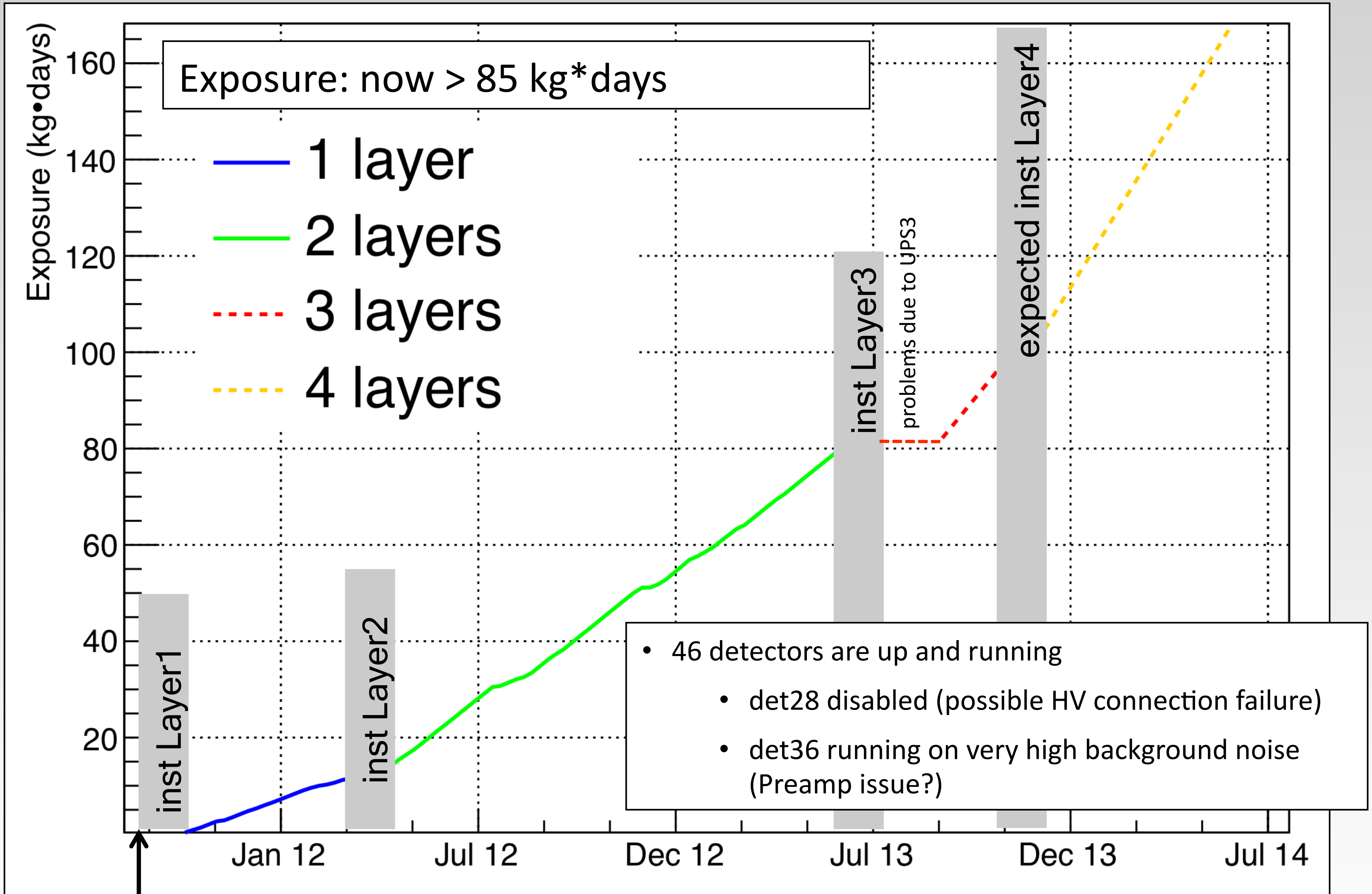




- **48/64 installed detectors**
- **128 preamp & lin-amp channels**
- **128 FADC channels (100MHz, 12bit)**
- **Pulse shape sampling and offline data analysis allows for:**

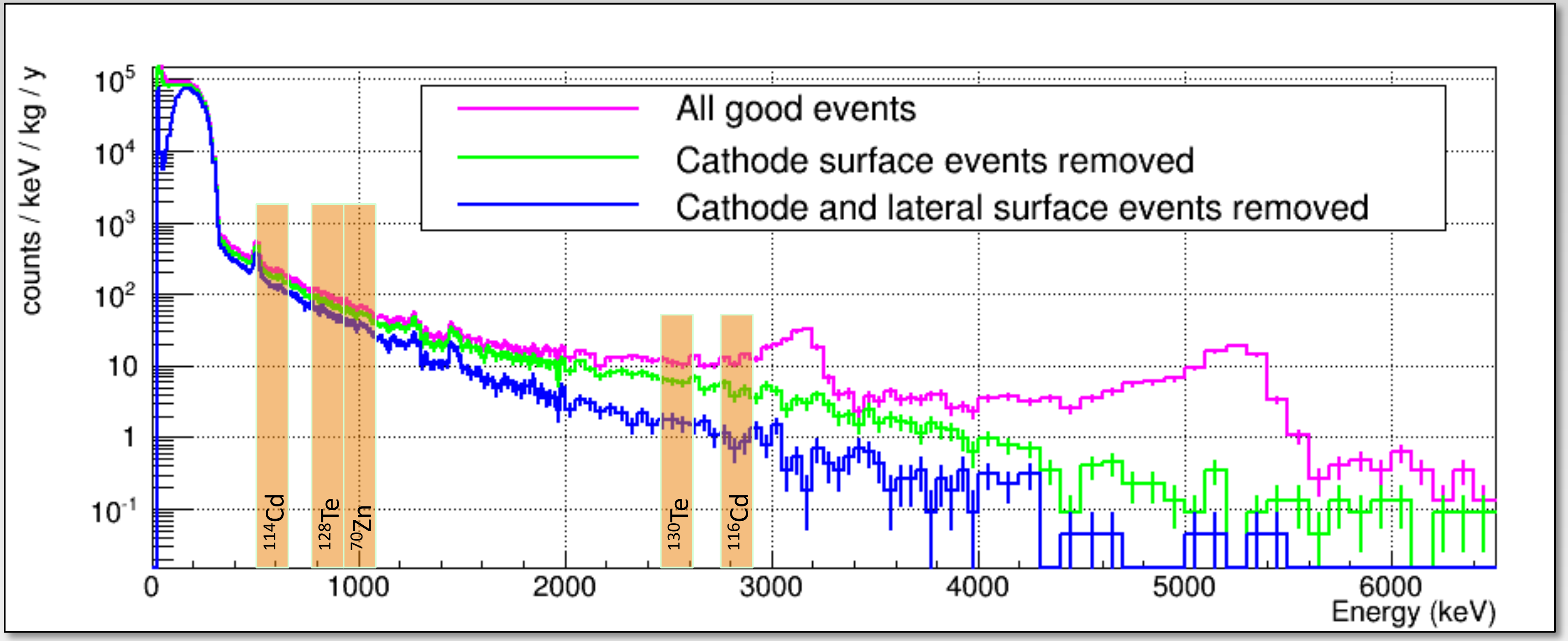
  event classification, single/multi-site-discrimination, determination of interaction depth, coincidence analysis, vetoing...

