Status of the COBRA Experiment

K. Zuber, TU Dresden

Erice, 18.9.2013

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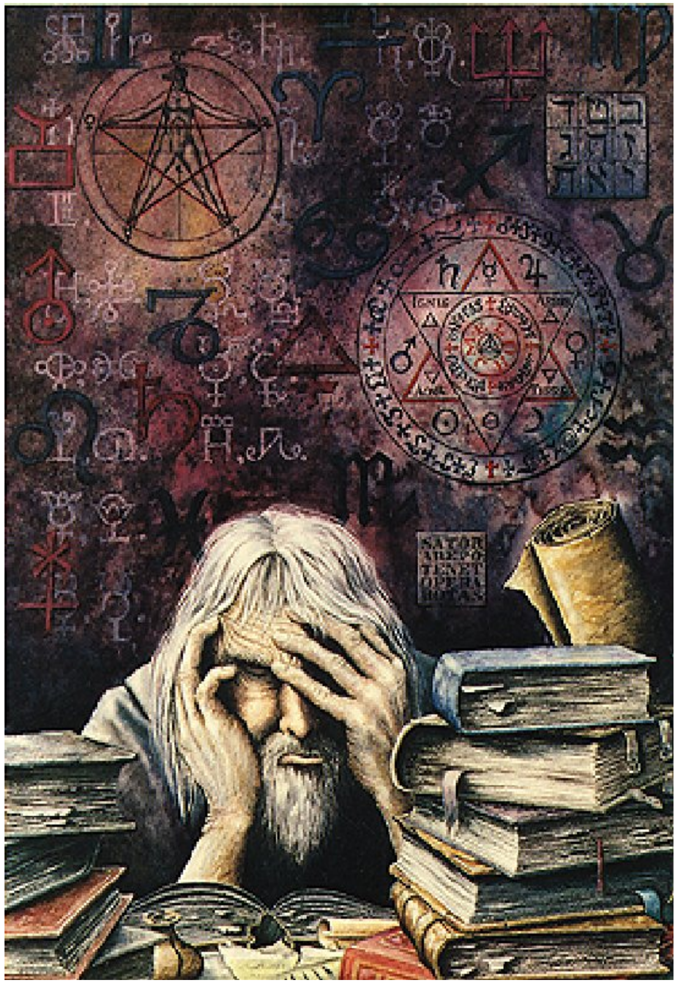
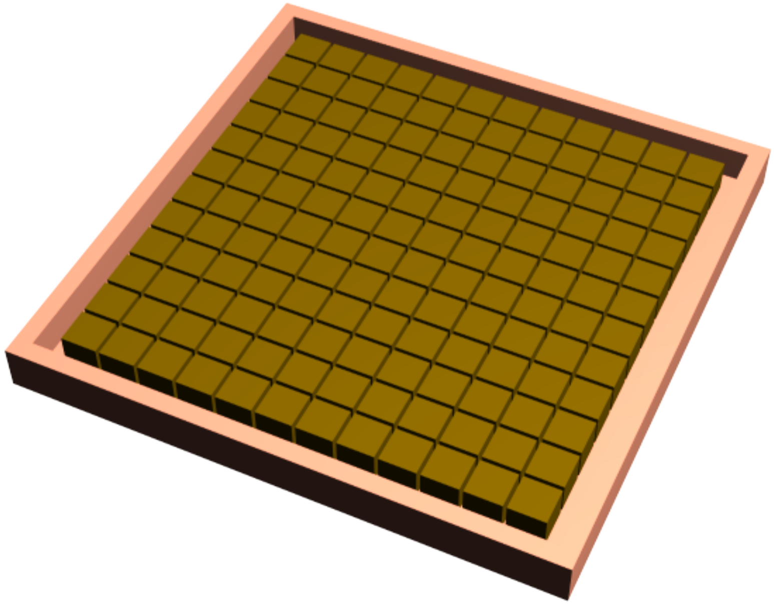
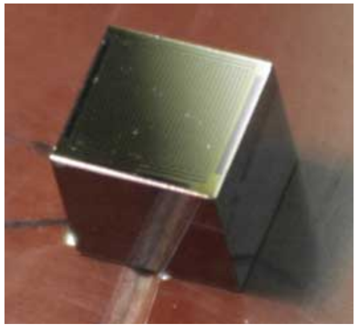


- Introduction
- CPG detectors
- The Gran Sasso set-up
- Plan for a large scale experiment
- Options (pixel, LSc)
- Summary

COBRA - The idea

Use large amount of CdZnTe Semiconductor Detectors





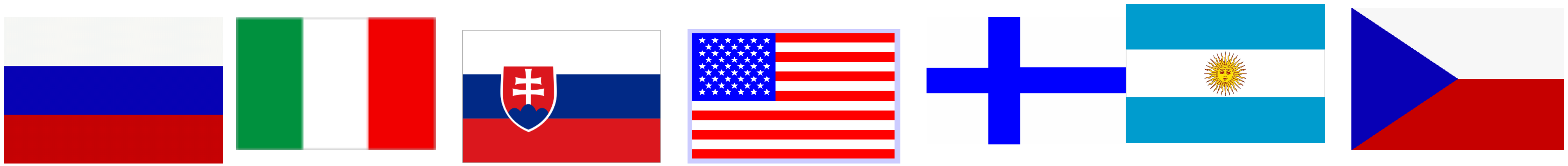
K. Zuber, Phys. Lett. B 519,1 (2001)

COBRA

More welcome!!!

Technical University Dresden
Technical University Dortmund
University of Hamburg
University of Erlangen-Nürnberg
Freiburger Materialforschung (FMF)
Laboratori Nazionali del Gran Sasso

Czech Technical University Prague
Washington University at St. Louis
University of Jyvaskyla
University of de la Plata
University of Bratislava
JINR Dubna

