Status and perspectives of COBRA

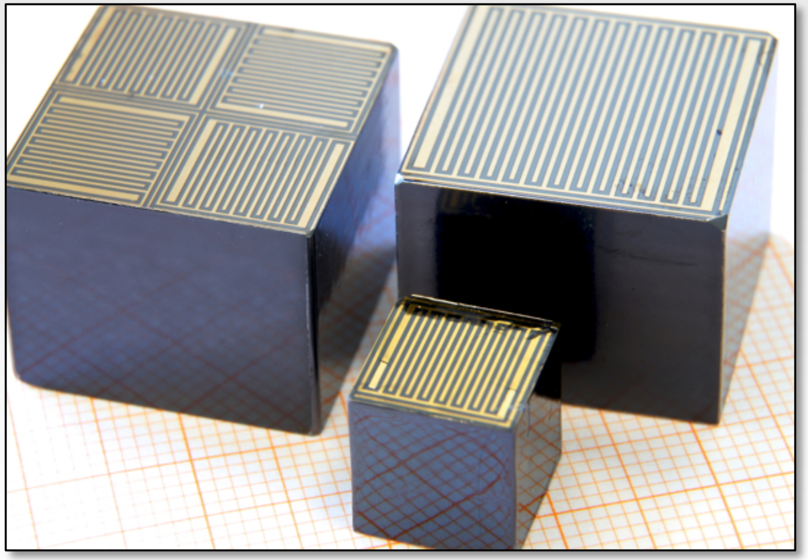
K. Zuber for the COBRA-Collaboration

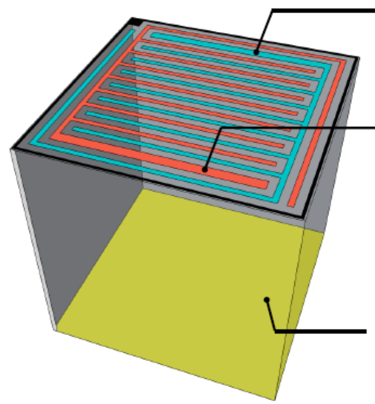
Idea: use room-temperature CdZnTe (CZT) semiconductor detectors

K. Zuber, Phys. Lett. B 519,1 (2001)

- Search for DBD of Cd-116 (Q-value = 2814 keV)

- Allows for searches of Te-130, Te-128, Zn-70, Cd-114 (two electrons)
- Allows for searches of Zn-64, Cd-106, Cd-108, Te-120 (positron/EC)
- Precision measurement of 4-fold forbidden Cd-113 beta decay
- Solar / Supernova (on very large scale...)





Benefits:

- Peak above 2.614 MeV line
- No cryogenics
- No magnets
- Strongly modular and scaleable
- Very compact
- Pulse shape analysis
- Internal veto
- Multidetector veto

➔

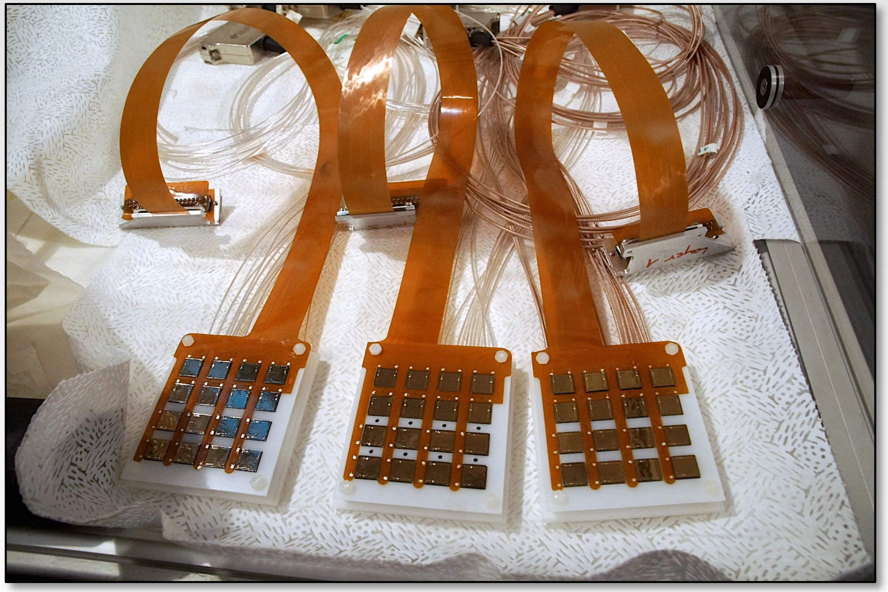
- Status of COBRA at LNGS
  (Running 64 CZT detectors of 1 cm^3)
- Towards COBRA upscale

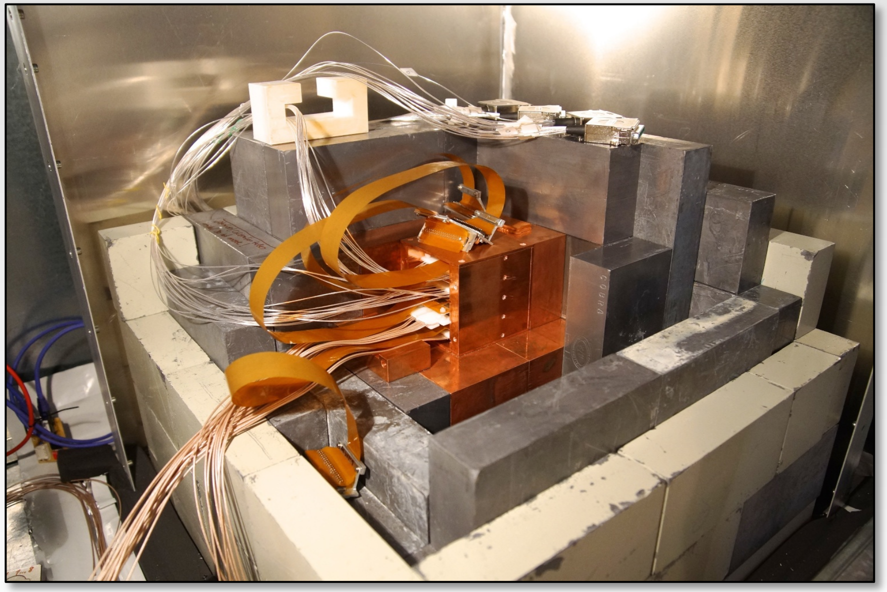
November'13:

- Finalization of the COBRA-demonstrator setup (64 x 1cm^3 detectors)

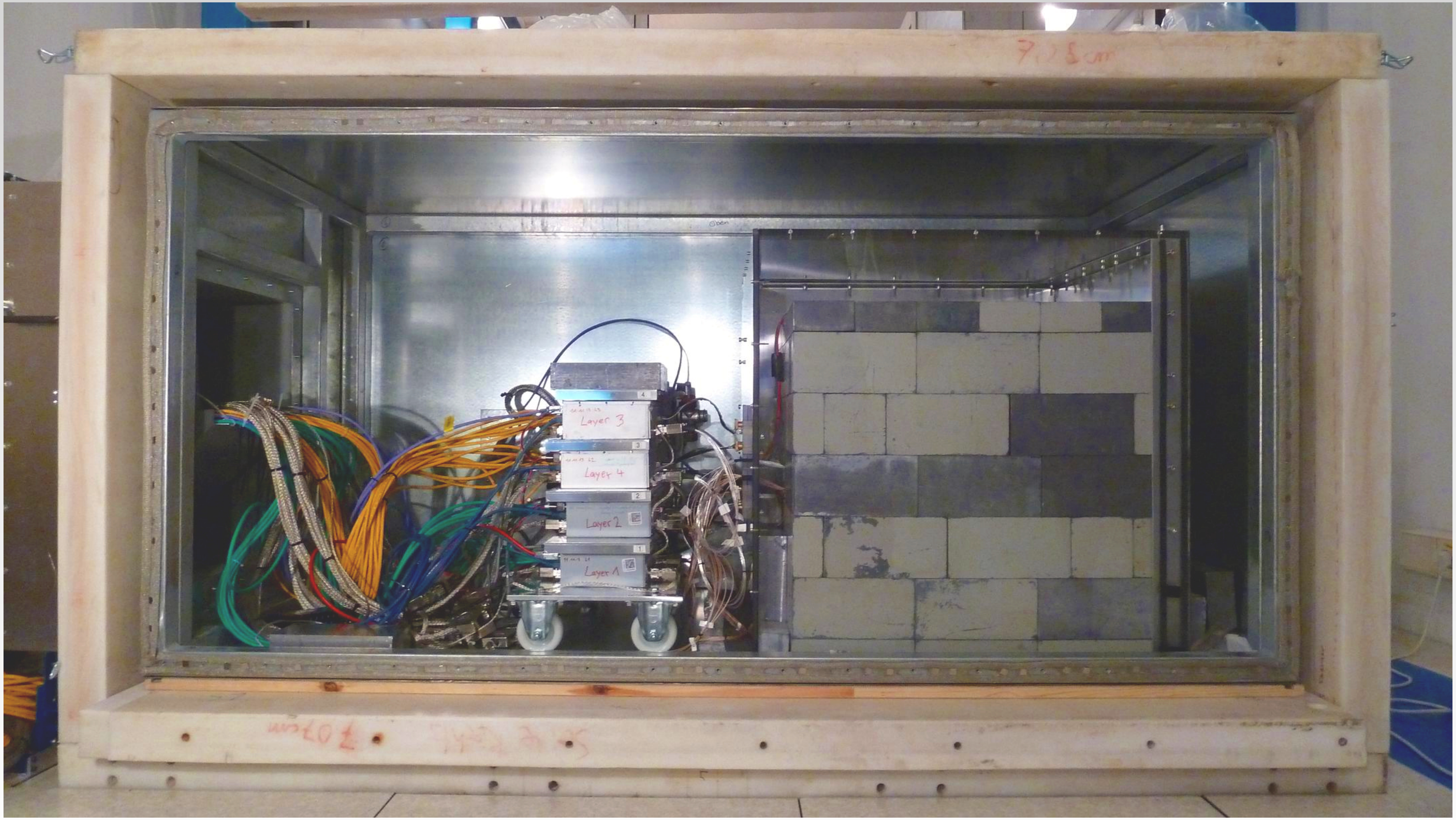
January'14:

- Since Jan'14 smooth and stable data taking



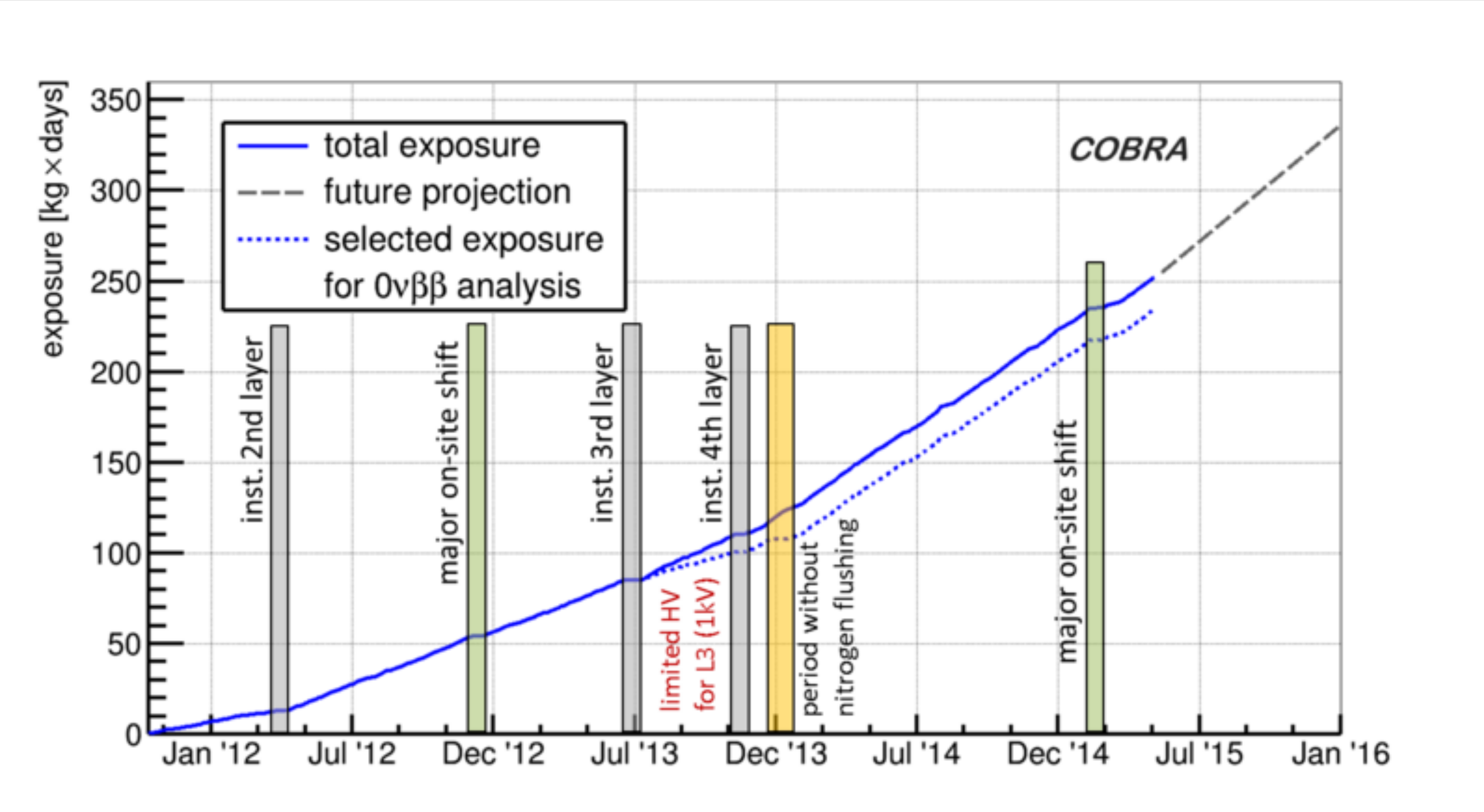


COBRA demonstrator @ LNGS



J. Ebert et al., arXiv:1507.08177

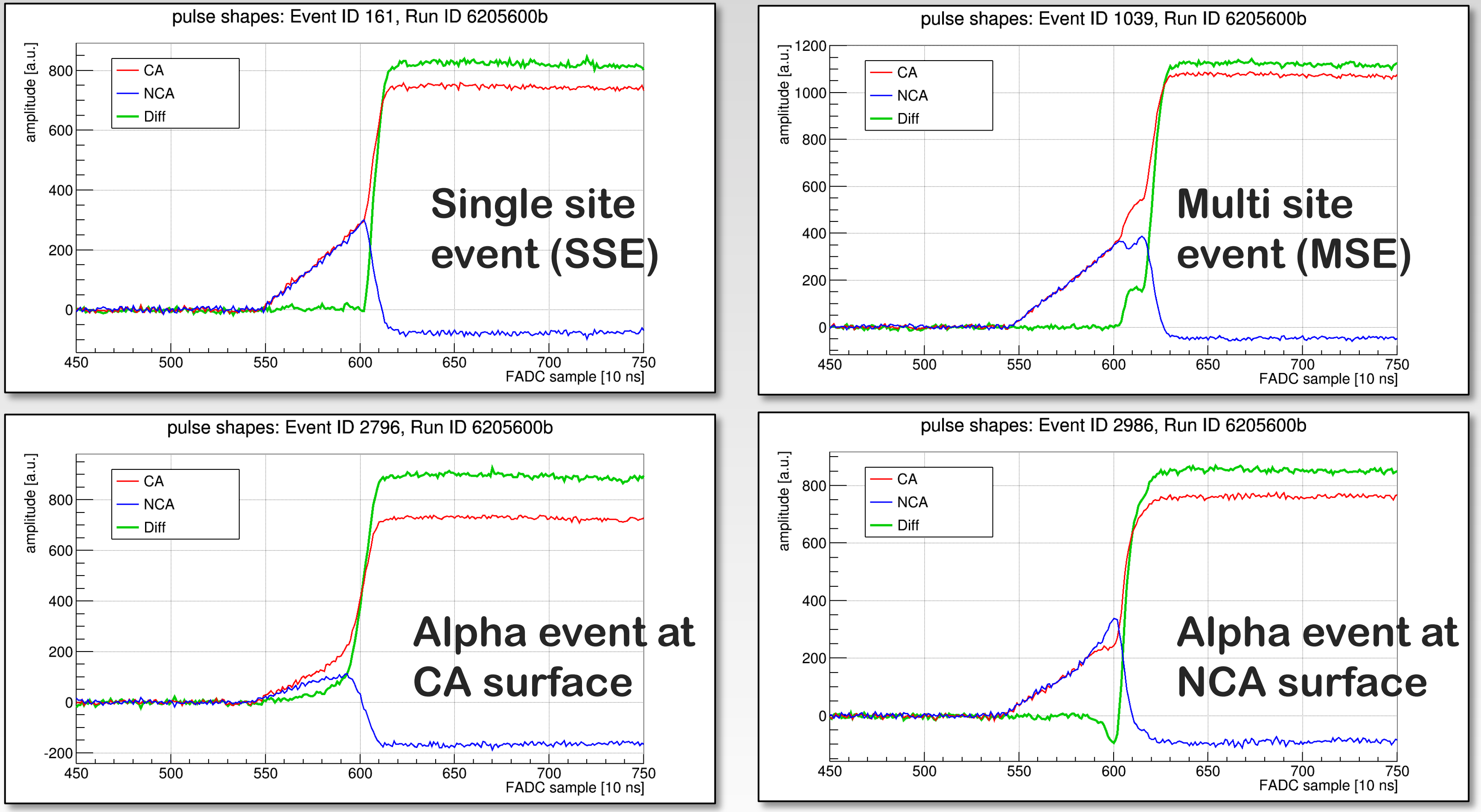
Exposure



- **218.8 kg*days of fully calibrated and evaluated data acquired as of Feb'15**

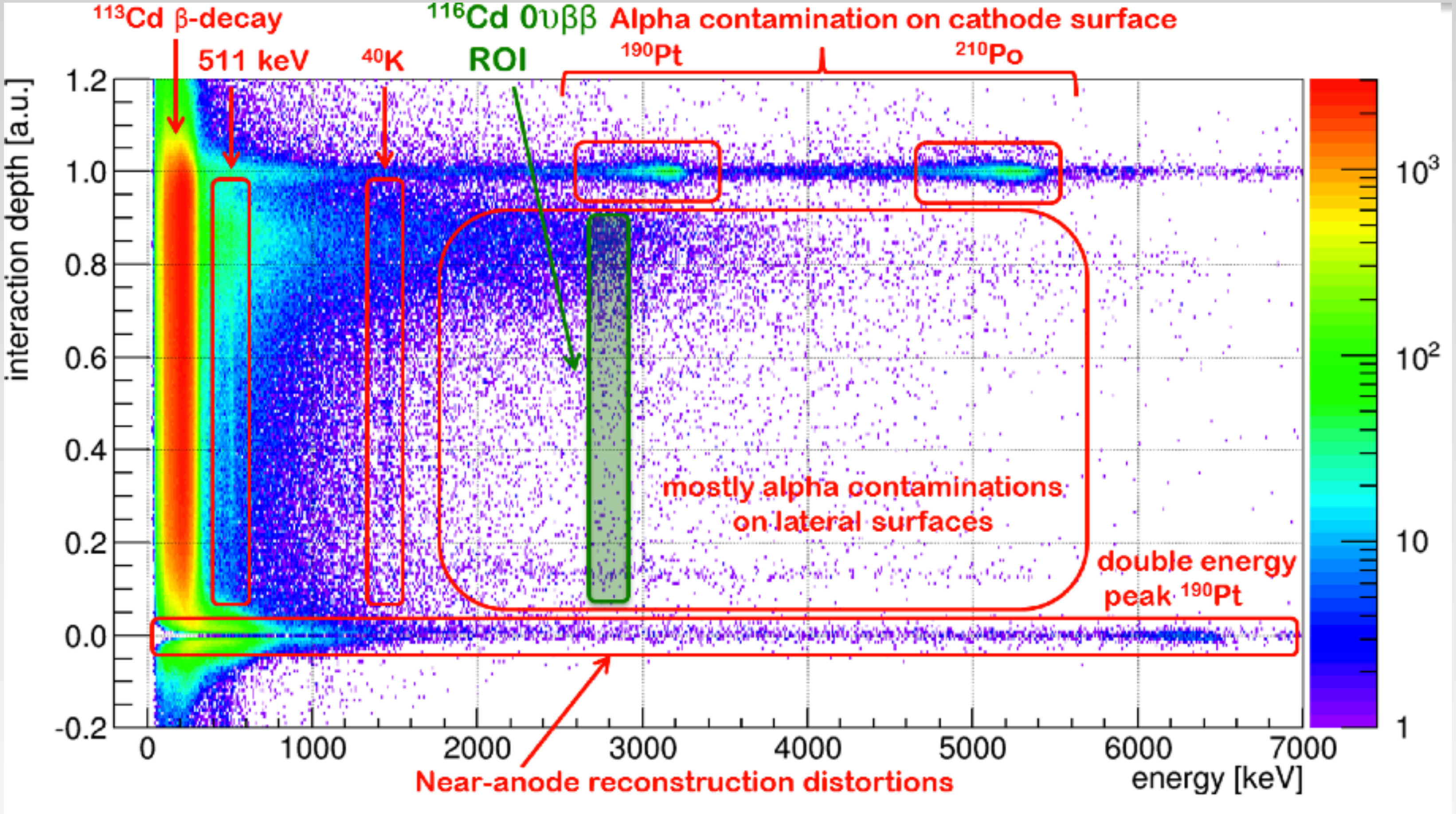
Pulse Shape Analysis (PSA)

- PSA allows for the identification of different types of events
- Development of powerful methods to remove background contributions



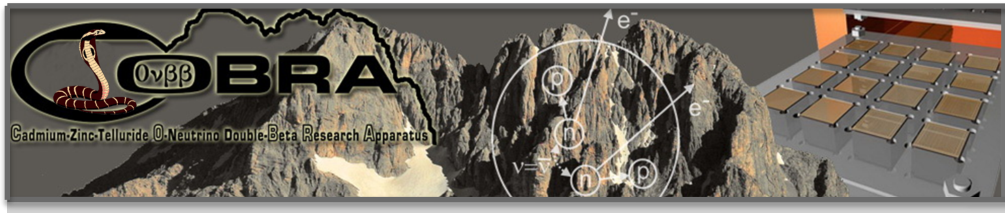
M. Fritts et al, NIM A 708,1 (2013), M. Fritts et al, NIM A 749,27 (2014)