Data taking at the LNGS



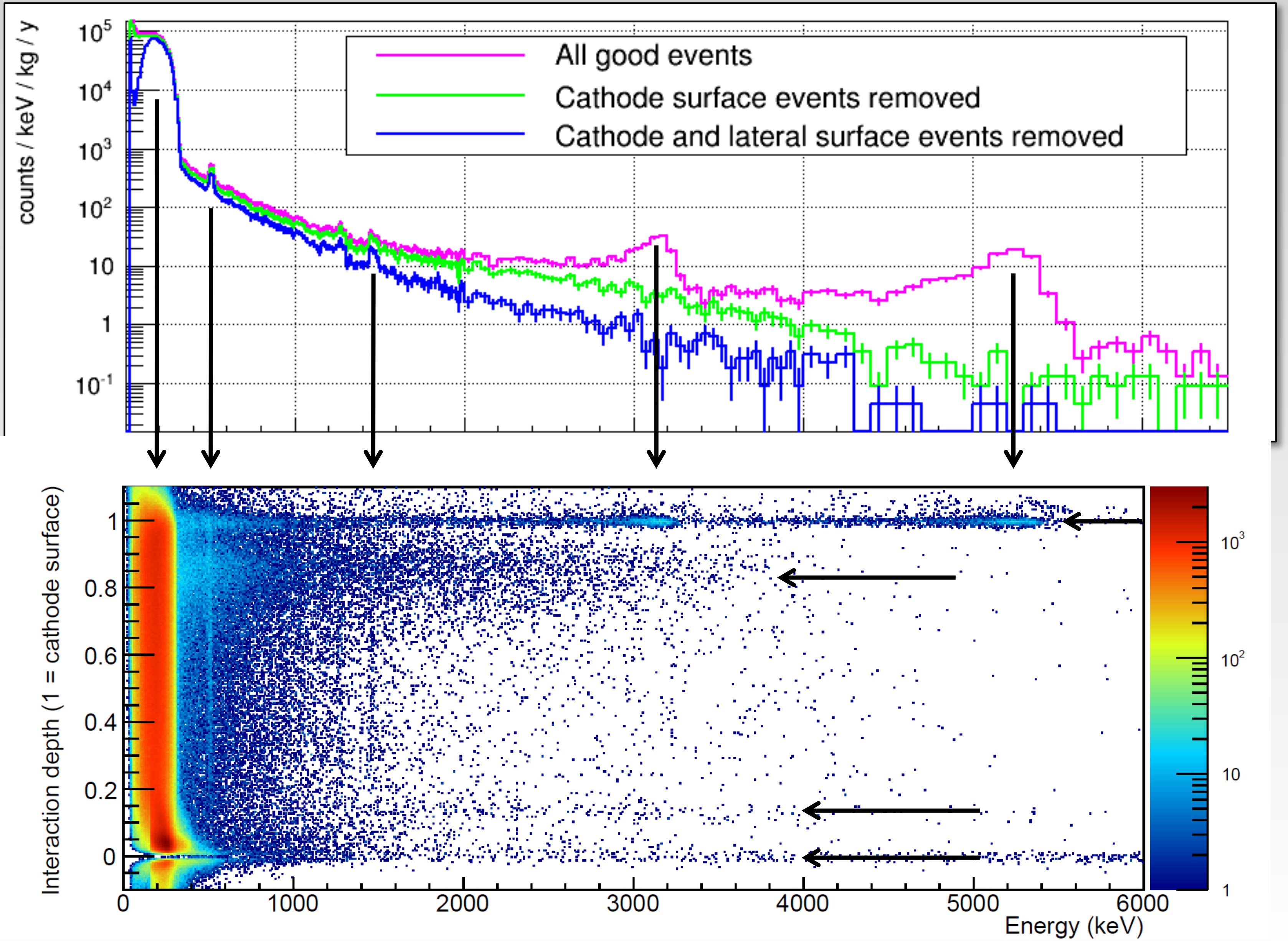
pulse shape data taking on new det layers started Oct'11