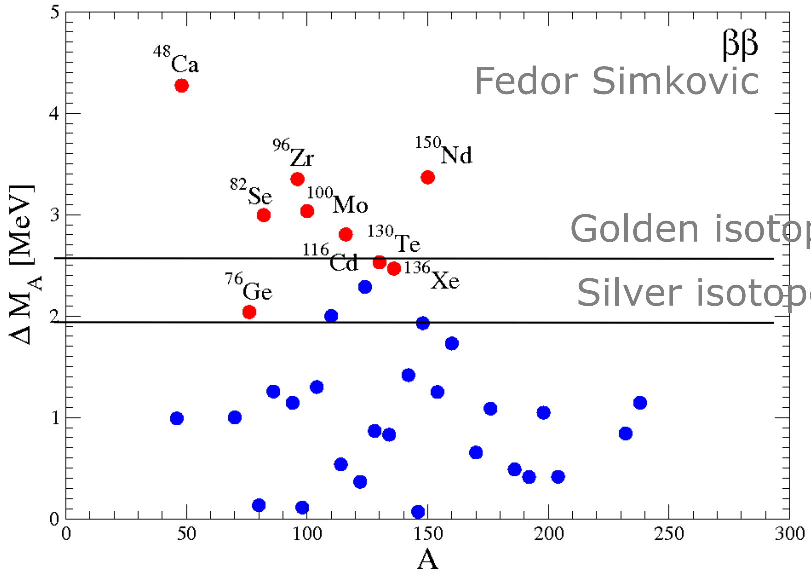


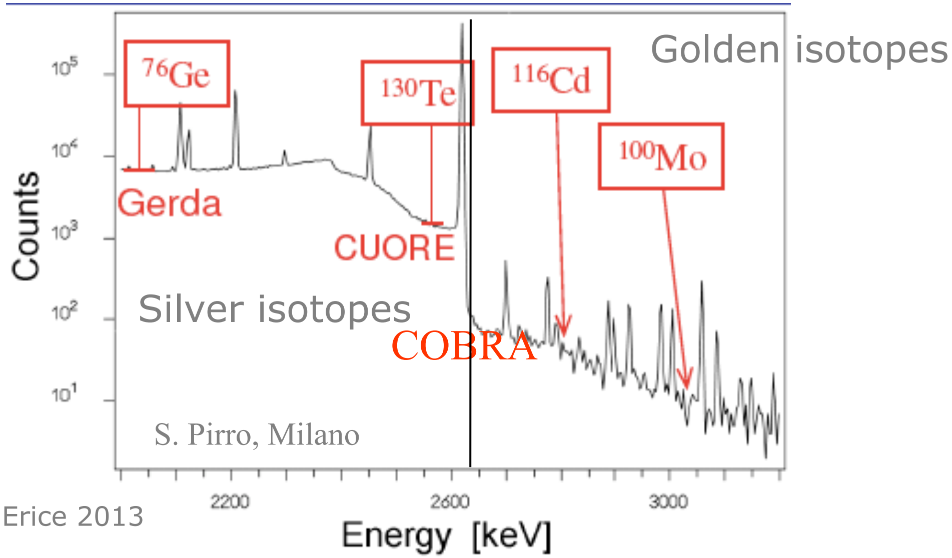
Isotopes

	nat. ab. (%)	Q (keV)	Decay mode
Zn70	0.62	1001	ß-ß-
Cd114	28.7	534	ß-ß-
Cd116	7.5	2813	ß-ß-
Te128	31.7	868	ß-ß-
Te130	33.8	2527	ß-ß-
Zn64	48.6	1096	ß+/EC
Cd106	1.21	2771	ß+ß+
Cd108	0.9	231	EC/EC
Te120	0.1	1722	ß+/EC

Advantages

- Source = detector
- Semiconductor (Good energy resolution, clean)
- Room temperature
- Modular design (Coincidences)
- Industrial development of CdTe detectors
- ^{116}Cd above 2.614 MeV
- Tracking („Solid state TPC")



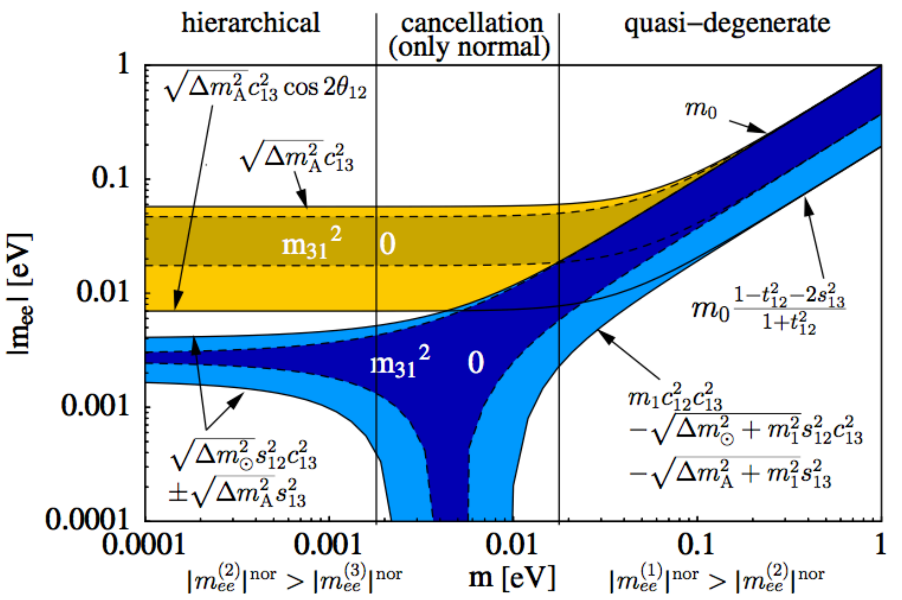


K. Zuber, Erice 2013

Mass hierarchies and DBD

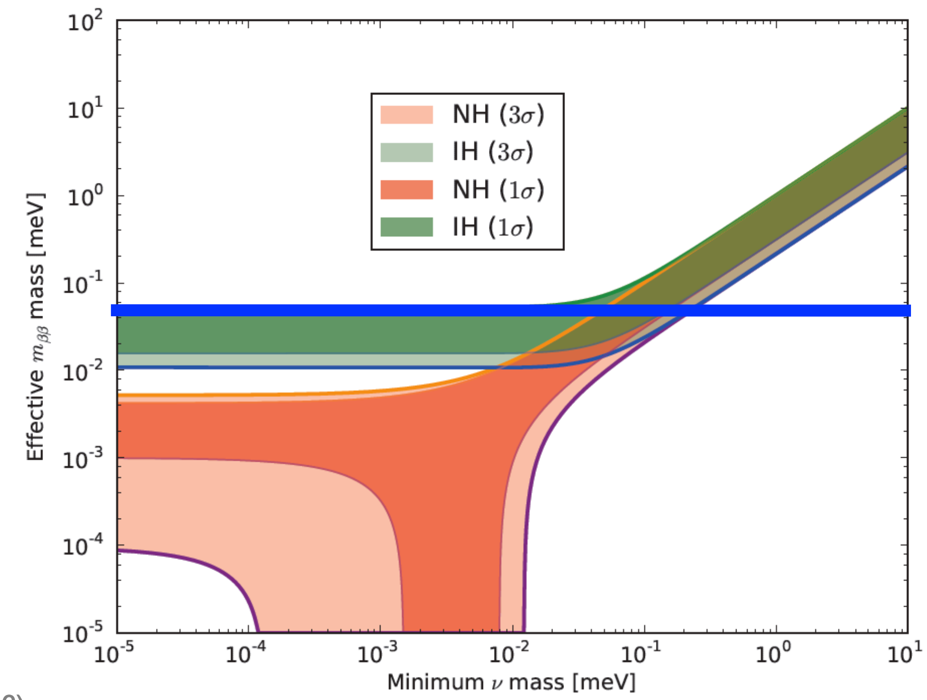
With the known oscillation results everything is fixed

General dependence



M. Lindner, A.. Merle, W. Rodejohann, Phys. Rev. D 73, 053005 (2006)

Current data



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Back of an envelope

iktp

This is the 50 meV option, just add 0‘s to moles and kgs if you want smaller neutrino masses

$T_{1/2} = \ln 2 \cdot a \cdot N_A \cdot M \cdot t / N_{\beta\beta}$ $(\tau >> T)$ (Background free)

For half-life measurements of 10^{26-27} yrs

1 event/yr you need 10^{26-27} source atoms

This is about 1000 moles of isotope, implying about 100 kg

Now you only can loose: nat. abundance, efficiency, background, ...