Identifying the features

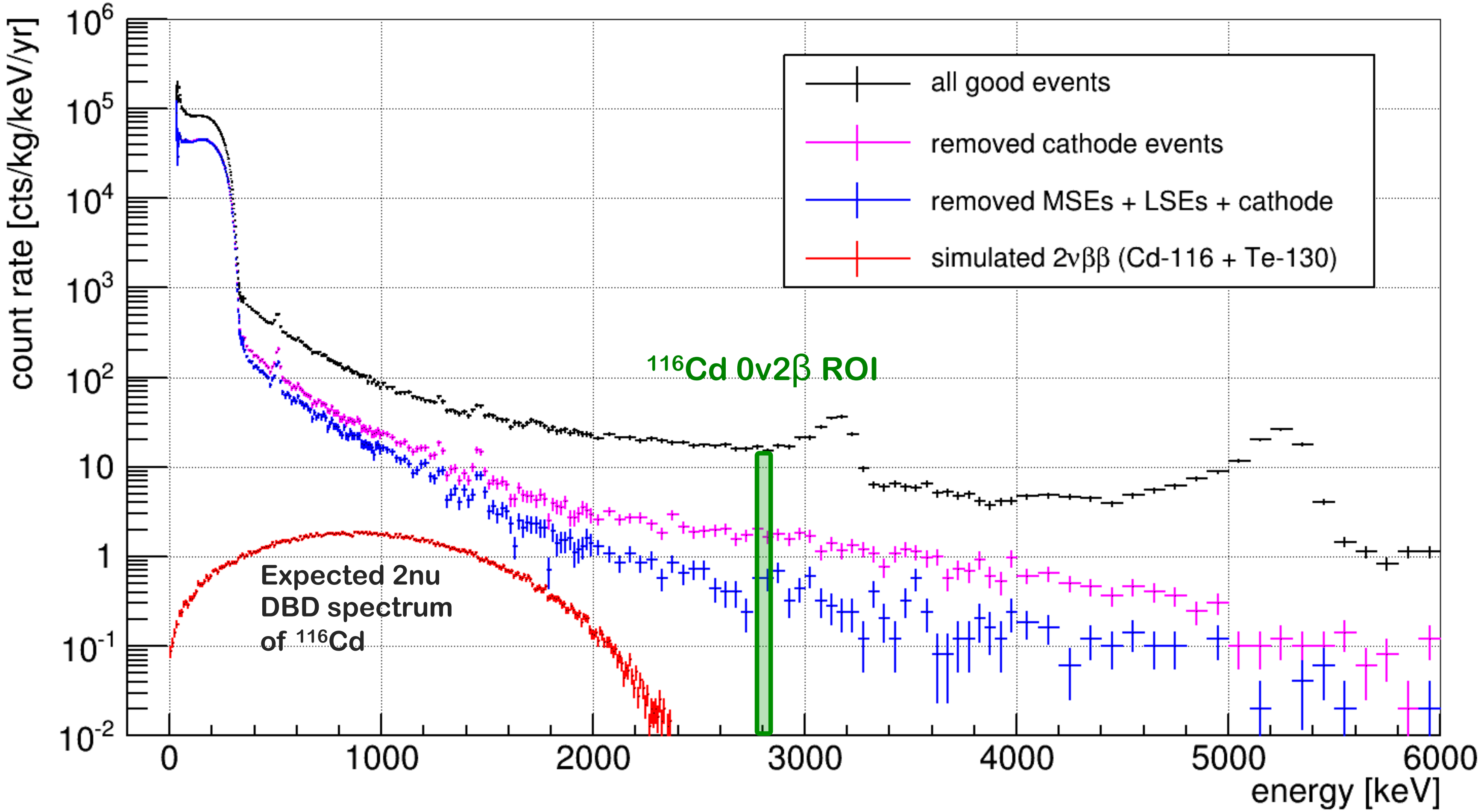


Intrinsic ^{113}Cd background, 4-fold forbidden β-decay, half-life: 7.9x10^{15} y

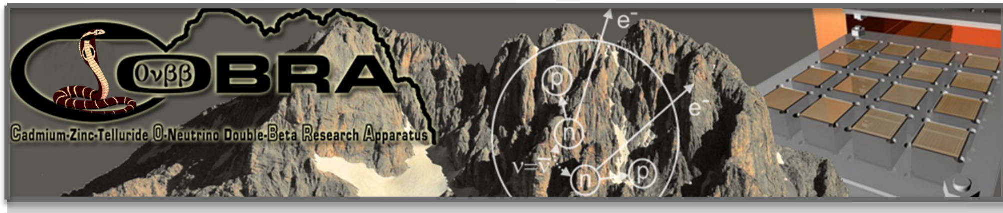
Used as intrinsic stability monitor… J. Ebert arXiv:1508:03217



Application of cuts



- **Background reduction by one order of magnitude in the ROI (^{116}Cd) due to PSA**
- **Background index ~ 0.5 cnt/keV/kg/y**



COBRA-Demonstrator Results

- Successful long term operation since Nov'11
- Acquisition of 218.8 kg x days calibrated exposure
- Main background limitation: Surface alphas!

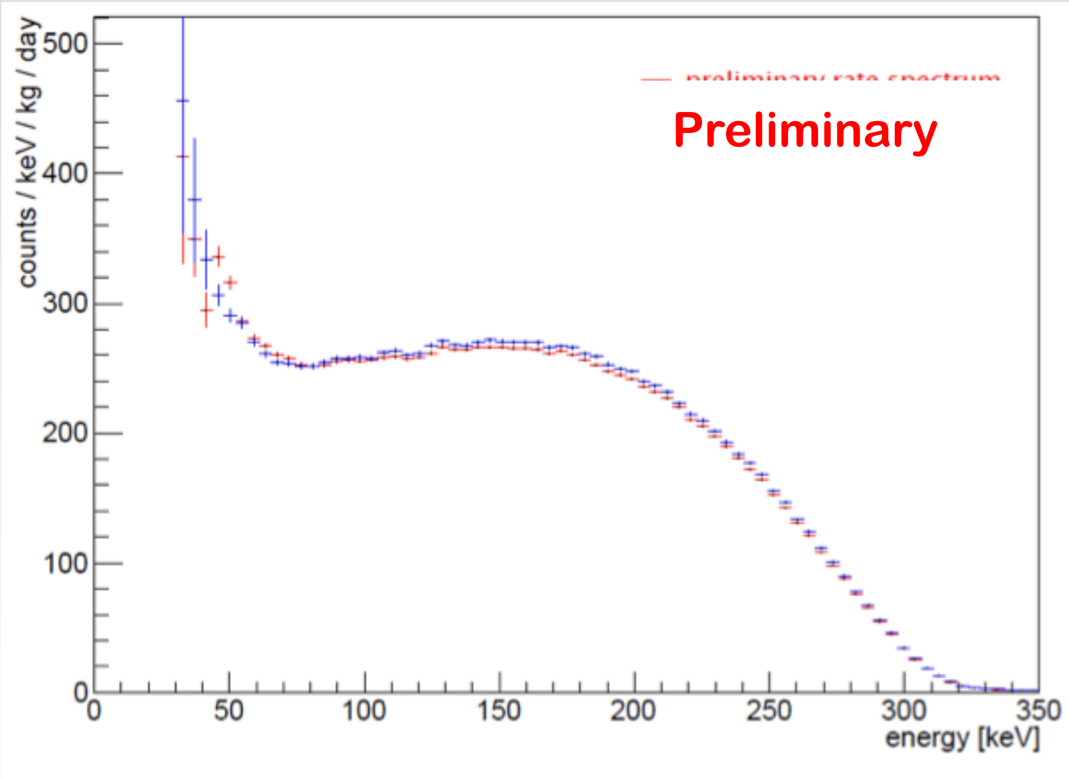
isotope	COBRA'09	COBRA'13	COBRA'15
^{114}Cd	2.0×10^{20}	1.06×10^{21}	**2.27×10^{21}**
^{128}Te	1.7×10^{20}	1.44×10^{21}	**2.39×10^{21}**
^{70}Zn	2.2×10^{17}	2.57×10^{18}	**6.12×10^{18}**
^{130}Te	5.9×10^{20}	3.88×10^{21}	**8.85×10^{21}**
^{116}Cd	9.4×10^{19}	9.19×10^{20}	**1.52×10^{21}**

World best

Preliminary results!!

- Cd-113 is one of only 3 know 4-fold forbidden beta decays
- Spectral shape is sensitive to quenched g_A

$$T_{1/2}^{-1} = PS \times g_A^4 \times ME^2$$

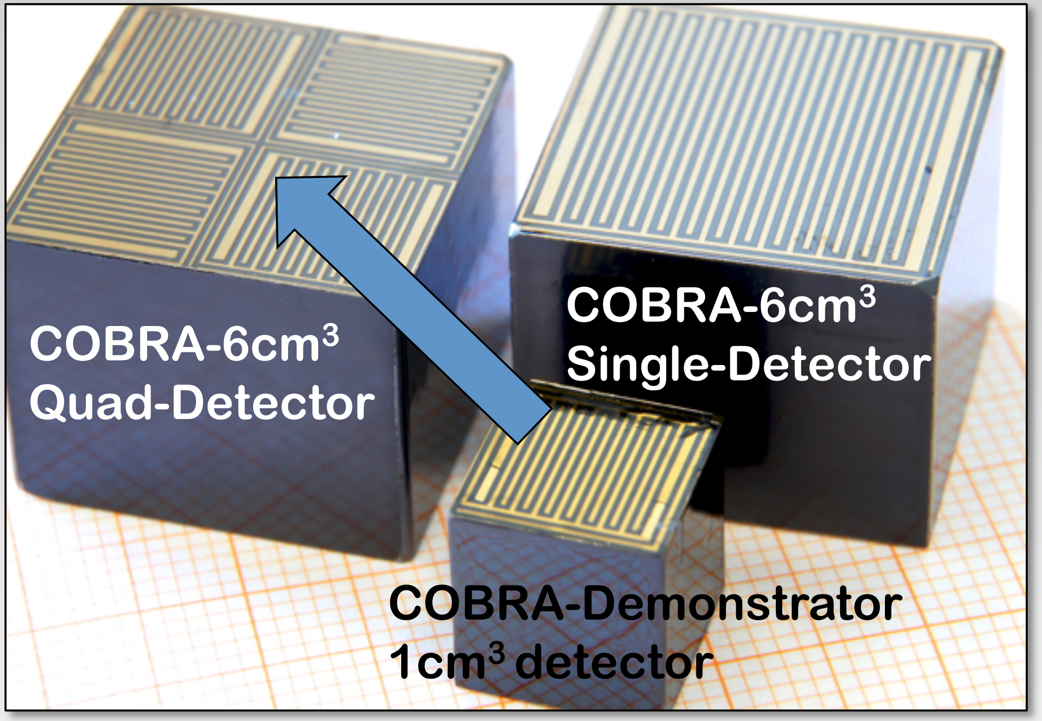


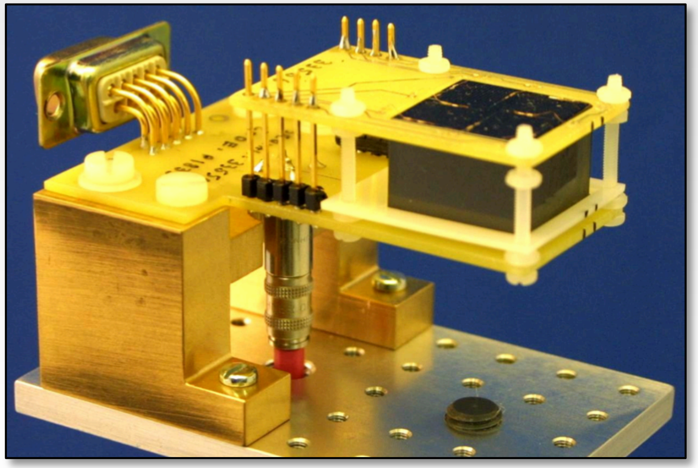
J. Suhonen, O. Civitarese, PLB 725,153 (2013)

Towards a Large-Scale Experiment: Detectors

Move to larger detectors mandatory:

- Reduction of surface/ volume ratio
- Increased detection efficiency for 0ν2β
- Reduction of total number of detectors/ channels per cm³ CZT