Low background data

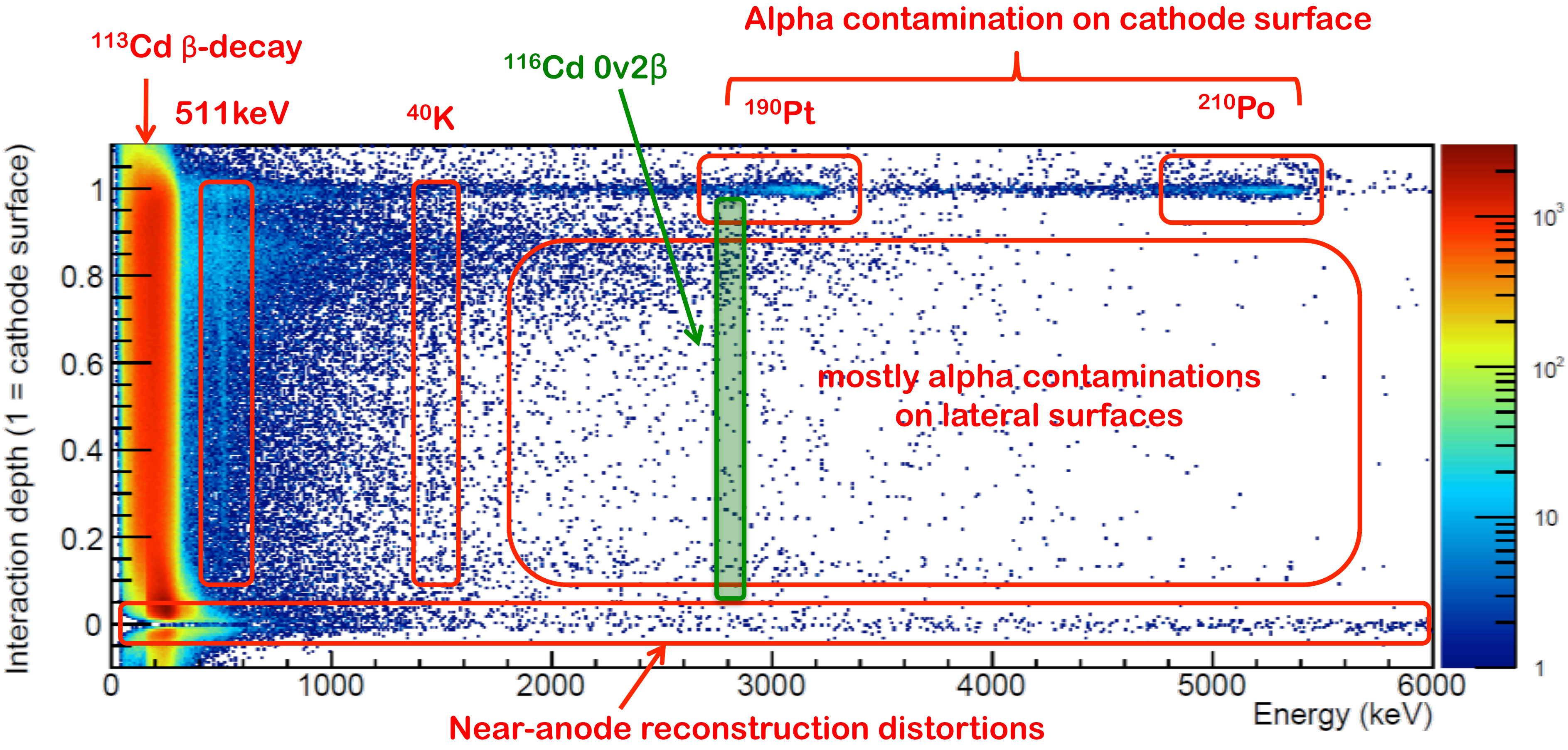


- 82.3 kg*days exposure of layer 1 and layer 2 (32 detectors in total)
- All events are single detector events (coincidences neglected)
- Pulse shape sampling and pulse shape analysis to discriminate surface events (alpha decays of Rn/daughters)
- Currently no rejection of multi-site events (under development)

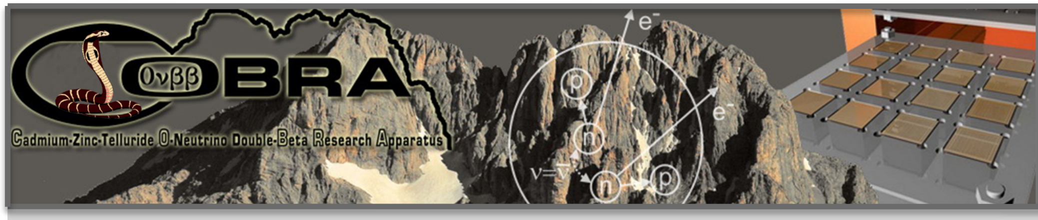
Depth reconstruction of features



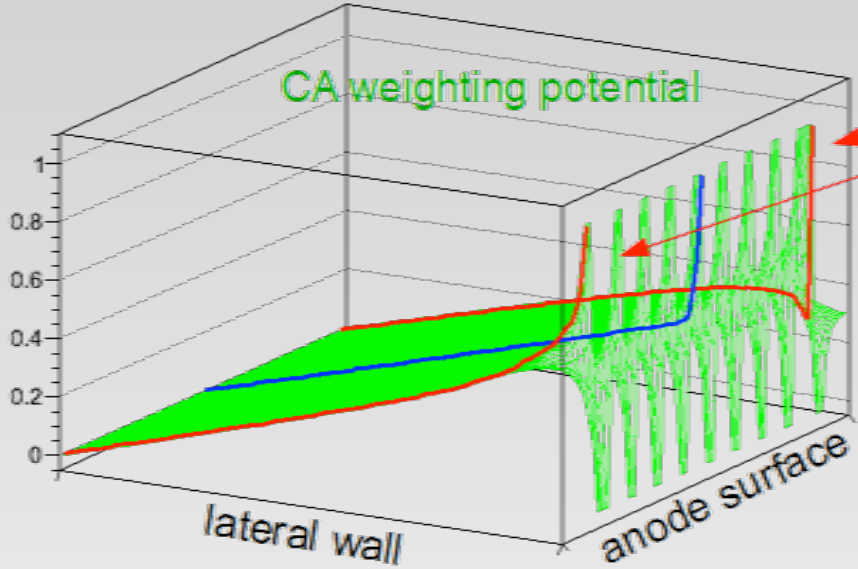
Identifying the features



- **Intrinsic ^{113}Cd background:**
  nat. abundance: 12.2%, four fold forbidden β-decay, half-life: 7.9x10^{15} y
- **^{190}Pt - part of anode and cathode metallization (50nm thickness):**
  nat. abundance: 0.01%, alpha decay: half-life: 6.5x10^{11} y (ca. 8 decays/det/month)