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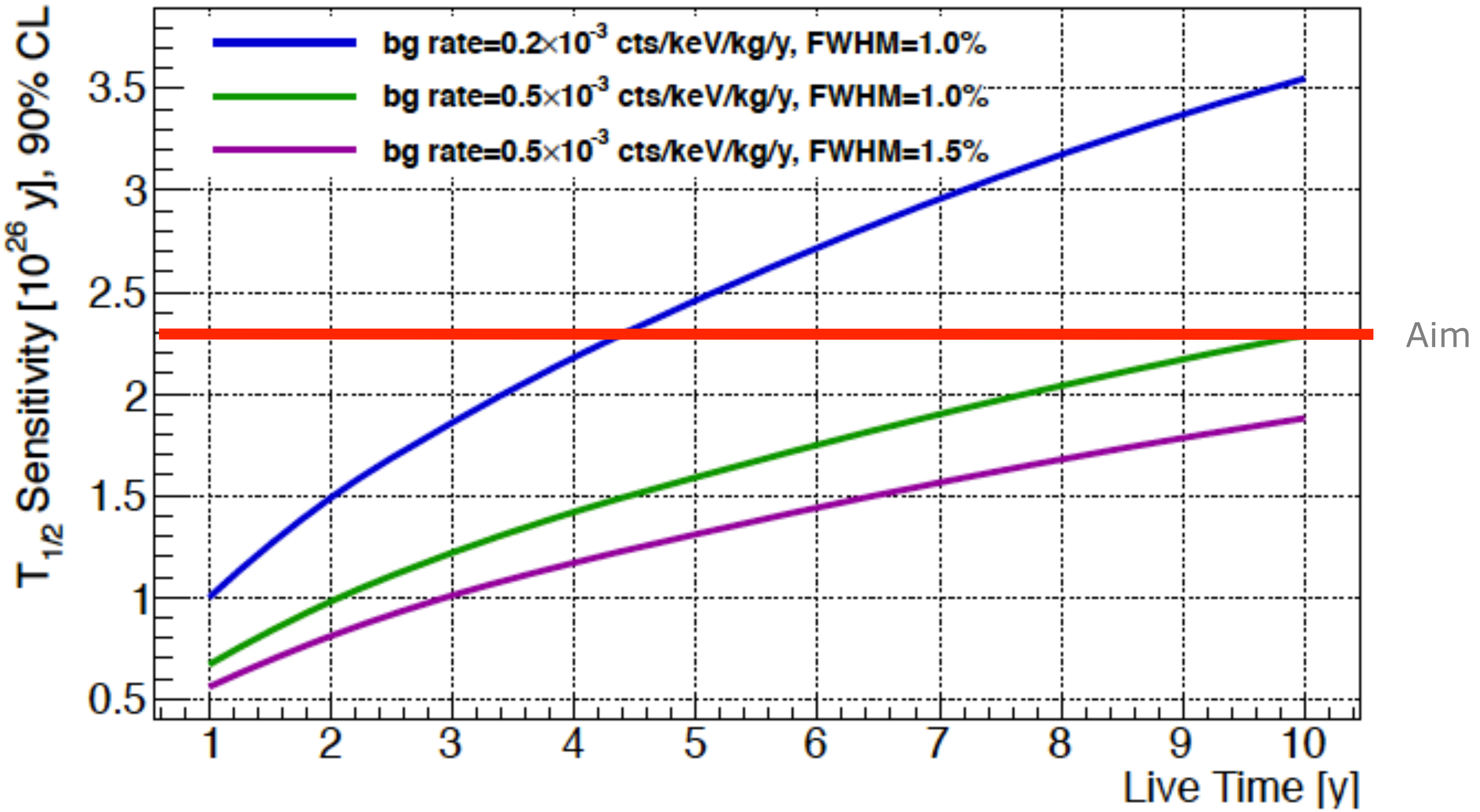
What does it mean for 116Cd?

Final number depends on used nuclear matrix element



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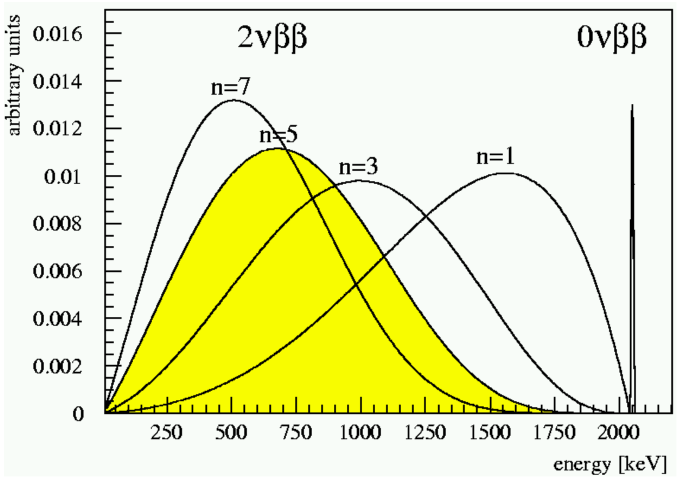
Spectral shapes

0νββ: Peak at Q-value of nuclear transition

Sum energy spectrum of both electrons



Measured quantity: Half-life

$1 / T_{1/2} = PS * NME^2 * (<m_\nu> / m_e)^2$

Experimental sensitivity depends on

$$T_{1/2}^{-1} \propto a\varepsilon\sqrt{\frac{Mt}{\Delta E B}}$$ (BG limited)

$$T_{1/2}^{-1} \propto a\varepsilon M t$$ (BG free)

If background limited $m_\nu \propto \sqrt[4]{\frac{\Delta E B}{Mt}}$

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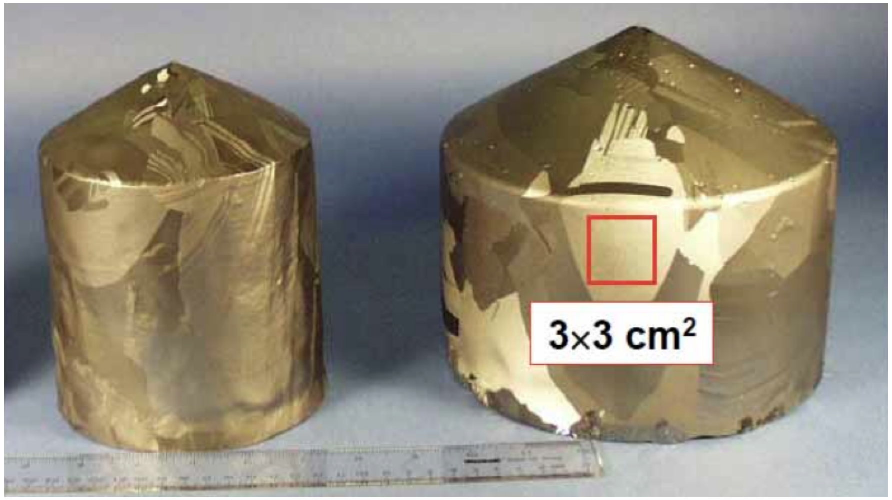
Cadmium-Zinc-Tellurid (CZT)

Properties as radiation detector

- Intrinsic II-VI-semiconductor (no doping necessary)
- Wide bandgap E_g=1,56 eV -> highly resistive (R_s=10^{11} Ωcm)
- High mean atomic number and density ($Z\approx 50$, ρ=5.8 g/cm^3)
- Electron Mobility:

  $(\mu\tau)_e = 1 \times 10^{-2}$ cm^2/V
- Hole Mobility:

  $(\mu\tau)_h = 5 \times 10^{-5}$ cm^2/V
- Ionic binding -> susceptible to lattice distortions
- High density of charge traps