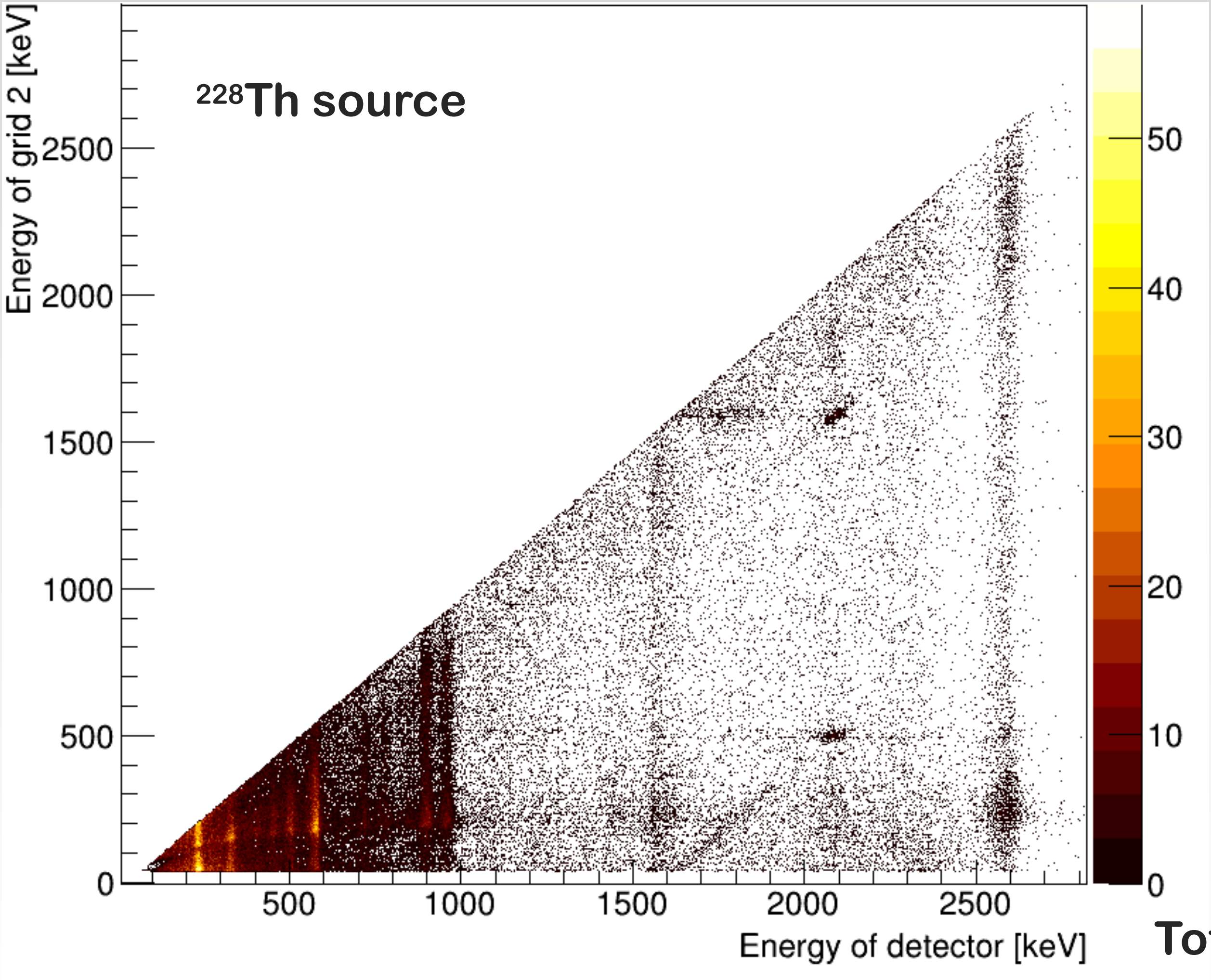




- Crystal size is commercially available
- <u>Lab-investigations on 6cm³ detectors have already started</u>
- Successfull reconstruction of energy and depth-of-interaction
- Intense investigations ongoing to transfer methods and algorithms from 1 to 6cm³ detectors

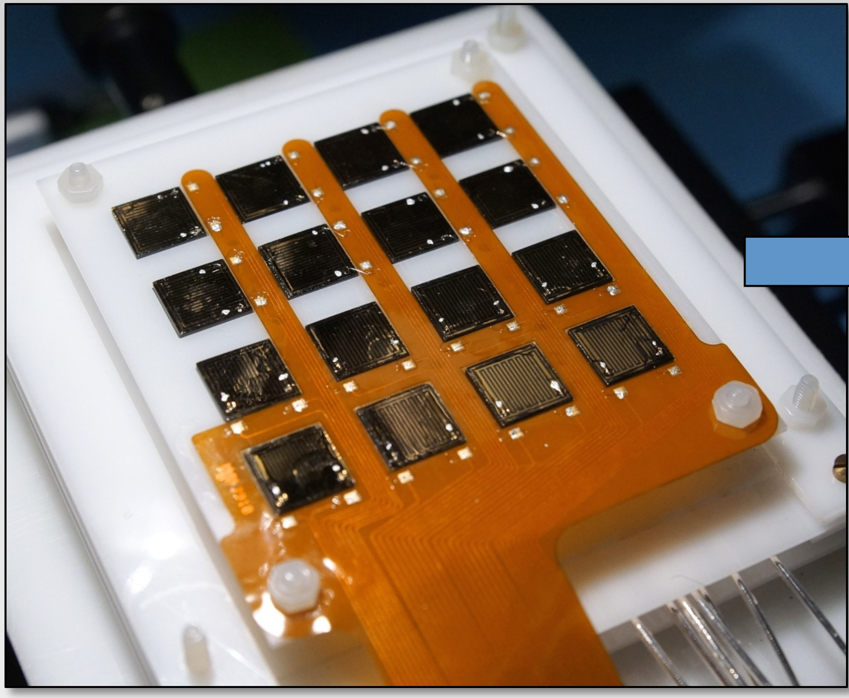
- **QUAD system : 4 independent detectors on one crystal**
- **Internal veto** possible

Energy of
one subsystem

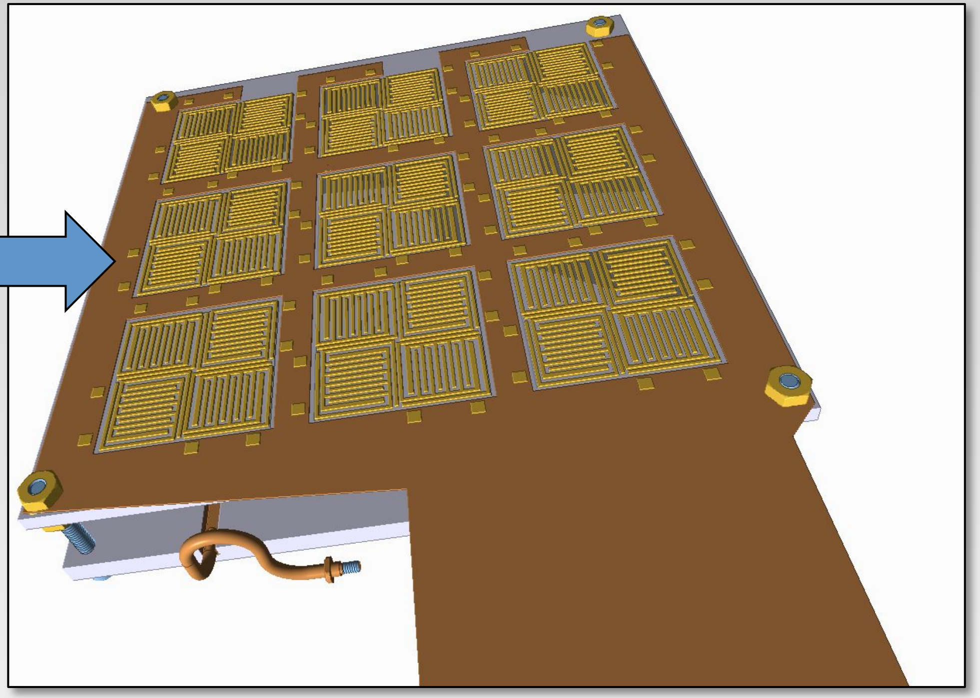


Total E

Towards a Large-Scale Experiment: Detector Layers



4x4 1cm^3 detector layer of the COBRA-demonstrator setup (m_{czt}=96g)

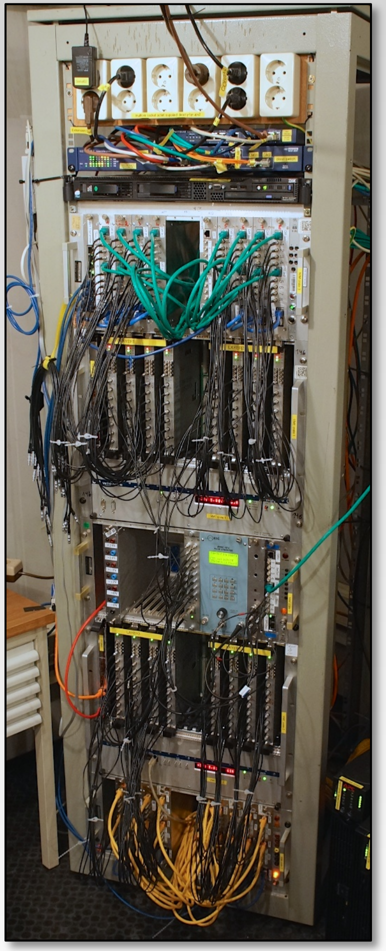


3x3 6cm^3 Quad-detector layer (Detector Module for Large-Scale COBRA), m_{czt}=324g

- **<u>Granted DFG-project:</u>** Assembly and low-background operation of a 3x3 Quad-detector module at the LNGS
- Preparations ongoing, detectors ordered, installation planned for 2016/17
- well approved technique to mount and operate CZT-detectors

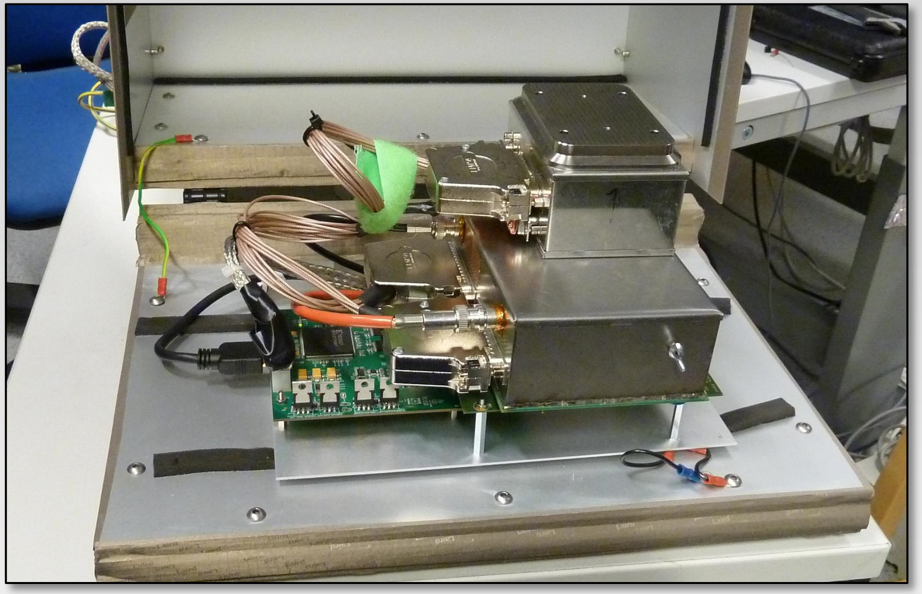
Towards a Large-Scale Experiment: DAQ-electronics

Discrete electronics



- 128 channel DAQ-Rack of the COBRA-Demonstrator at LNGS
- Fully loaded 19“ rack

Highly integrated electronics

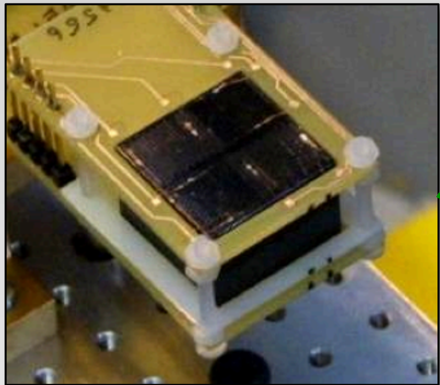


- 128 channel ASIC-FPGA based DAQ-system (switched capacitor array)
- Table top setup
- Cooperation with IDEAS
- <u>Development-system in lab available</u>
- Adaptation ongoing