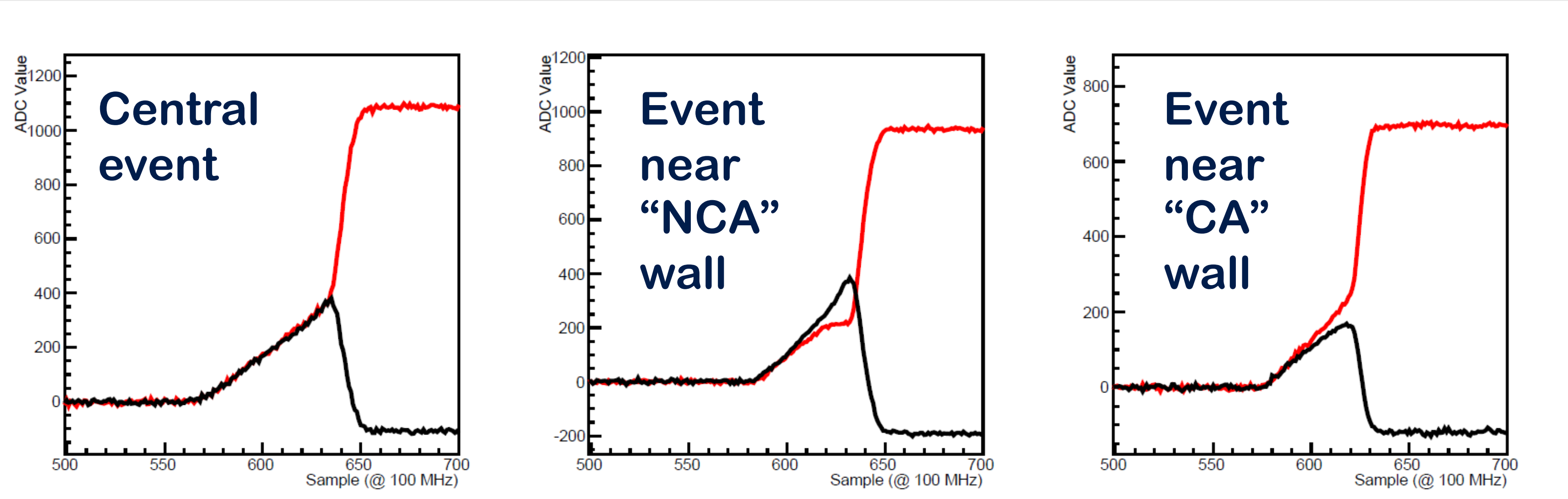


Identifying lateral surface events



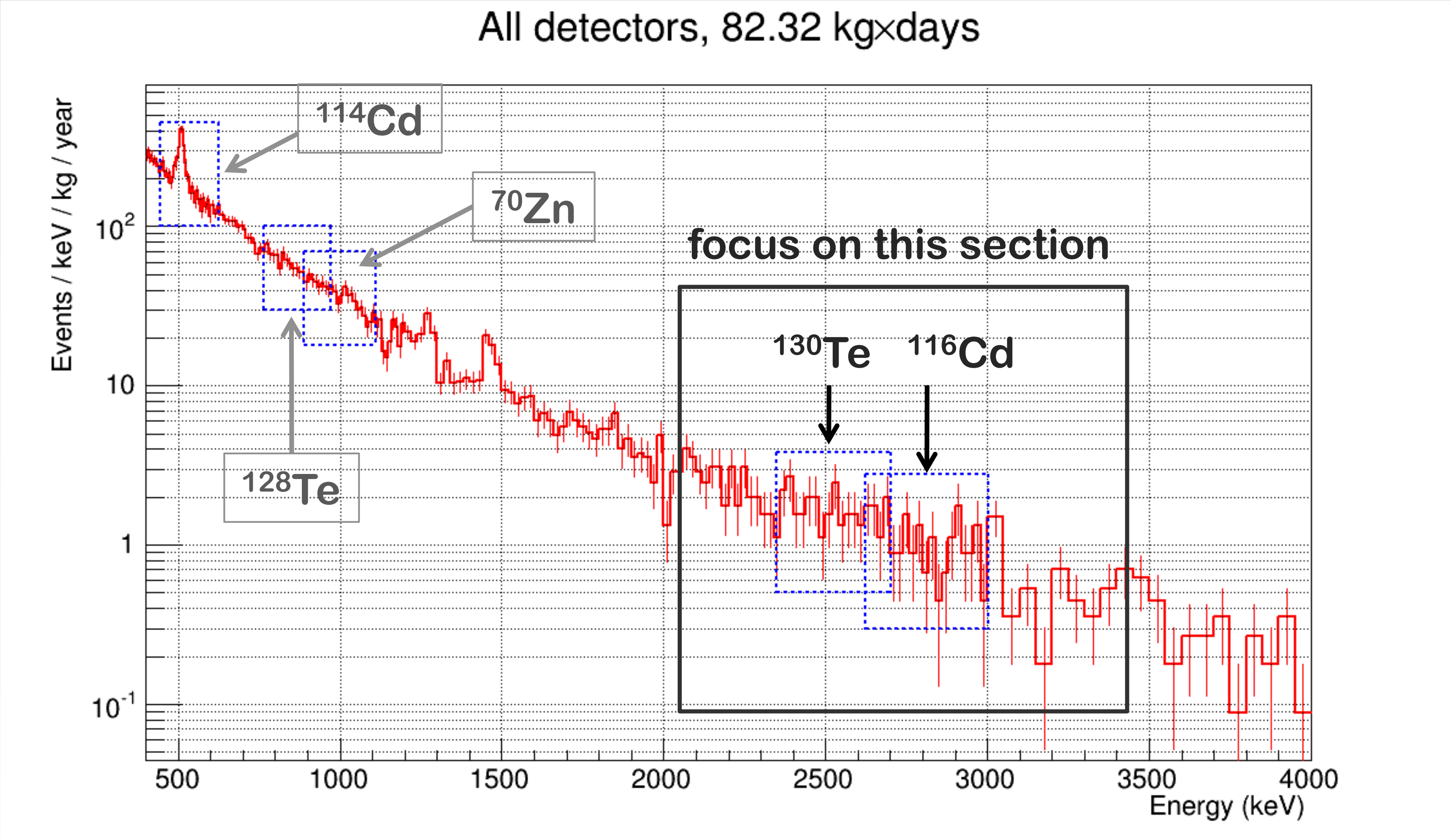
Distortions near walls

- Lateral surface events identifiable through PSA
- Fringing effect in weighting potentials near the detector edges distorts the pulses



PSA allows for an effective background reduction

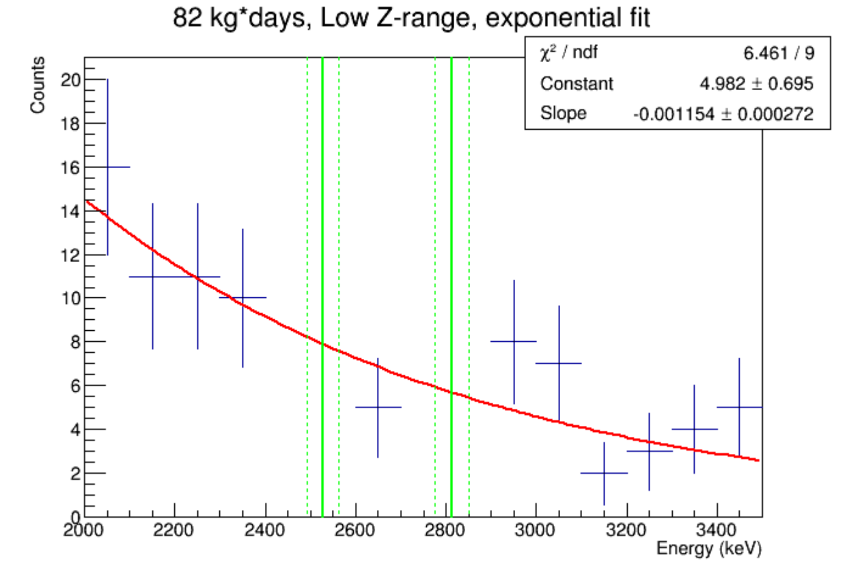
Where are we now?