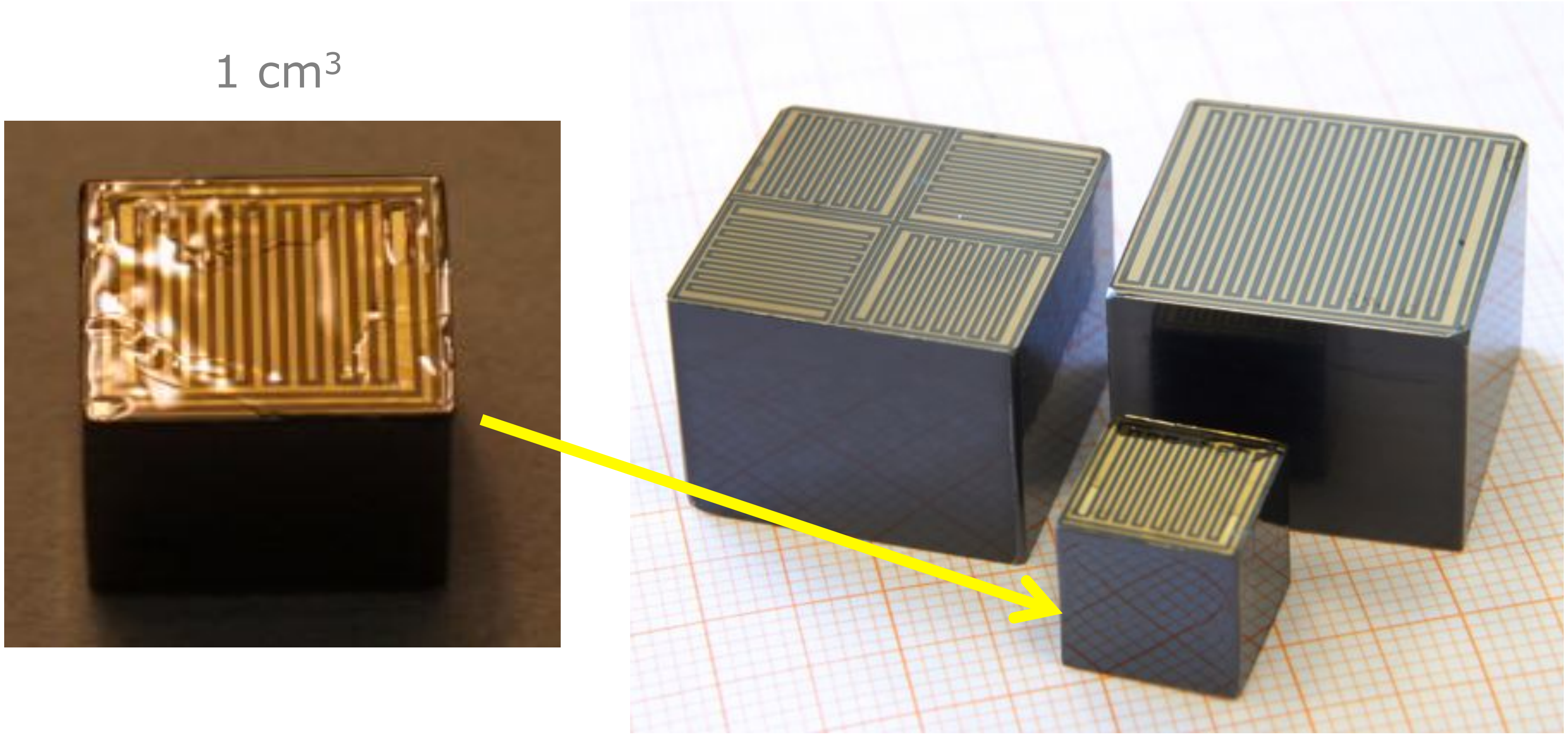


CZT-ingots manufactured by eV Microproducts

Default – CPG detectors

Energy measurement only

1 cm^3



Major exp. step: Installation of 64 1cm^3 CZT detectors at LNGS

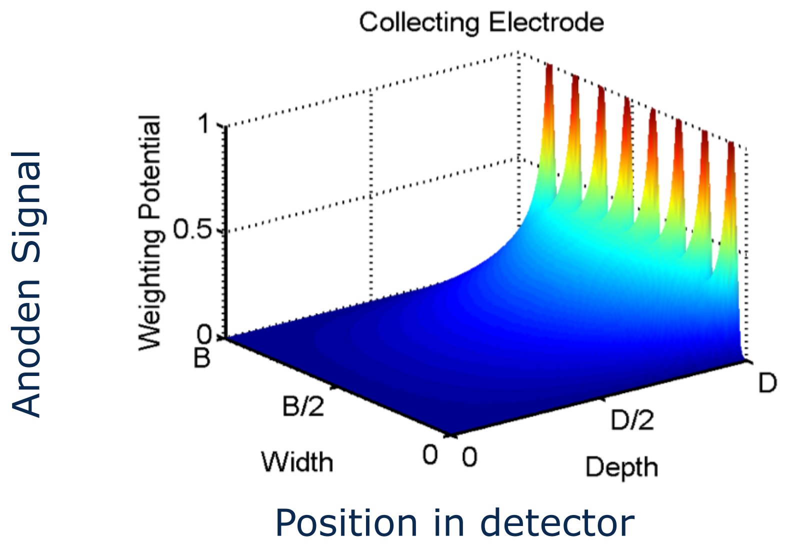
CPG detectors

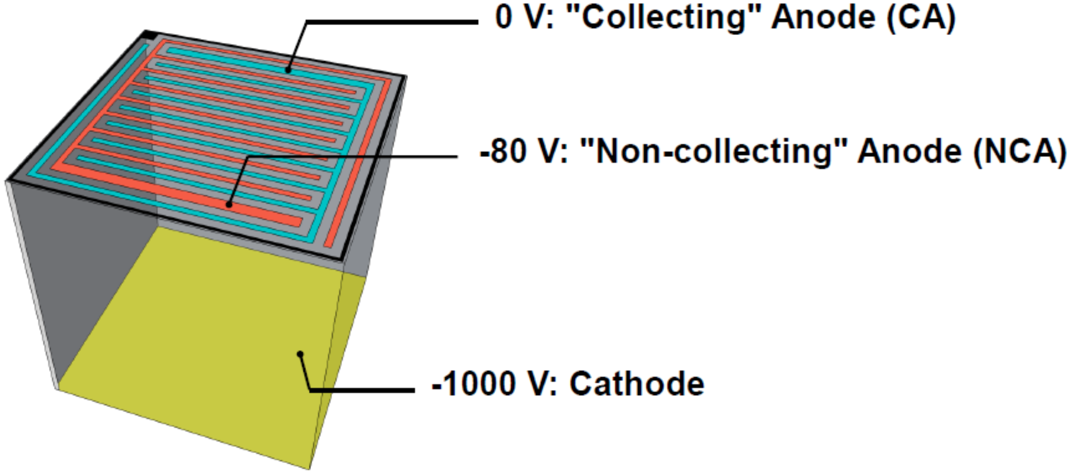
CPG = coplanar grid detectors

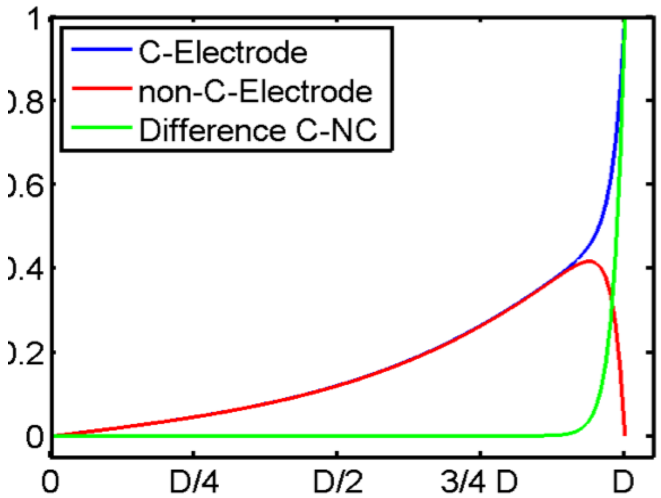
Mobility and trapping of charge carriers quite different