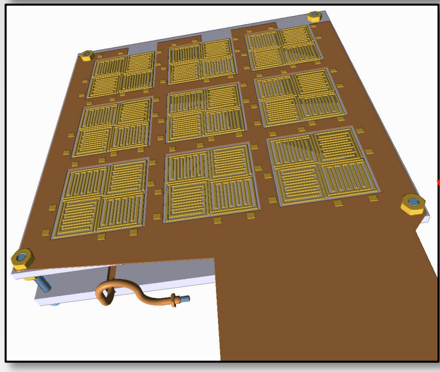
Large-Scale COBRA design

Combination of all new developments to assemble a detector module

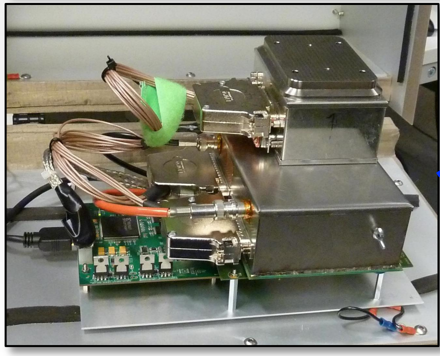
6 cm³ Quad detector

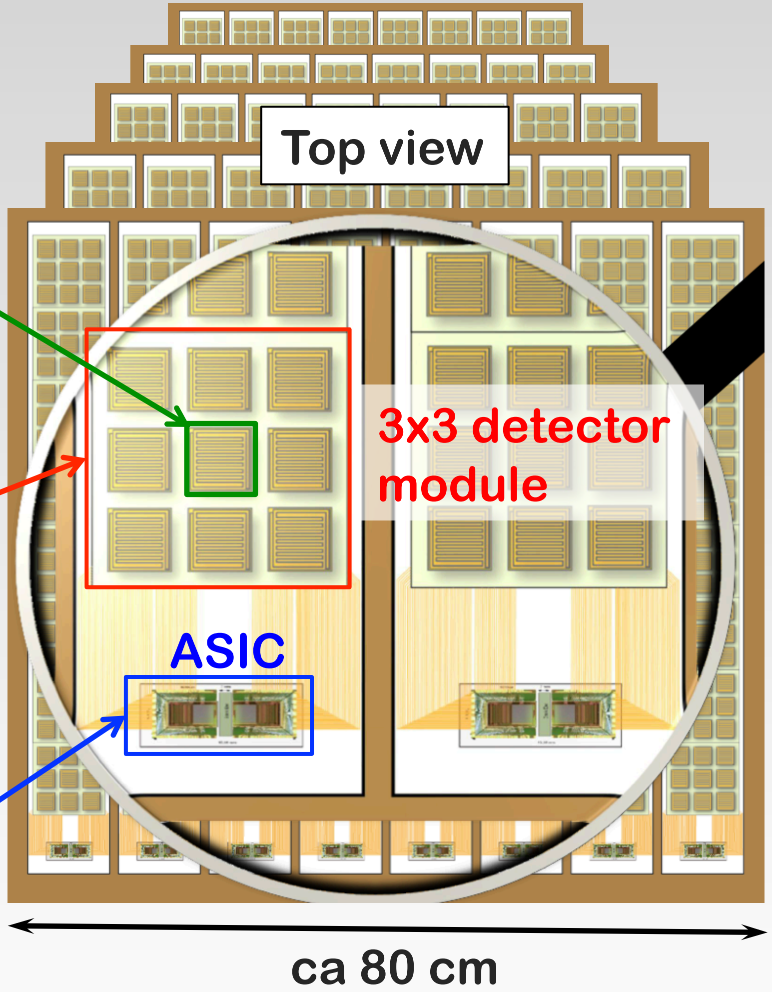


Modular design



Integrated electronics

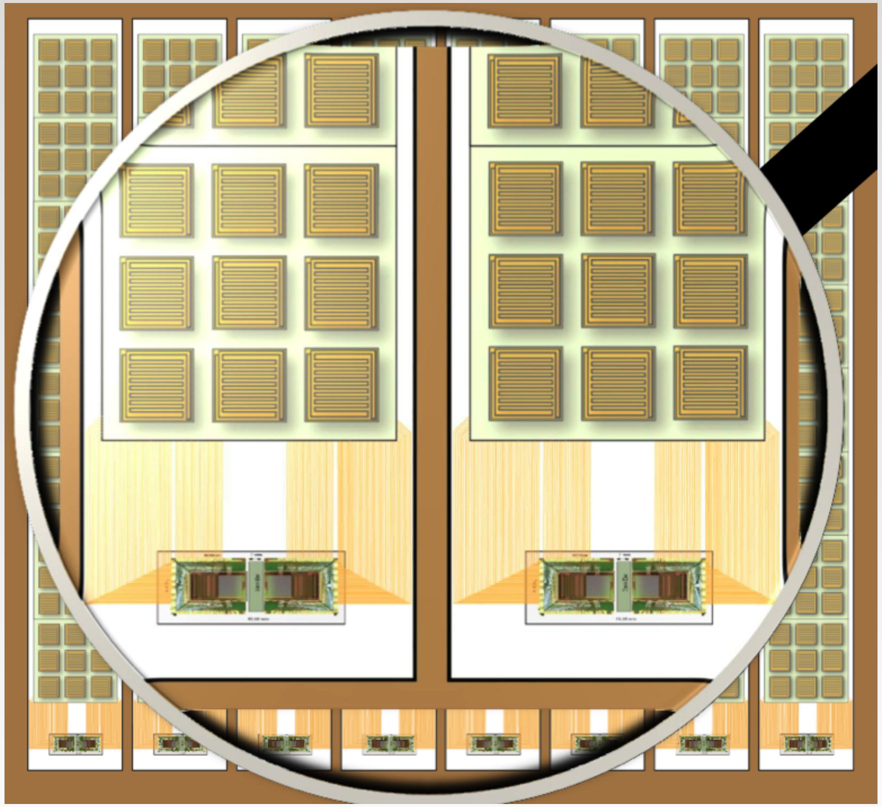


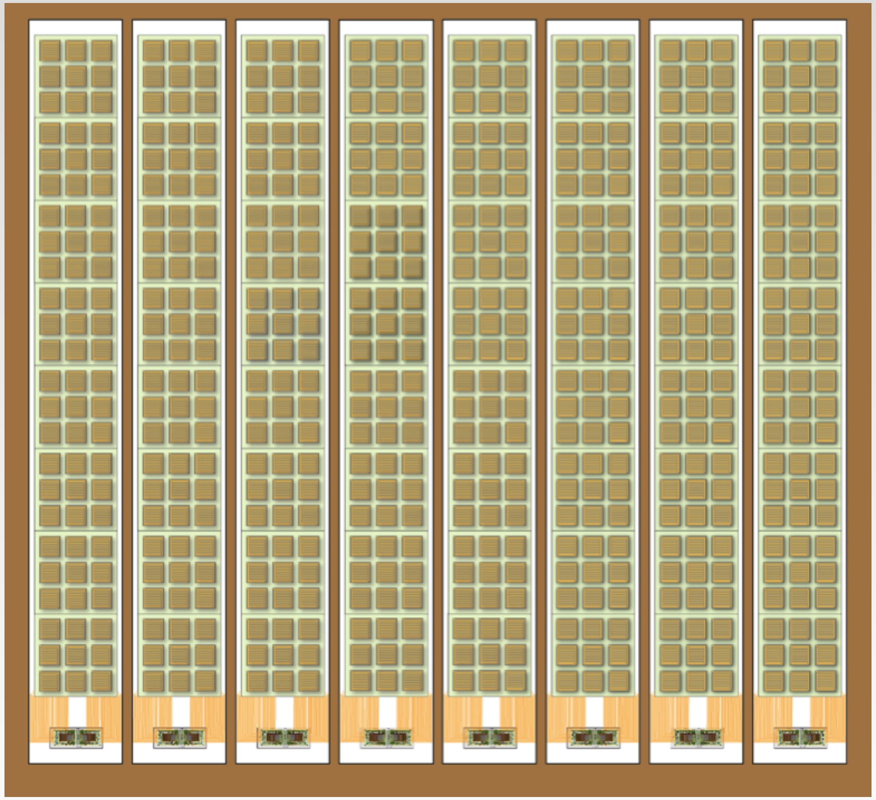


Large-Scale COBRA design

Modules ➔ Detector Module Carrier (DMC) ➔ layers ➔ towers

Strongly modular: 8 modules form one DMC, 8 ladders one layer



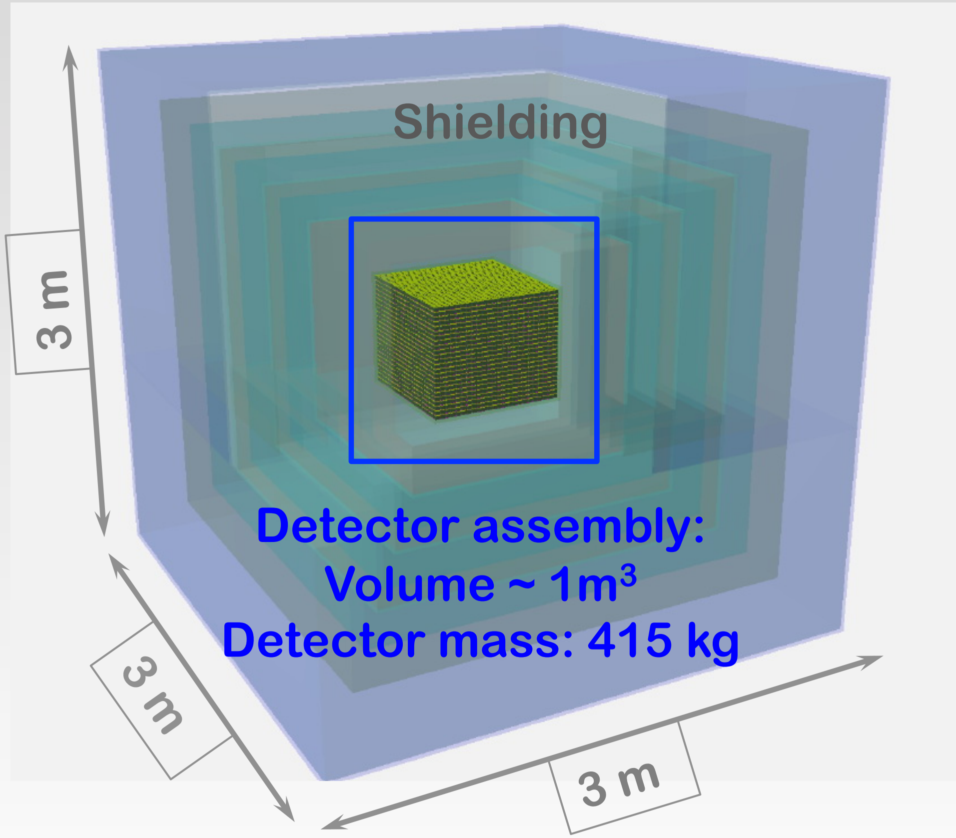


How to build a large scale experiment?

- Basic unit: 3x3 Detector Module (DM): 9 x 36g = 0.324kg / DM
- 8 Modules assembled on a Detector Module Carrier (DMC): 8 x 0.324 kg = 2.6 kg / DMC
- 8 DMC to form one Detector Layer (DL): 8 x 2.6 kg = 20,8 kg / DL
- 20 DL setup:

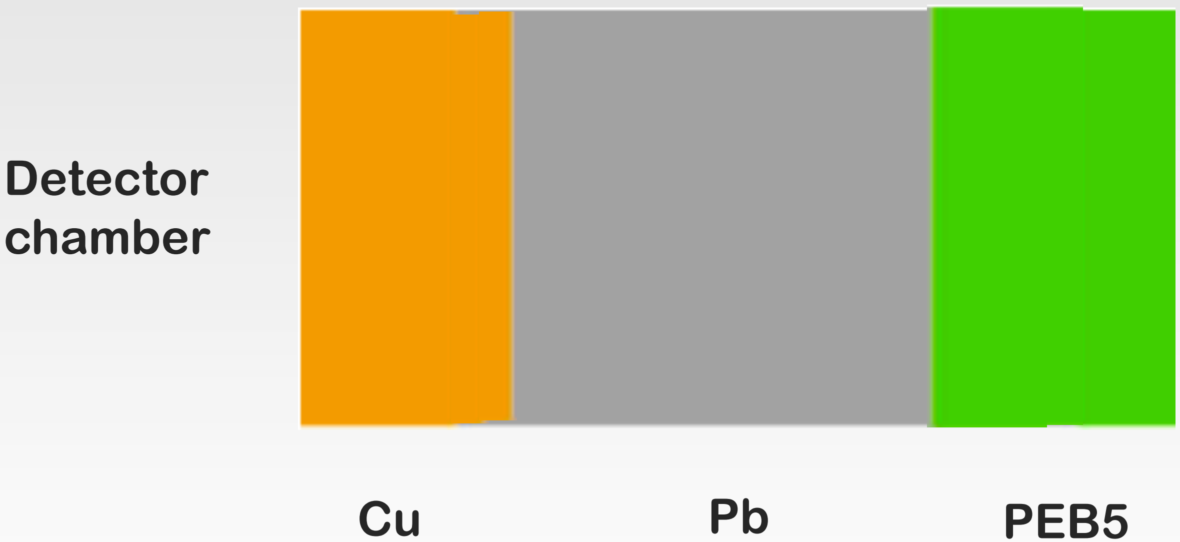
  20 x 20,8 kg = 415 kg total detector mass (11.520 detectors)
- Height of a detector layer: ~ 5 cm ➔ total height ~ 1m