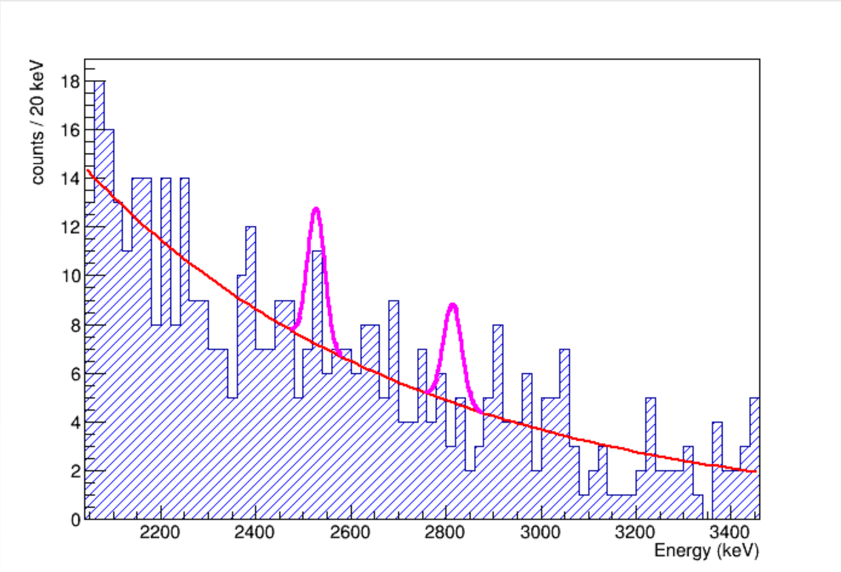
reduced background rate due to PSA, effective suppression of surface events

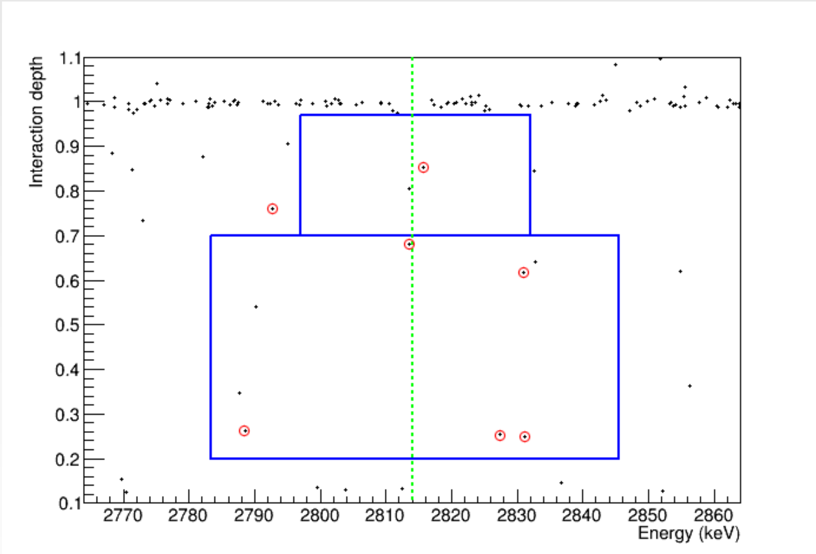
background @ 2.8MeV ≅ 1 cnt/keV/kg/y

High energy range analysis



- Background model based on side-band analysis
- ROI of ^{130}Te and ^{116}Cd not included in background model
- Assumed same shape for all detectors (individual detector specifics neglected)
- Peaks shown in magenta are signals excluded at 90%CL for limit calculation





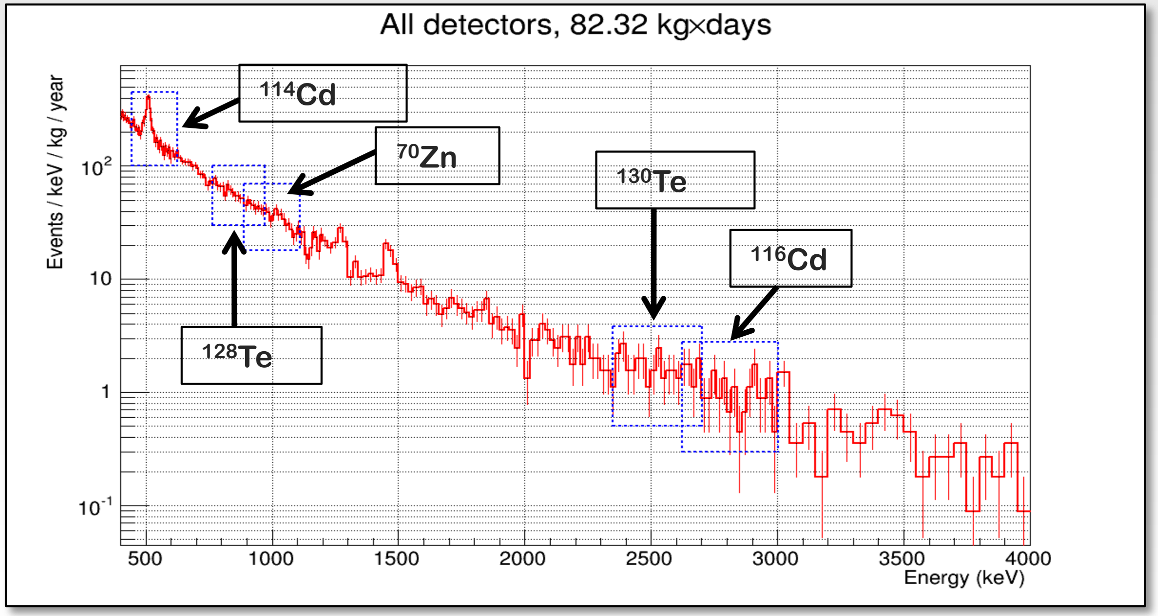
7 survivors of high quality cuts
(blue is the mean acceptance window)

New COBRA half-life limits

PRELIMINARY! (publication pending)

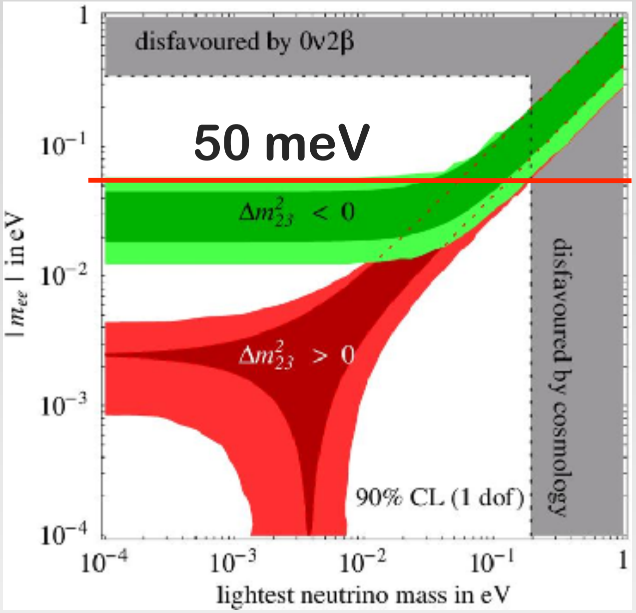
isotope	COBRA'09	COBRA'13	world's best
^{114}Cd	2.0×10^{20}	**1.06×10^{21}**	1.1×10^{21}
^{128}Te	1.7×10^{20}	**1.44×10^{21}**	1.1×10^{23}
^{70}Zn	2.2×10^{17}	**2.57×10^{18}**	1.8×10^{19}
^{130}Te	5.9×10^{20}	**3.88×10^{21}**	3.0×10^{24}
^{116}Cd	9.4×10^{19}	**9.19×10^{20}**	1.7×10^{23}