Frisch grid principle of wire chambers applied to CZT

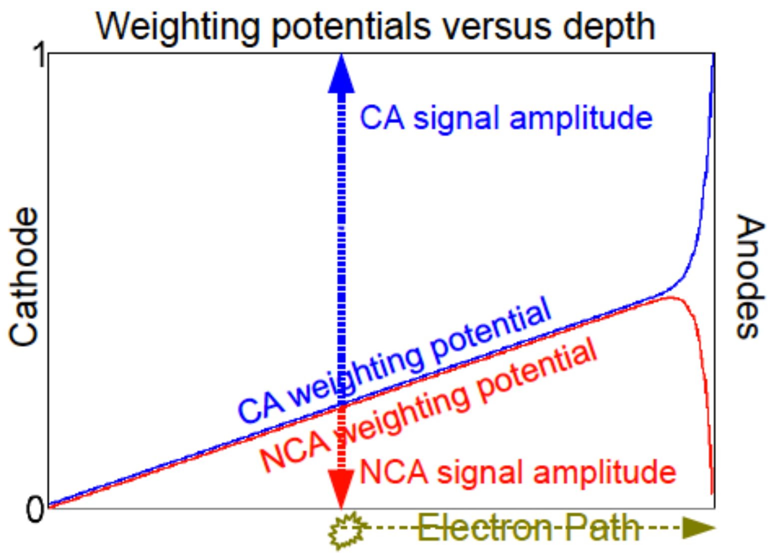
(P. Luke, IEEE Trans. NS 42, 207 (1995))

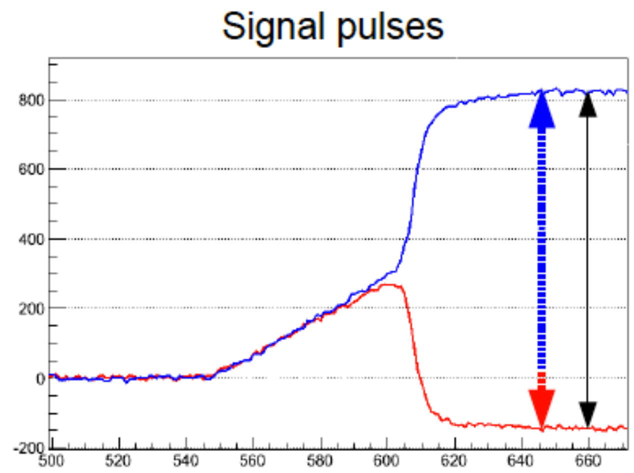






CPG principle and Ramo weighting potential





- $CA - NCA$ proportional to energy (electron signal only)

- BONUS: can determine interaction depth:

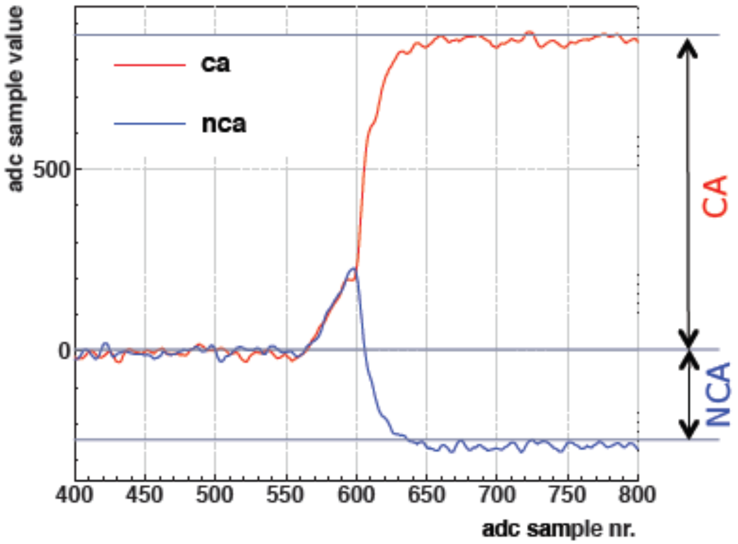
$$z = \frac{CA + NCA}{CA - NCA}$$

Distance from anode plane
0 = anode, 1 = cathode
(monotonic but not linear)

(also energy and depth can be corrected for trapping effects)

M.Fritts et al, NIM A, Volume 708, 21 April 2013, Pages 1-6, http://dx.doi.org/10.1016/j.nima.2013.01.004

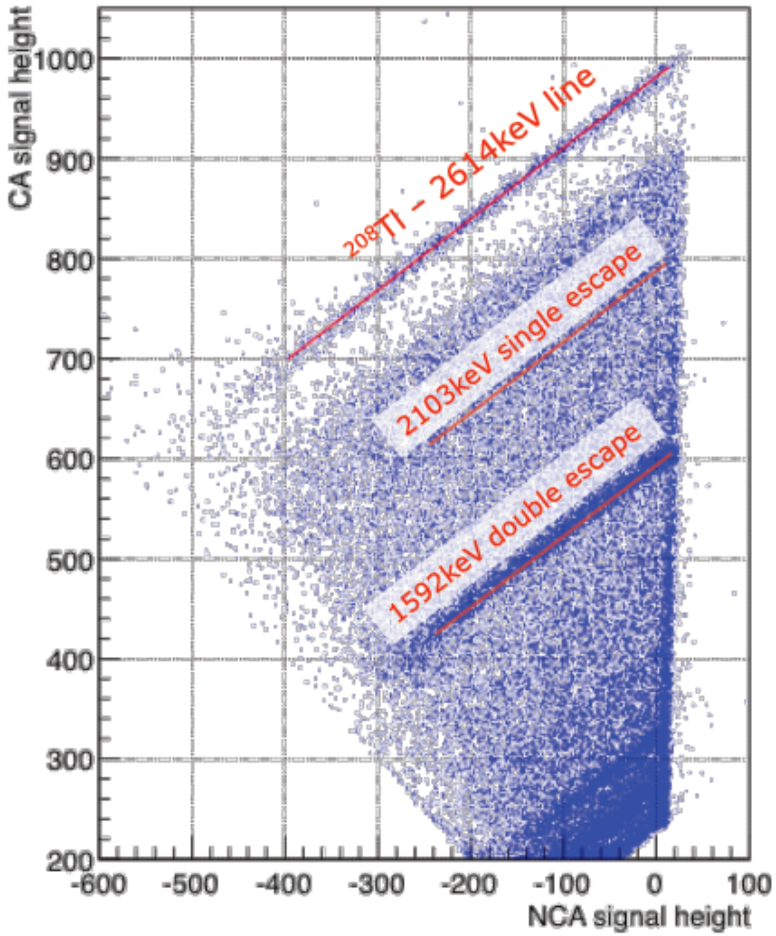
Weighting function



$$(\mu\tau)_e \propto \frac{1+wf}{1-wf} \qquad Q \propto CA - wf\ NCA$$

correction of charge trapping by empirical determination of the weighting factor wf