  Could fit in the ladder lab

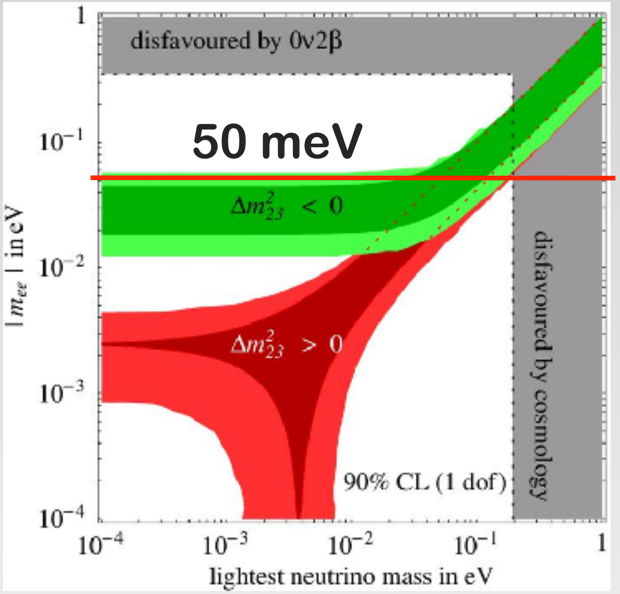


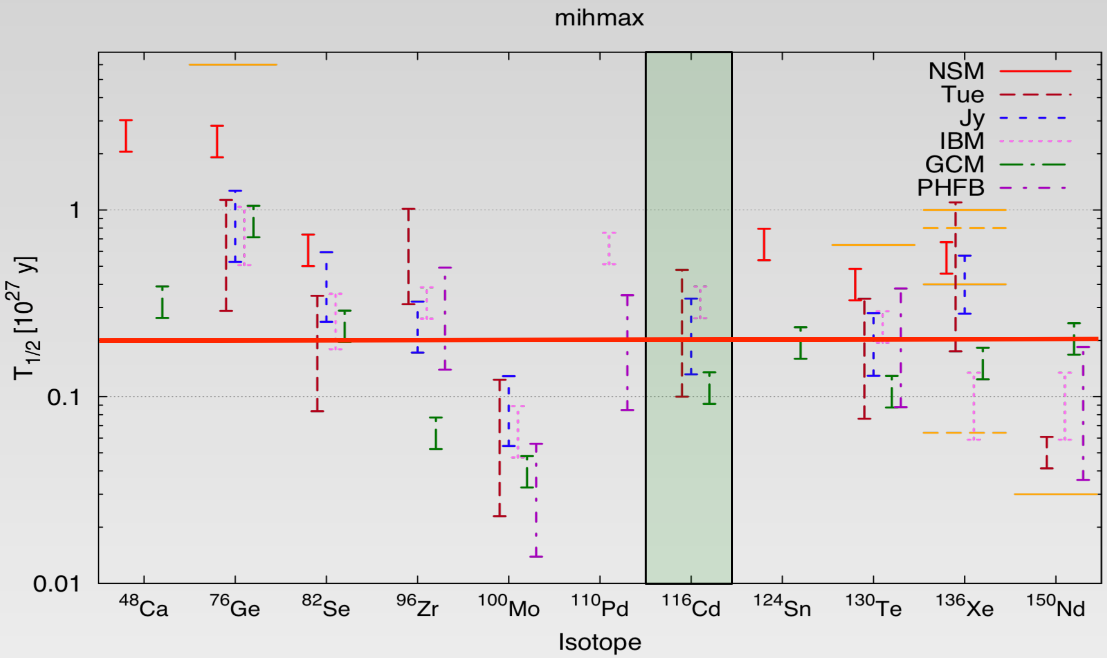
Shielding

- Massive Monte Carlo campaign
- Best shielding: 10 cm Cu – 20 cm Pb - 10 cm PEB5



Scientific goals for the large-scale COBRA setup

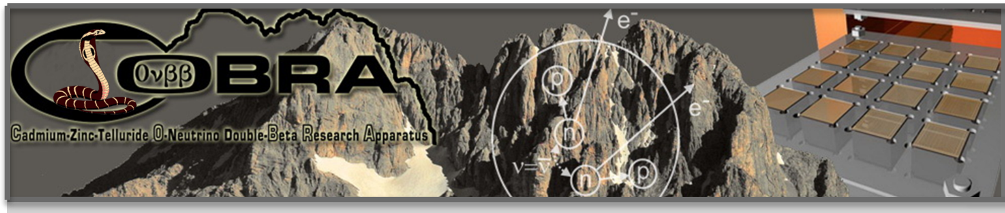




A. Dueck, W. Rodejohann, K. Zuber,
arXiv:1103.4152, Phys. Rev. D 83,113010 (2011)

- to reach a sensitivity of 50 meV/c^2 with ^{116}Cd, the detectable half-life must be longer than:

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

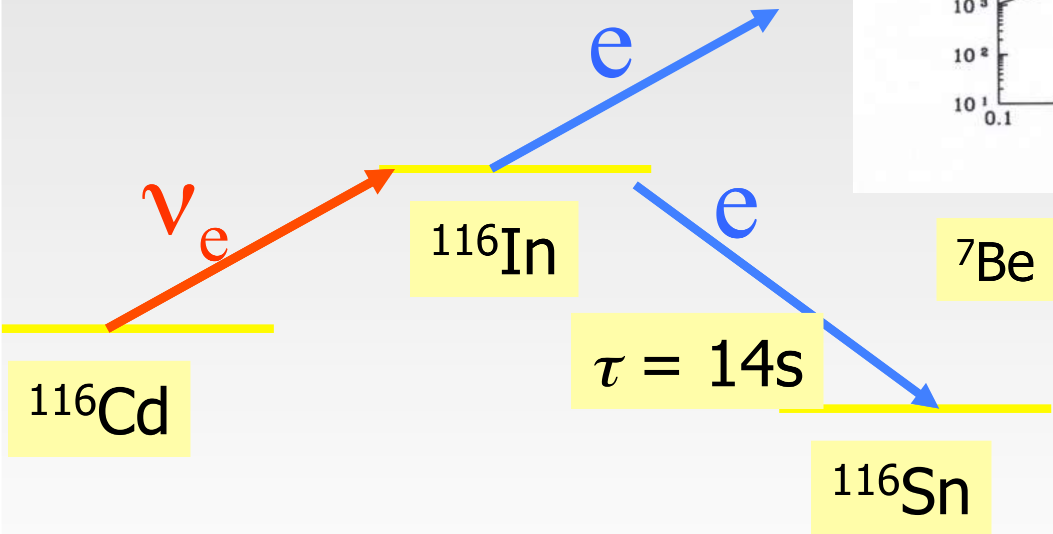


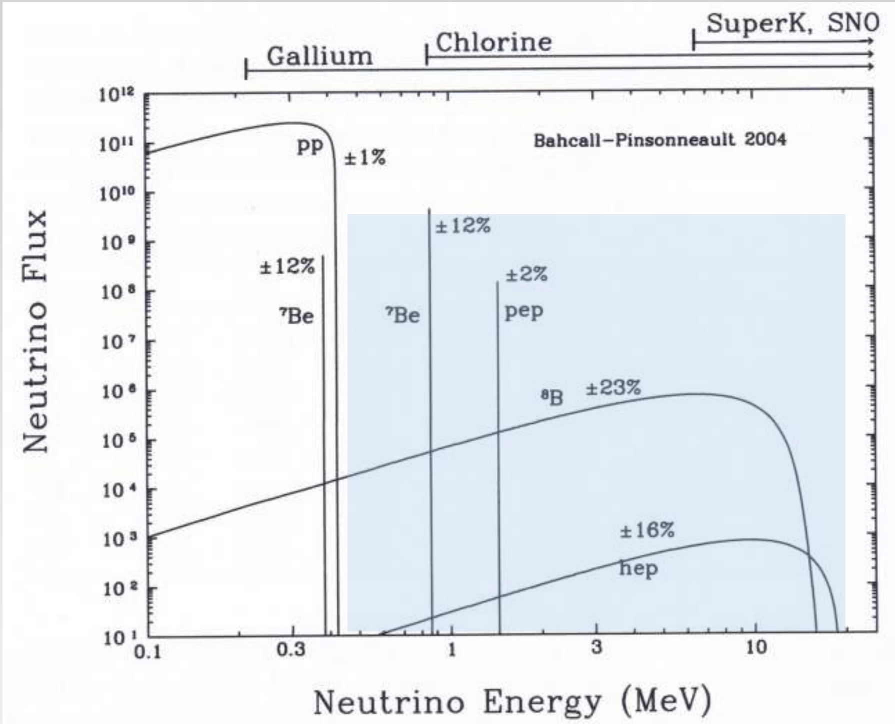
Other physics I

Solar neutrinos

Threshold : 464 keV

Signal:
Coincidence in a single detector





^{7}Be contribution g.s. alone: 227 SNU

K. Zuber, Phys. Lett. B 571,148 (2003)

Other physics II

Supernova signals

NC interactions:

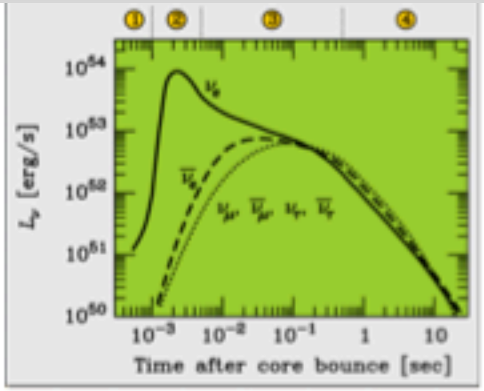
$$\nu_l + {}^{116}\mathrm{Cd} \rightarrow {}^{116}\mathrm{Cd}^* + \nu_l',$$

$$\bar{\nu}_l + {}^{116}\mathrm{Cd} \rightarrow {}^{116}\mathrm{Cd}^* + \bar{\nu}_l',$$

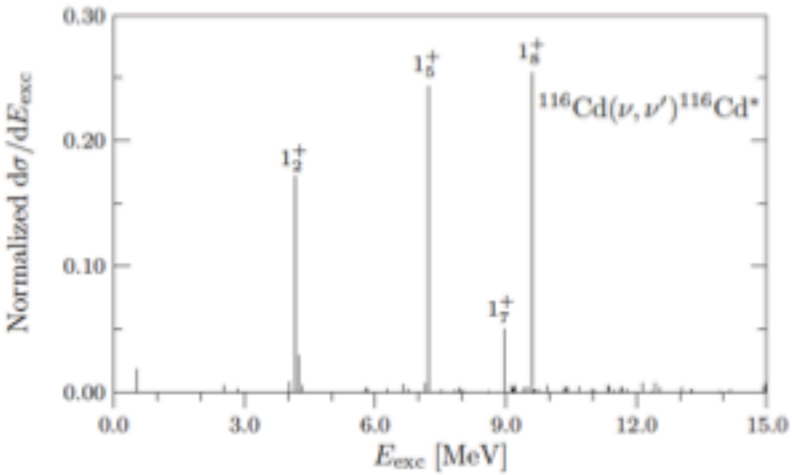
CC interactions:

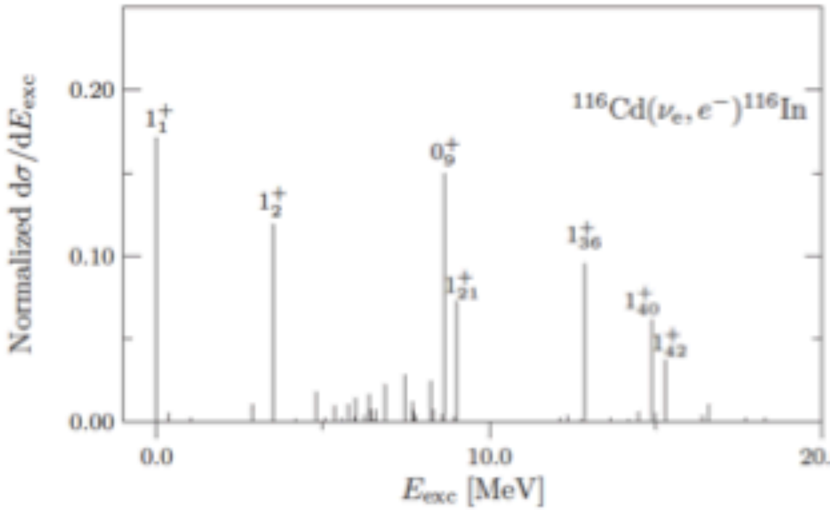
$$\nu_l + {}^{116}\mathrm{Cd} \rightarrow {}^{116}\mathrm{In} + l^-,$$

$$\bar{\nu}_l + {}^{116}\mathrm{Cd} \rightarrow {}^{116}\mathrm{Ag} + l^+$$



W. Almosly, E. Ydrefors, J. Suhonen, JPG 40,095201 (2013)

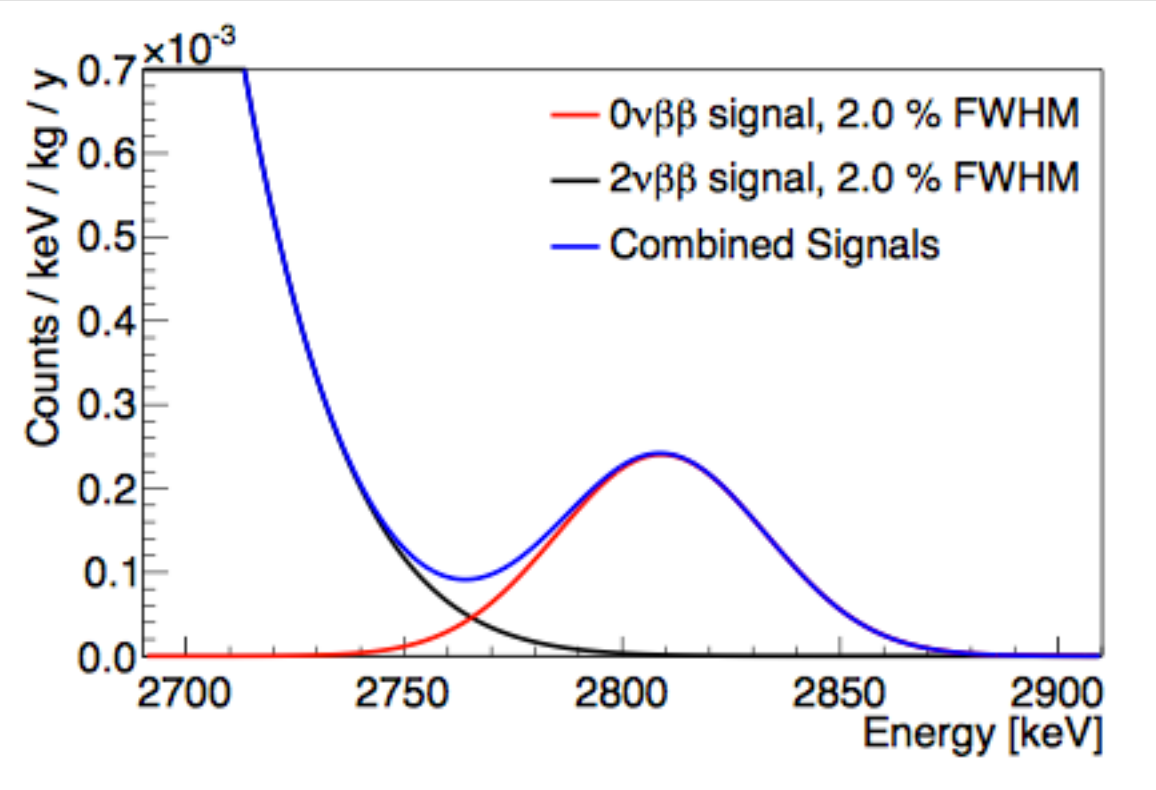




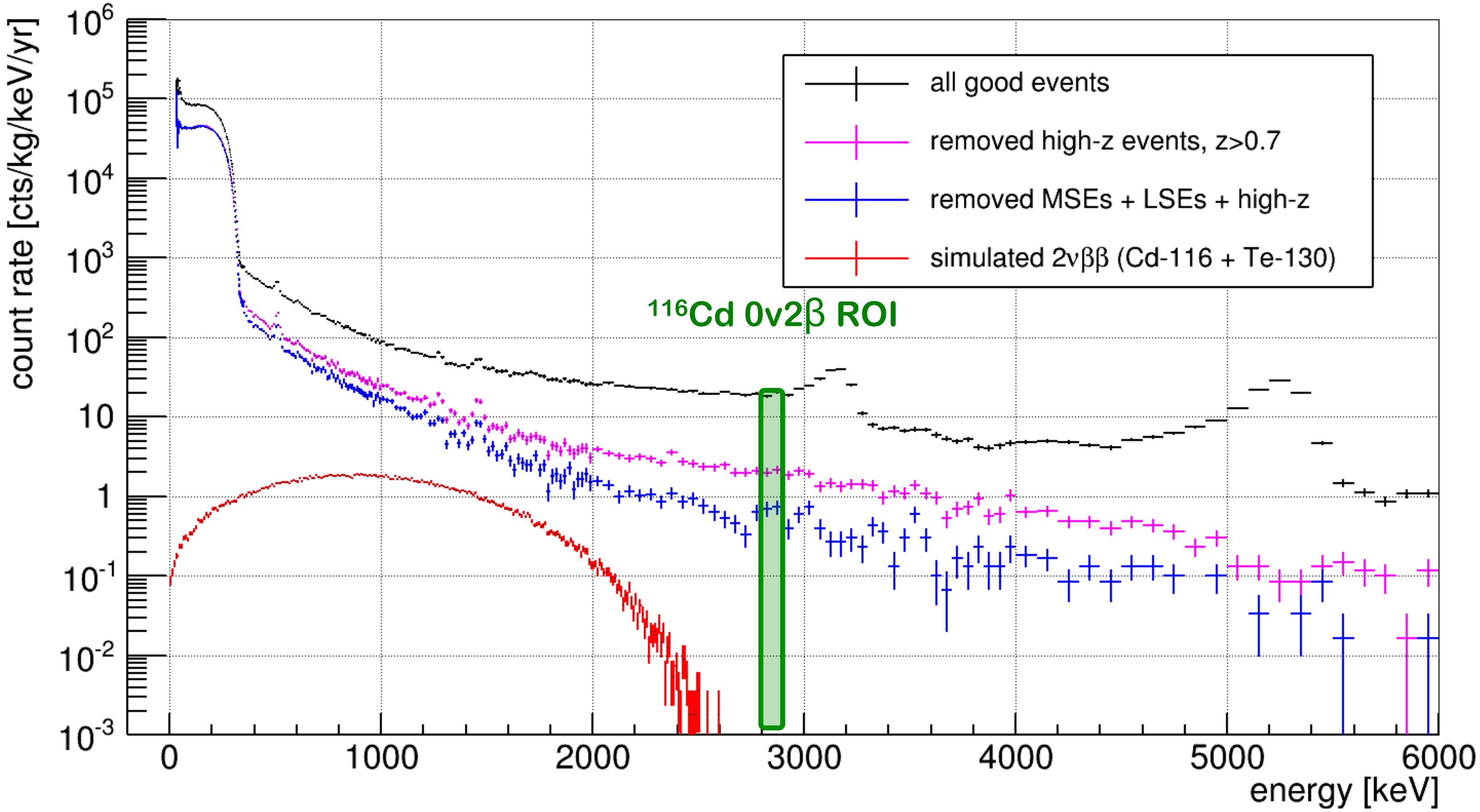
W. Almosly, E. Ydresfors, J. Suhonen, JPG 42,095106 (2015)

Towards a large experiment (2nu DBD background)

- Assuming 2 x 10^{26} yrs half-life for 0nu DBD
- Shown are 2% FWHM, aim is 1.3% FWHM
- All functioning detectors at LNGS show less than 2%



Technical challenges

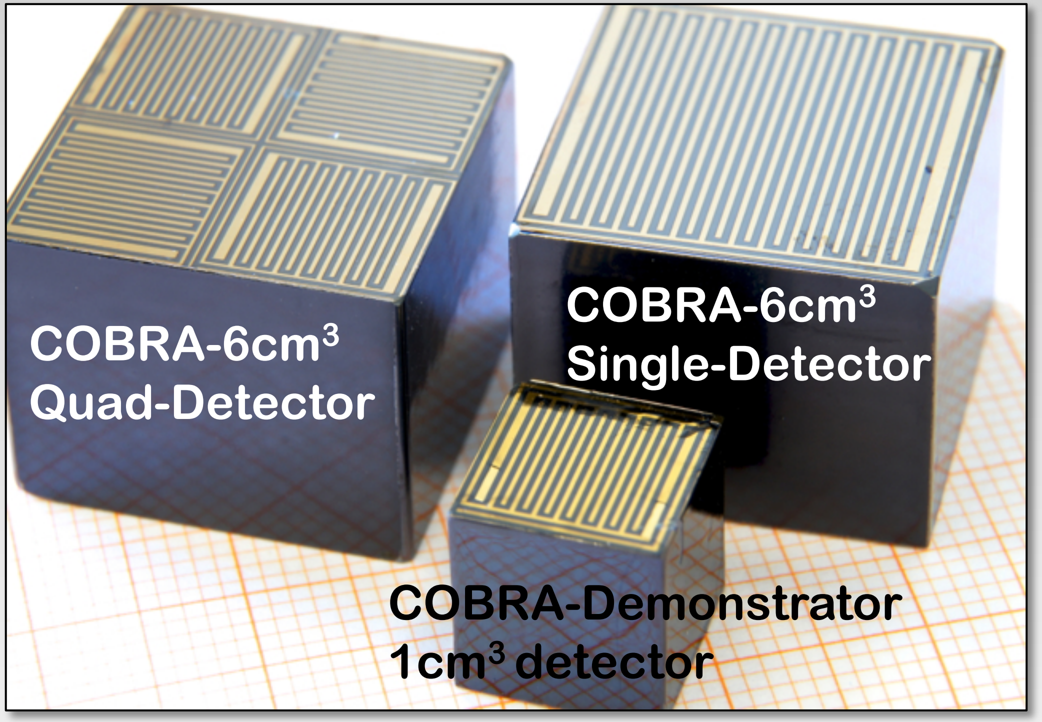


Main challenge: Reduction of background-index in the ROI:

Current background: ~0.5 cnts/keV/kg/yr

Required background: ~0.001 cnts/keV/kg/yr

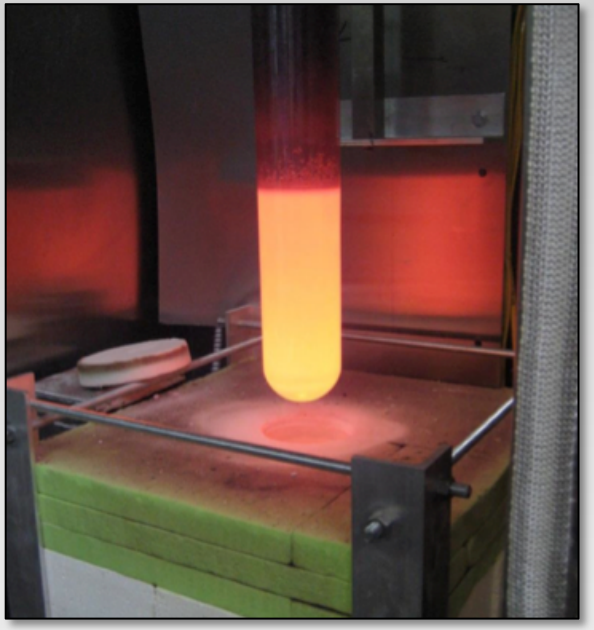
Technical challenges



- 90% enr. ^{116}Cd available commercially (NEMO-3)
- Purification can be done (NEMO-3, PPM Materials)
- Redlen & eV Products recycle raw material
- Redlen total annual CZT manufacturing: 200kg (all sizes and types)

- 1% E_{res} at 2.8MeV with standard 1cm^3 detectors and has been demonstrated
- E_{res} < 1% at 662 keV has been shown for 6cm^3 detectors based on 11x11 pixelated design (Z. He, Uni Michigan)
- Can high E_{res} be achieved with the Quad-design – investigation ongoing
- Contacting scheme