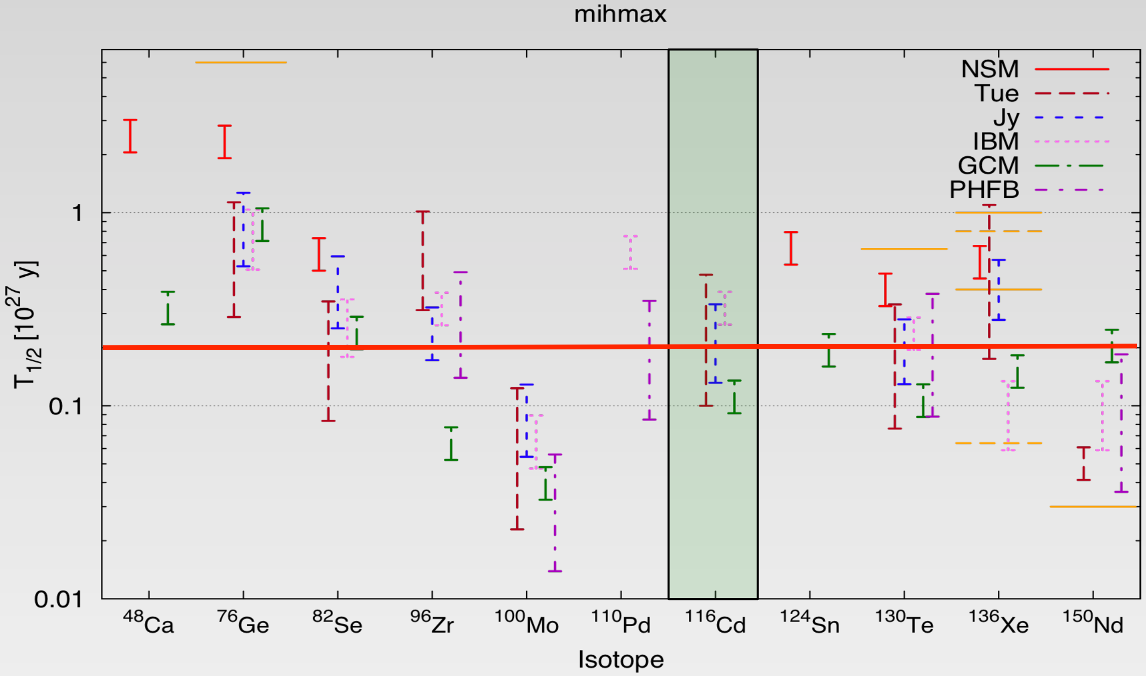
based on 82.3 kg*days exposure of layer 1 and layer 2



- **Main background contribution currently caused by alphas**
- **Some detectors affected by a higher background rate**
- **Improvement expected for continous handling under clean-room conditions for all manufacturing and commissioning steps**

Required sensitivity for touching the IH

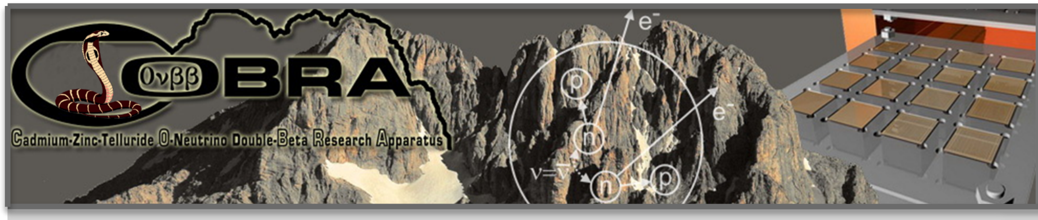




A. Dueck, W. Rodejohann, K. Zuber,
arXiv:1103.4152, Phys. Rev. D 83,113010 (2011)

to reach a sensitivity of 50 meV/c² with ^{116}Cd, the detectable halflife must be greater than:

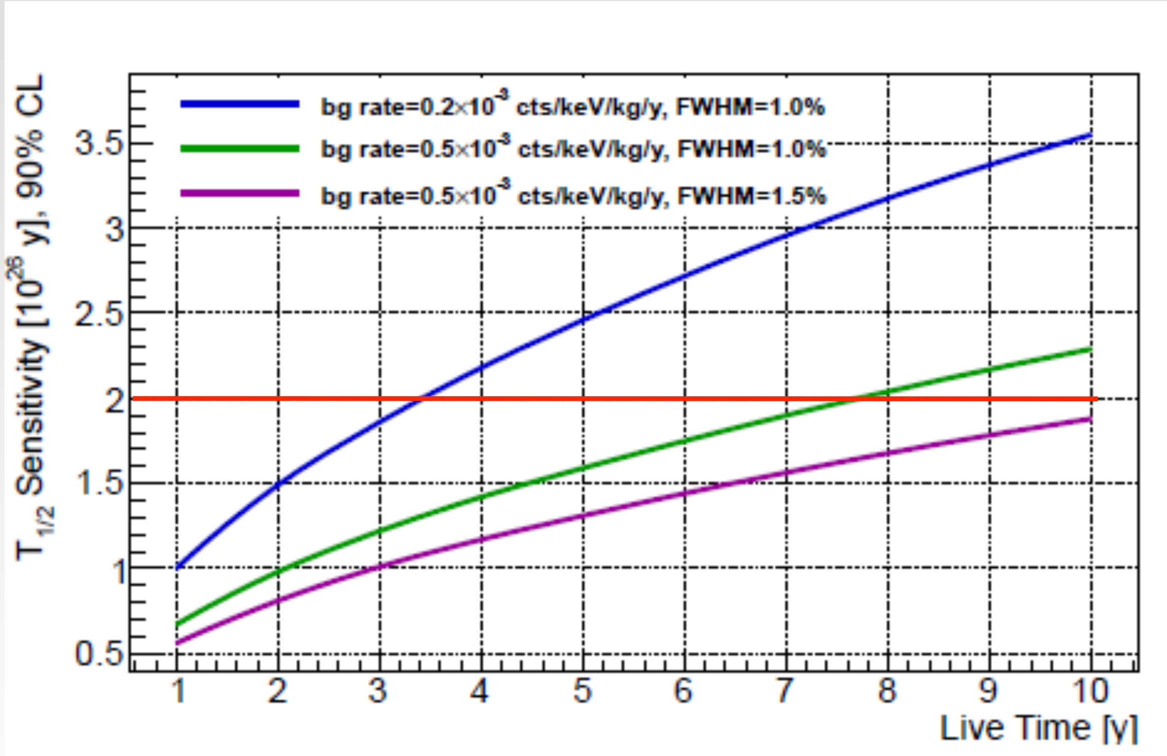
$T_{1/2} > 2 \times 10^{26}$ y (depending on NME)