^{228}Th calibration data



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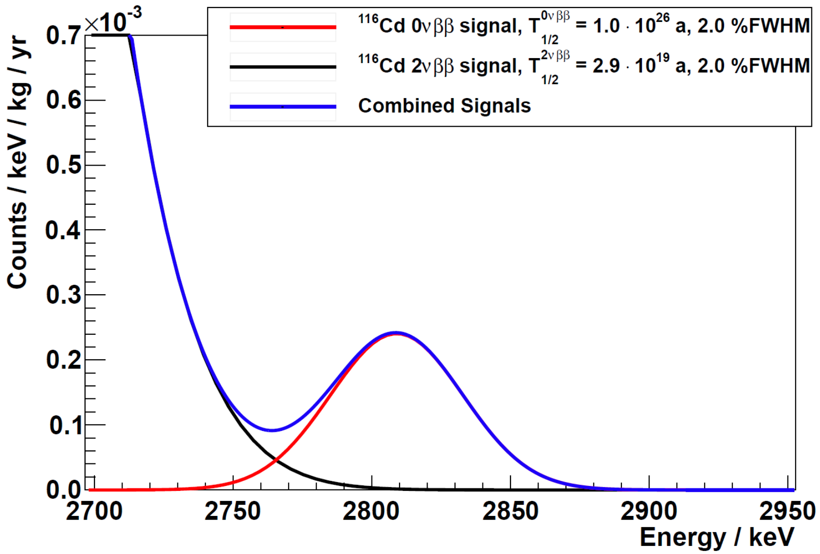
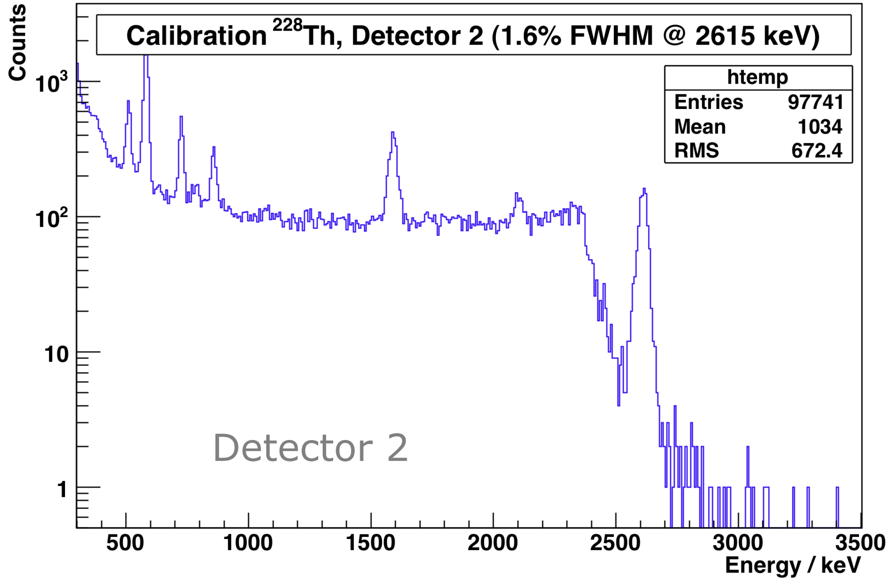
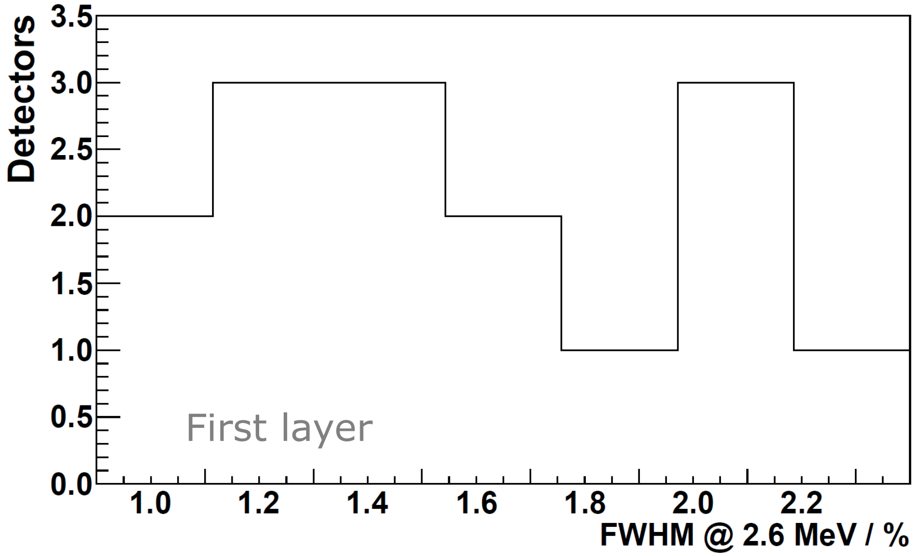
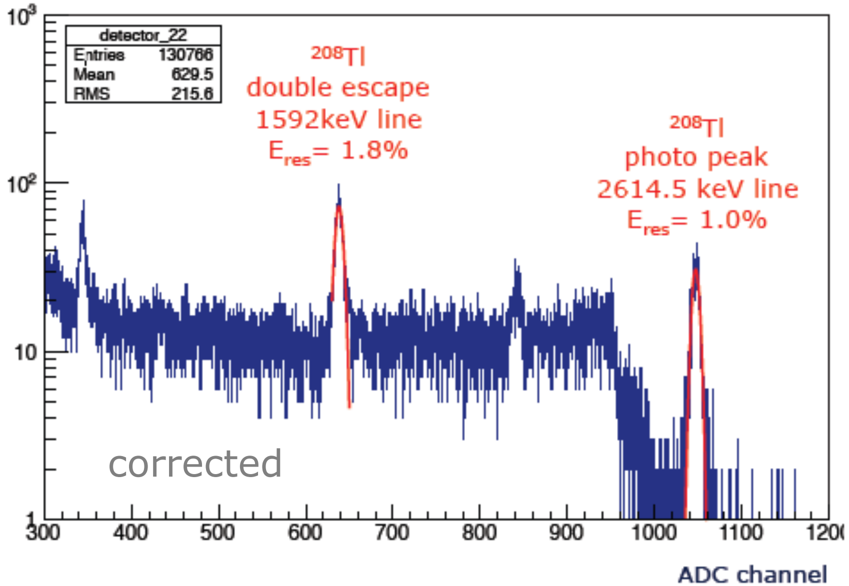
Energy resolution