Costs



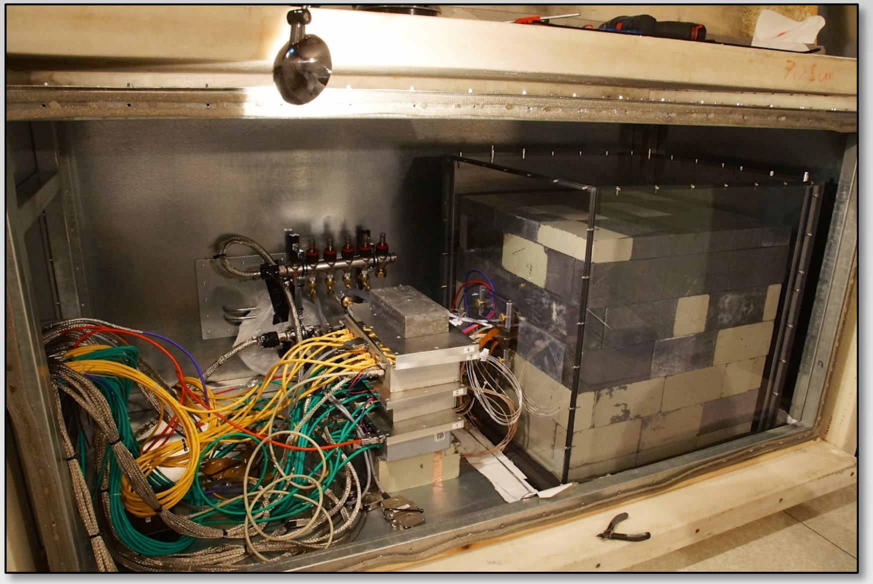
Main Costs:

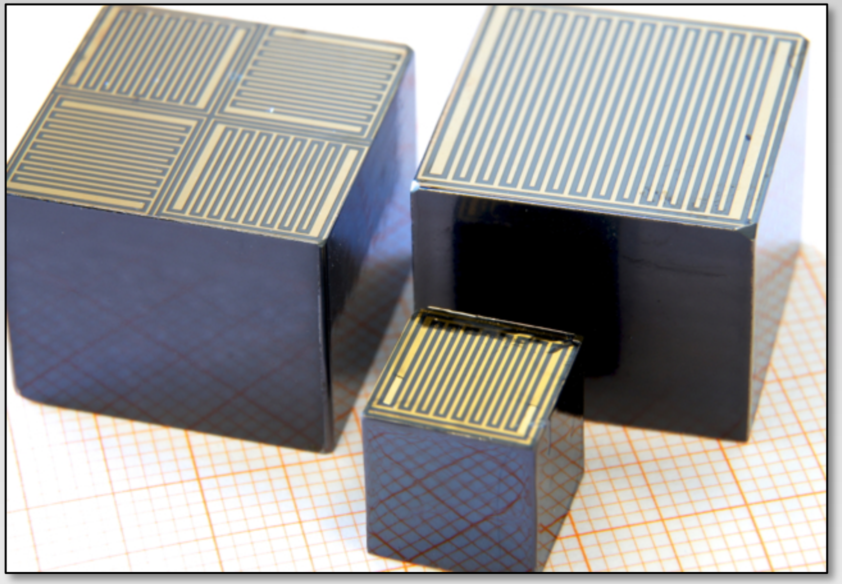
- Enrichment of ^{116}Cd for detector manufacturing
- Purification at PPM-Materials
- Detector manufacturing of high performance Quad-CPG detectors at Redlen and eV Products
- Requirements for cleanroom compatible manufacturing at vendor sites

Requests for technical and technological infrastructures

- Cleanroom for detector module assembly mandatory
- Preferably integrated into lab-environment with direct connection to experimental setup

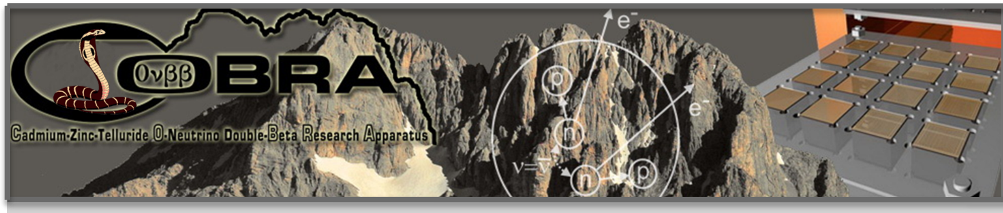
Safety issues



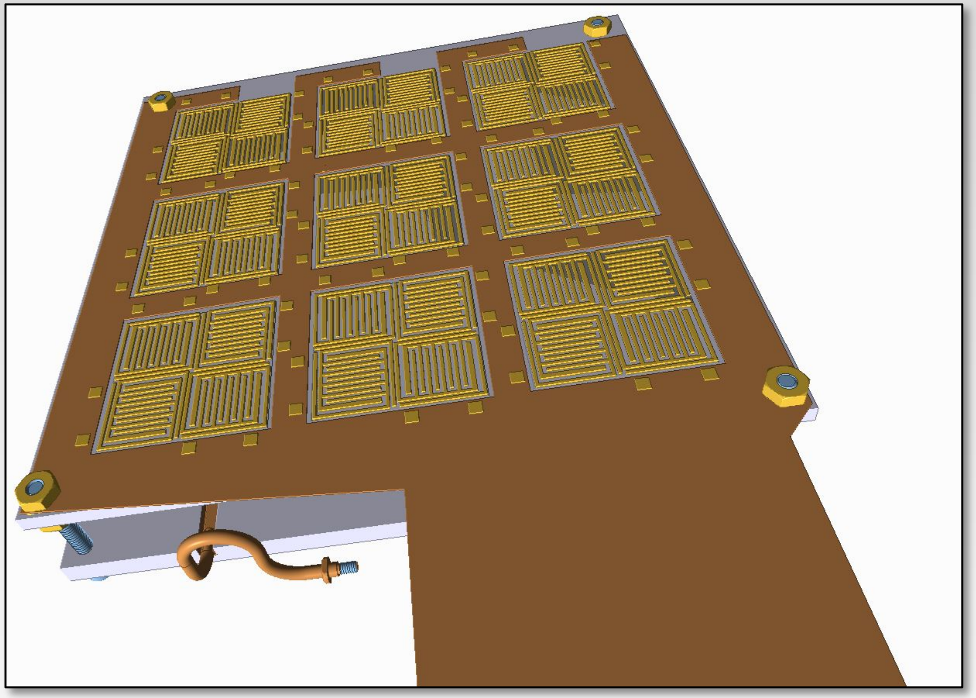


COBRA detectors are room-temperature semiconductors, very low risk:

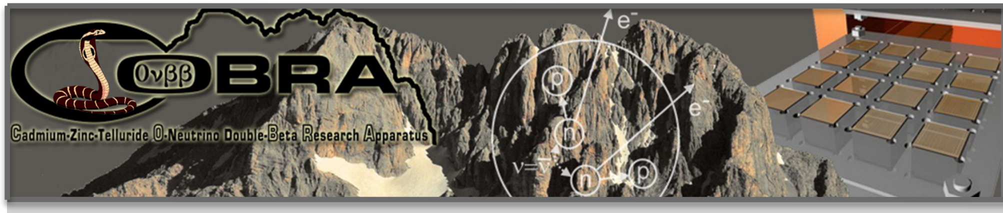
- Inert semiconductor material (CZT)
- No flammable liquids
- No toxic liquids
- No cryogenic gases (besides the nitrogen for flushing the setup)
- No cryostats
- Calibration sources needed (low activity ^{228}Th, ^{22}Na)



Time scales



- Funded DFG-project to build of 3x3 layered 6cm^3 detector, operation has started in fall 2014
- Detector investigations and development of evaluation methods ongoing
- Installation of first 3x3 detector module at the LNGS planned for 2016/17
- Option to build solid state scintillator around crystals exists for 2017
- Technical Design Report by 2018



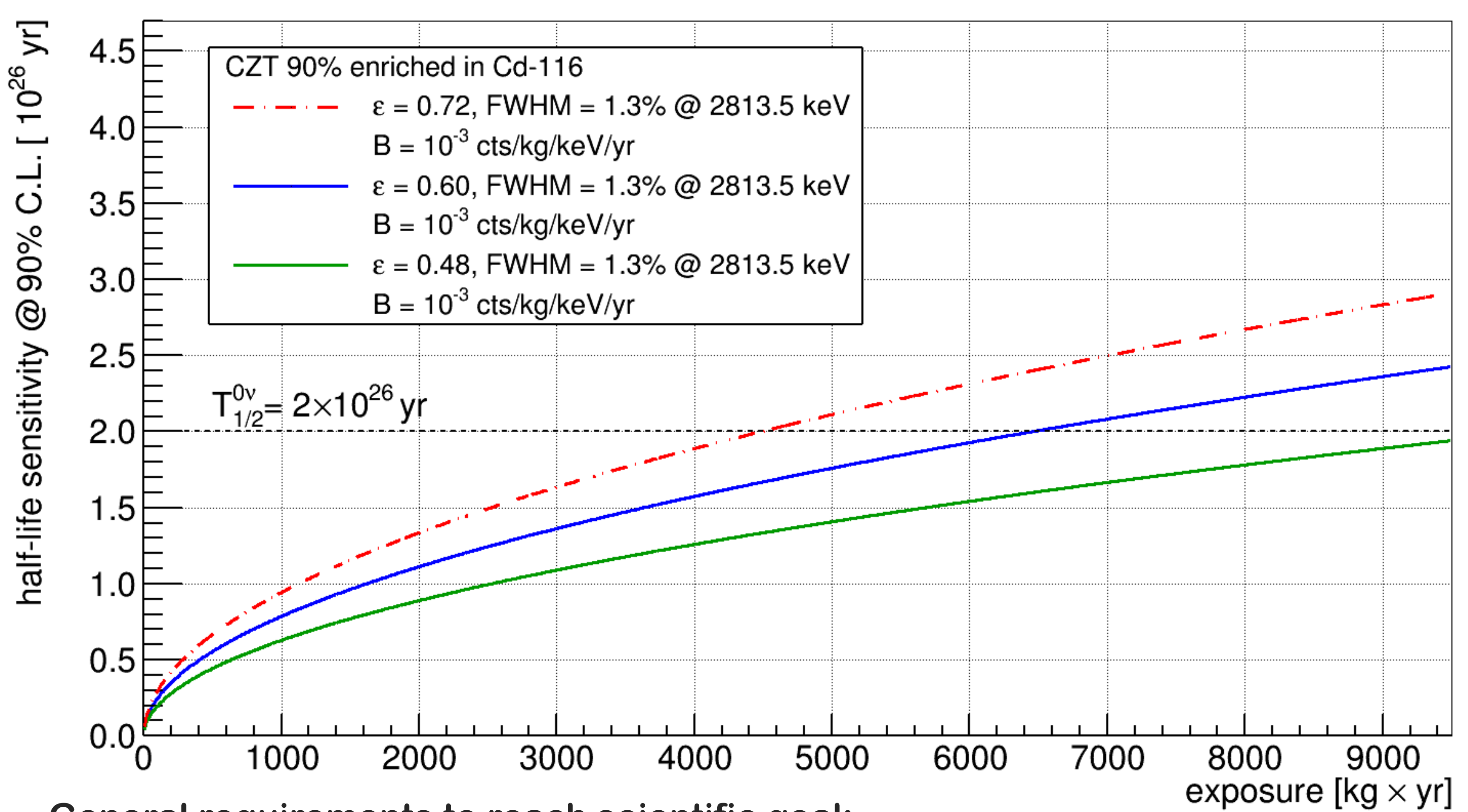
Conclusions

- COBRA is based on room temperature CZT detectors
- COBRA was the only DBD experiment in the original SNOLAB proposal to CFI
- Major target is Cd-116, one of six isotopes beyond the Tl-208 line
- Strong interest on Cd-113 spectral shape for g_A
- COBRA demonstrator with 64 detectors running at LNGS since Nov. 2013
- COBRA is a low risk experiment, very modular and easily scalable

- COBRA is working with a Canadian company on the detectors, some Canadian institutes show interest… So why not running the experiment in SNOLAB?

More collaborators welcome!

Projected sensitivity of a large-scale COBRA setup



General requirements to reach scientific goal:

- **Detection- & cut-efficiency as high as possible: $\varepsilon_{tot} > 0.6$**
- **Energy resolution: FWHM < 1.3% @ 2.8MeV**
- **Background index: B < 10^{-3} cnts/keV/kg/yr**
- **^{116}Cd enrichment: 90%**