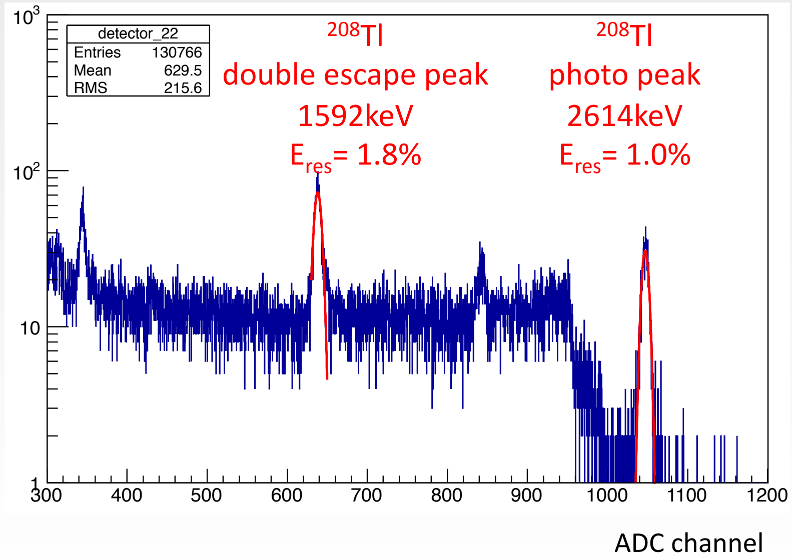
Requirements to reach 2×10^{26} y

$$T_{1/2}^{-1}\Big|_{det} \propto \alpha\, \varepsilon_{tot} \sqrt{\frac{M\cdot t}{\Delta E\cdot B}}$$

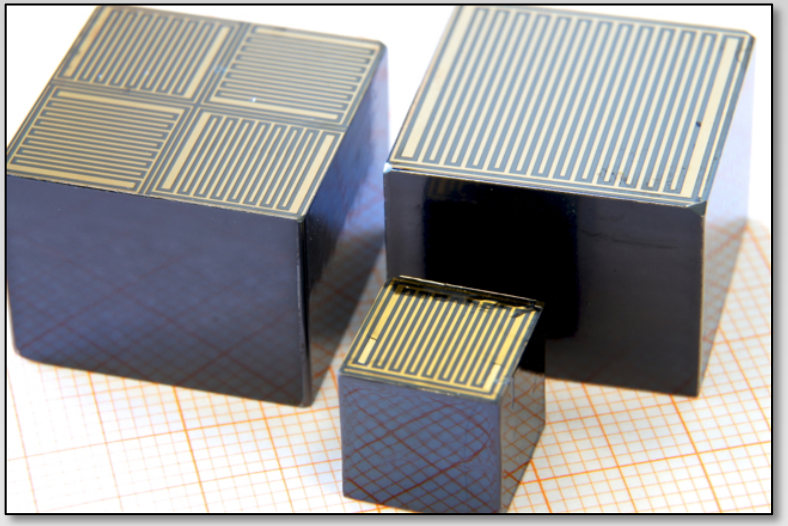
- α: 90% ^{116}Cd enrichment
- ε: improve detection efficiency by installing larger detectors
- M: total mass (CdZnTe) 420 kg,
- t: experiment lifetime > 4 y
- B: reduce background to less than 10^{-3} cts/keV/kg/y – still a challenge
- ΔE: achieve energy resolution smaller than < 1%@2.8 MeV (already achieved with 1cm³ det)