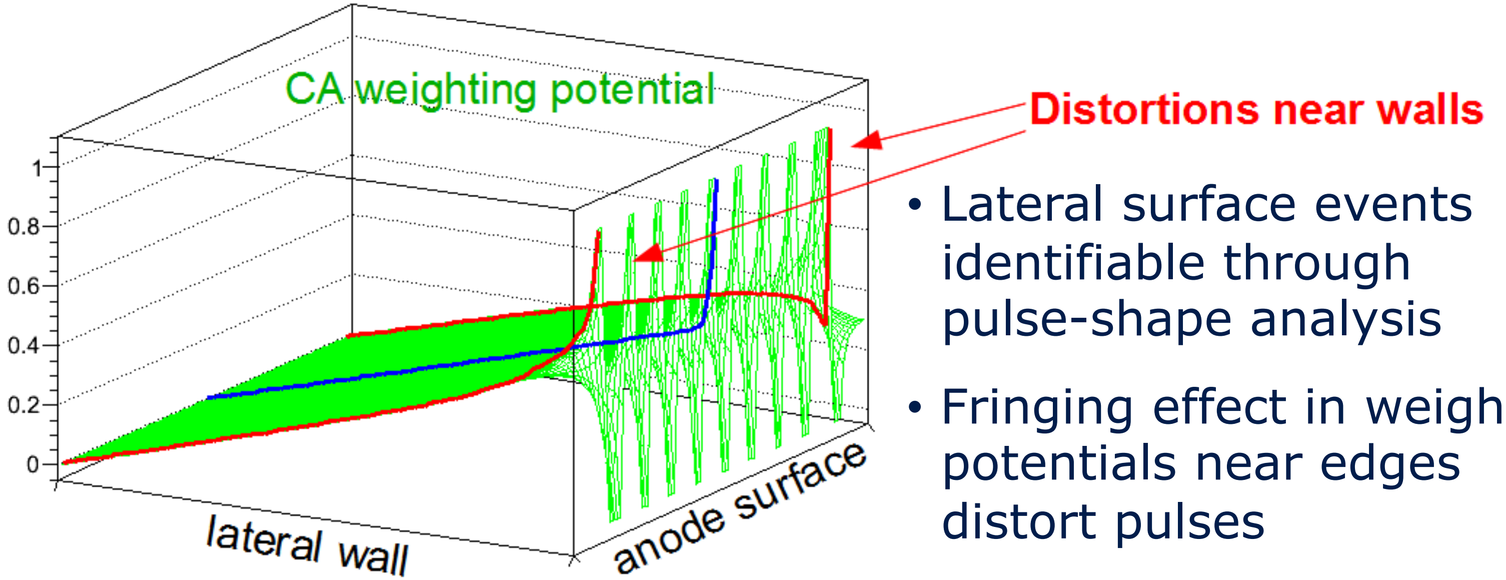




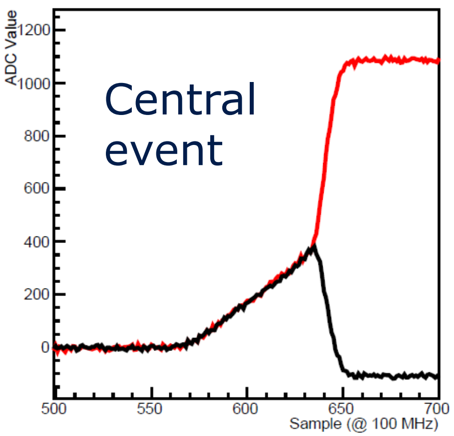


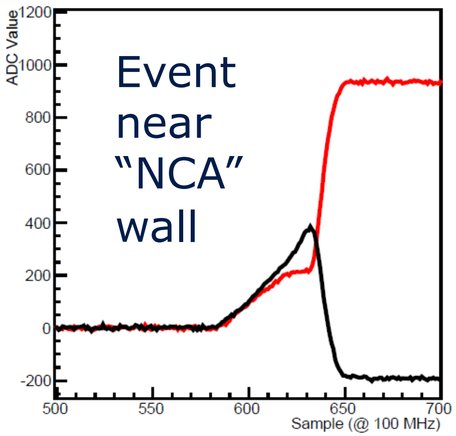


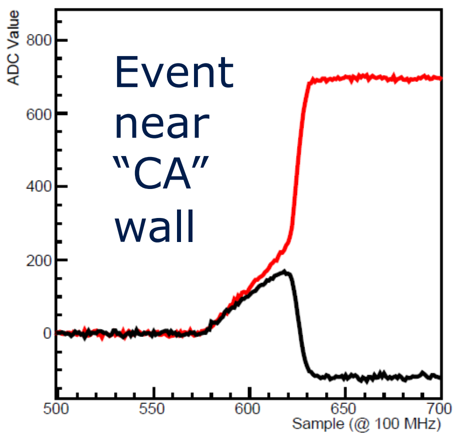
Lateral wall events



- Lateral surface events identifiable through pulse-shape analysis
- Fringing effect in weighting potentials near edges distort pulses