estimated sensitivity of a large scale setup

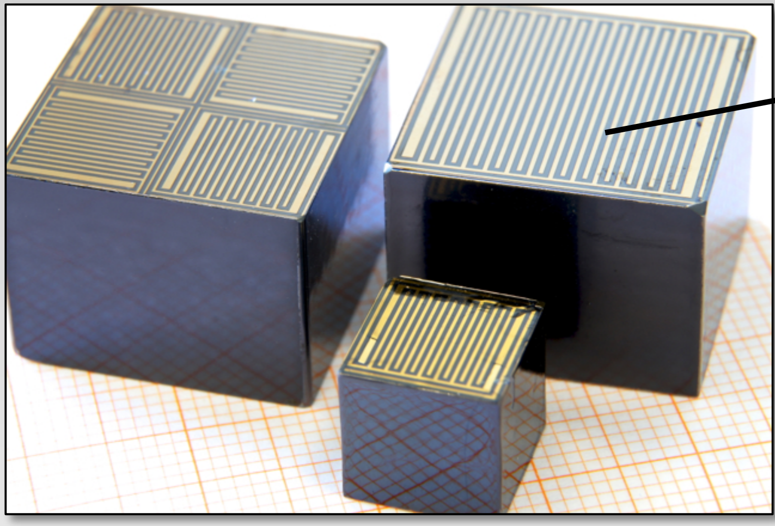


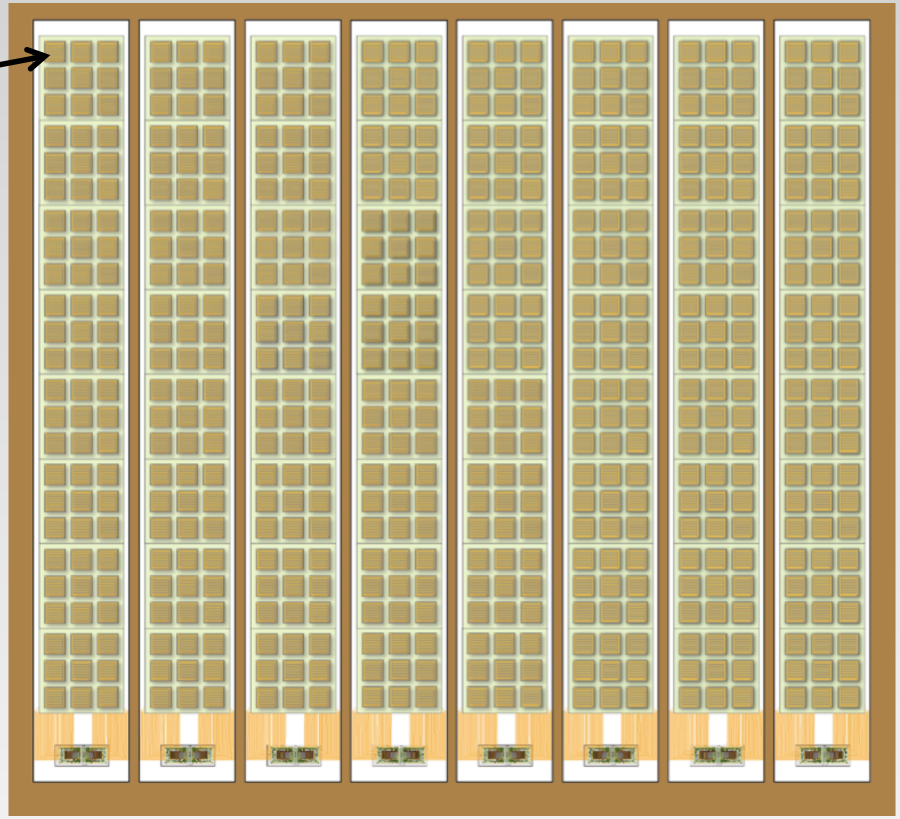
Towards a large scale setup



- Switch to larger detectors 2×2×1.5 cm^3
  - Higher detection efficiency (60% full energy efficiency for $0\nu2\beta$ of ^{116}Cd)
  - Smaller surface-to-volume ratio
  - Investigations on 6cm^3 detectors start immediately

Towards a large scale setup





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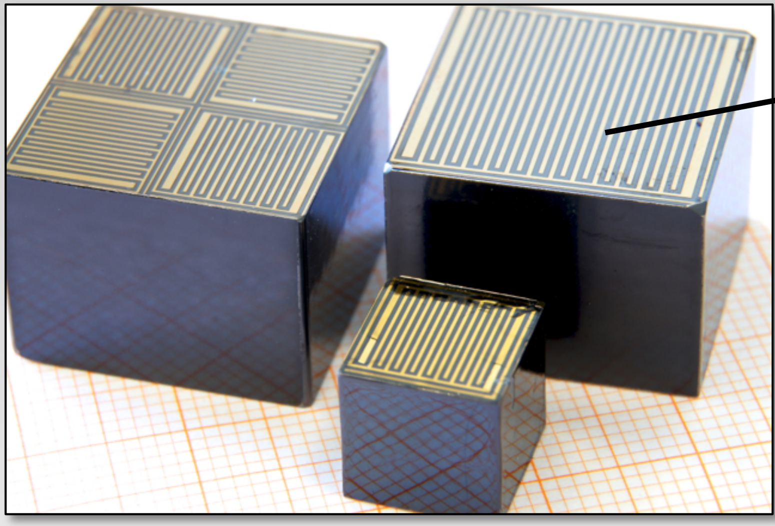

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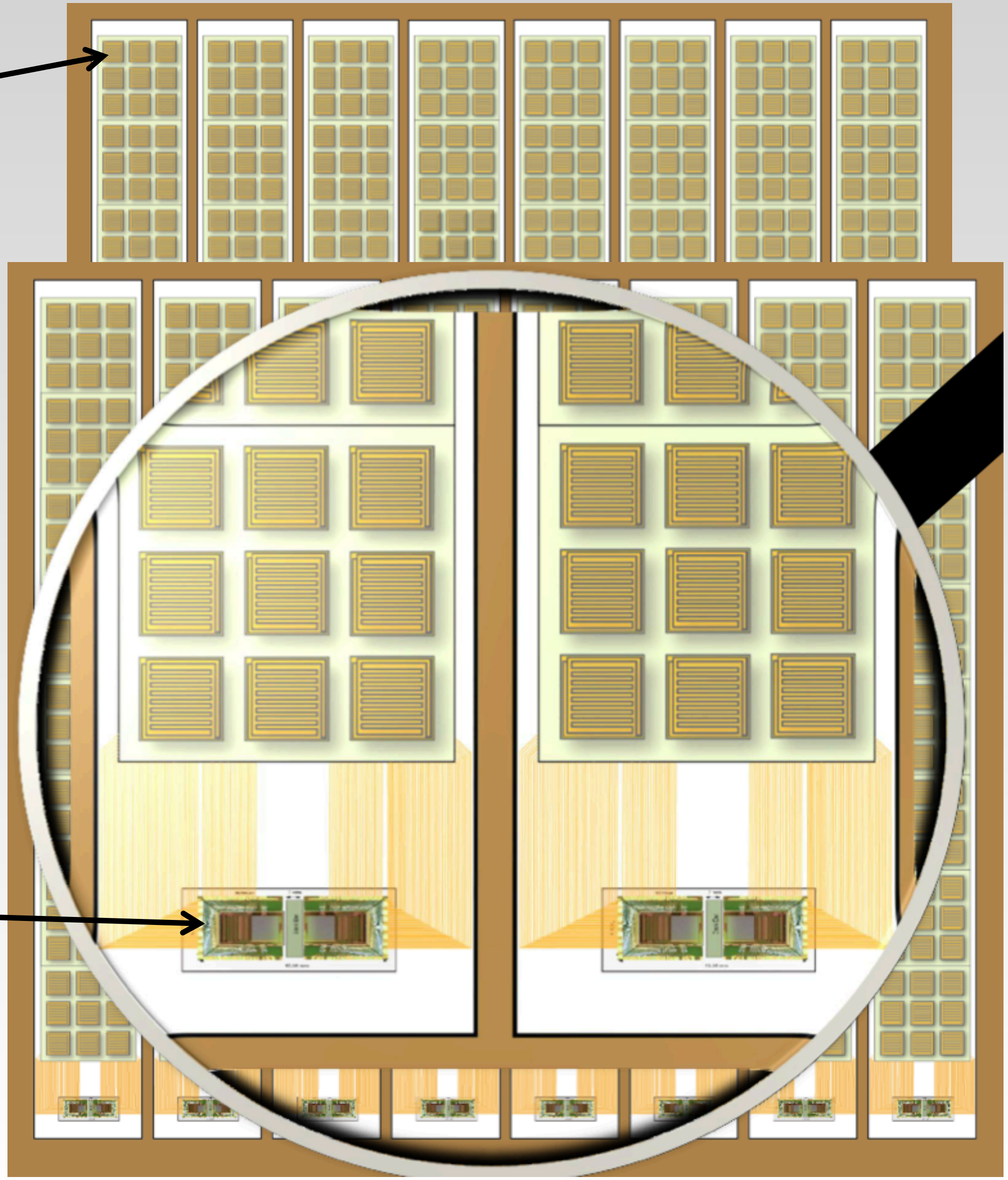
  - Higher detection efficiency (60% full energy efficiency for 0ν2β of ^{116}Cd)
  - Smaller surface-to-volume ratio
  - Investigations on 6cm^3 detectors start immediately
- Use of highly integrated DAQ electronics (ASIC/FPGA, development ongoing, increased number of channels with reduced power consumption)



Thank you for your attention

COBRA-Collaboration-Meeting, October’13, Dortmund, Germany