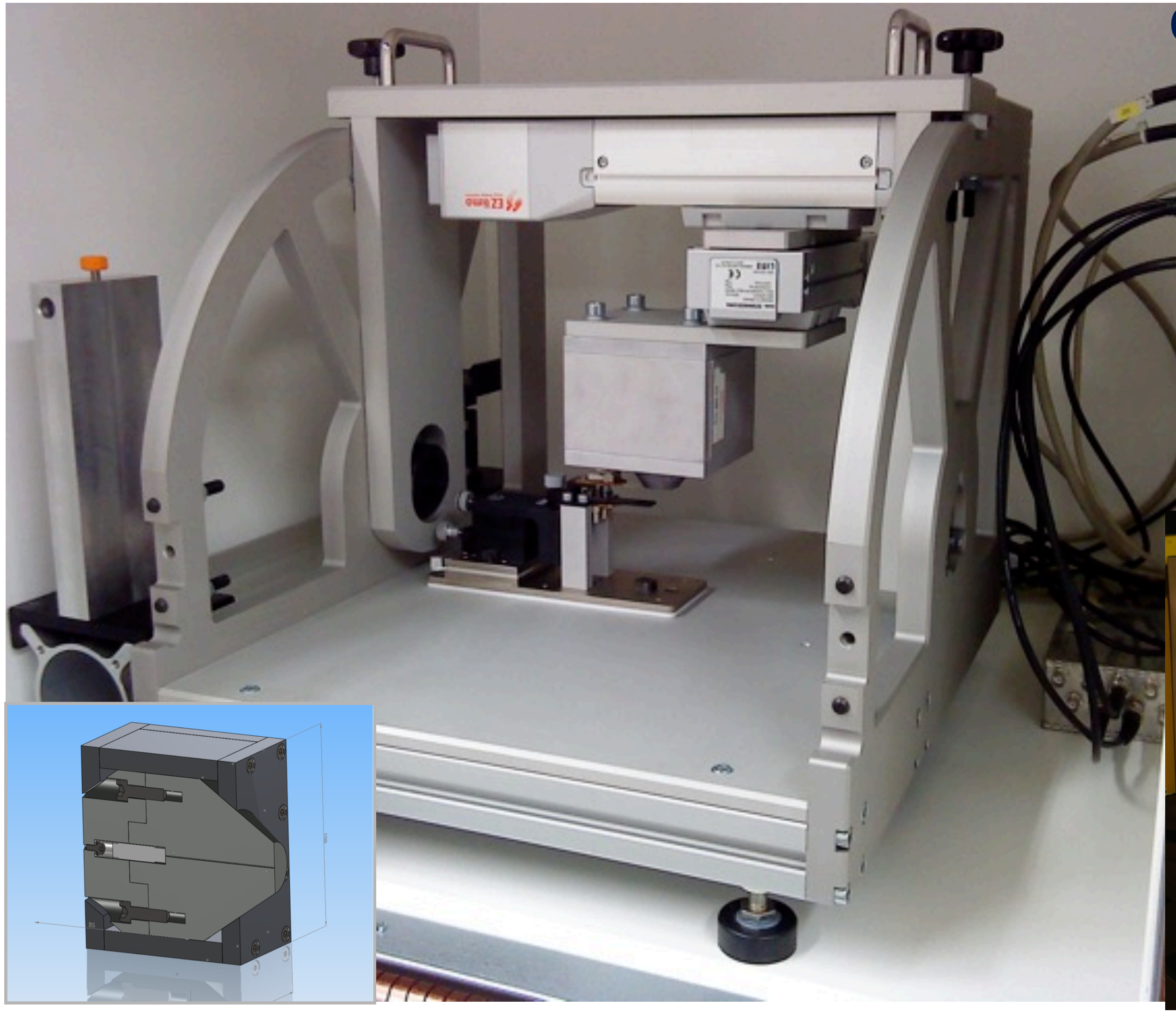
Underground - LNGS

Recently upgraded into the former Heidelberg-Moscow hut

The 64 detector array

Detector tomography

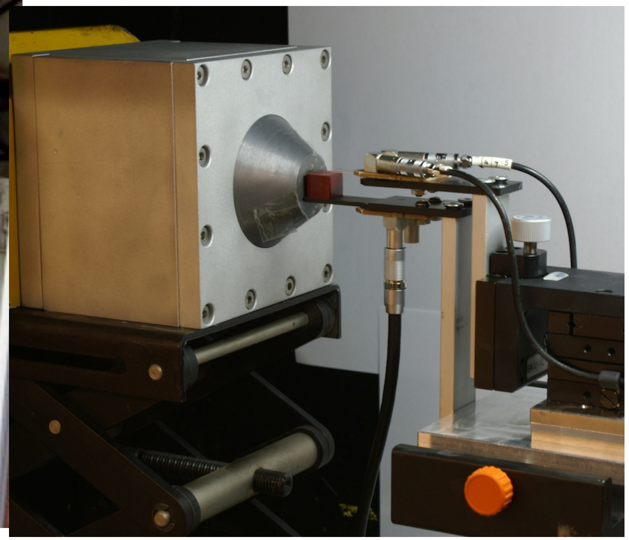
First step: Flushing calibration



Second step: Scanning

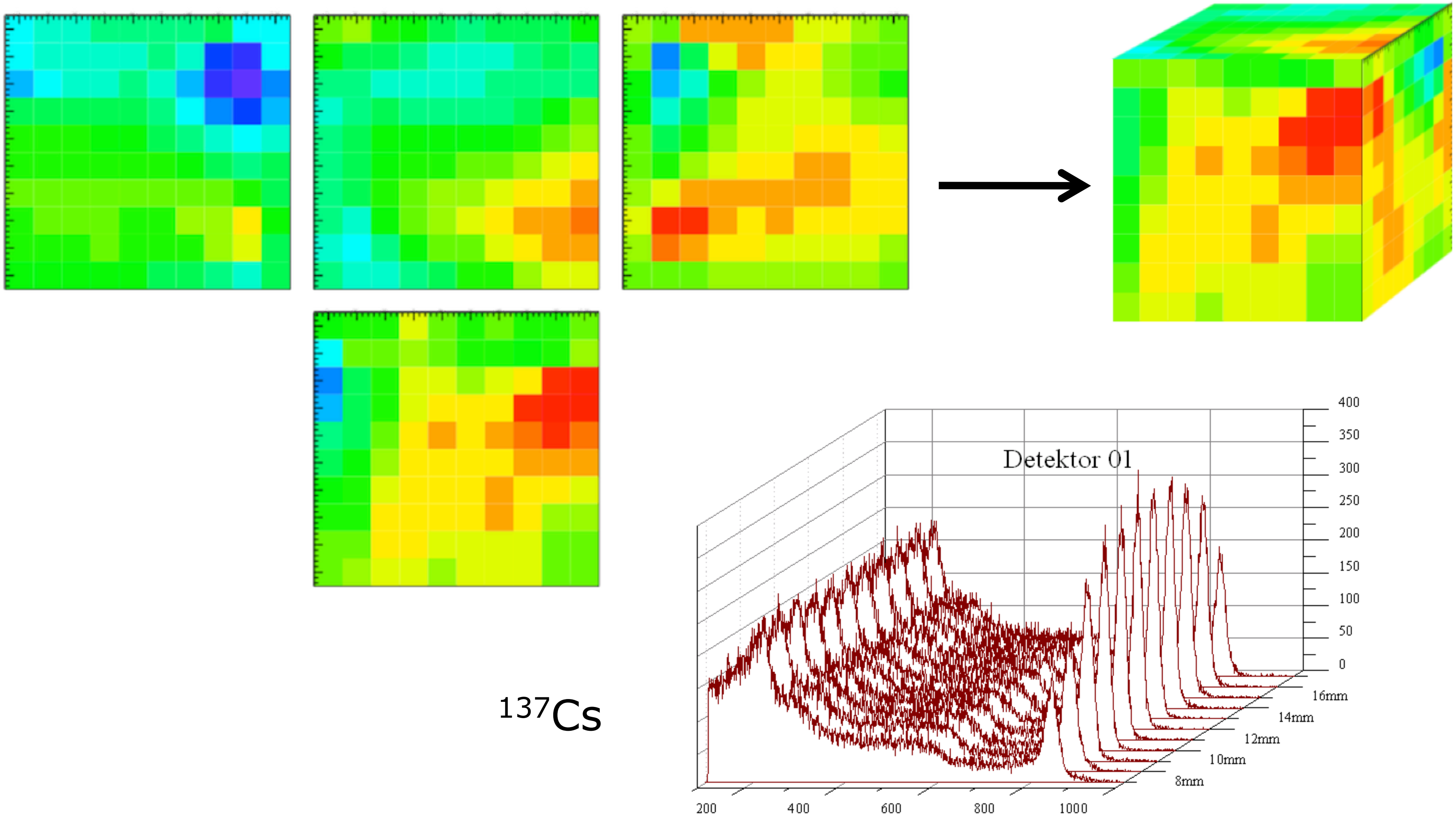
Collimator-channel

- 6cm length
- 500µm diameter
- Opening angle <1°
- Special resolution: <1mm
- 100MBq ^{137}Cs



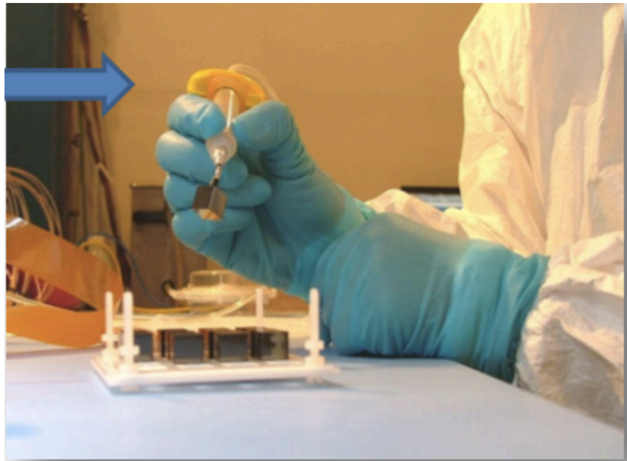
Detector tomography

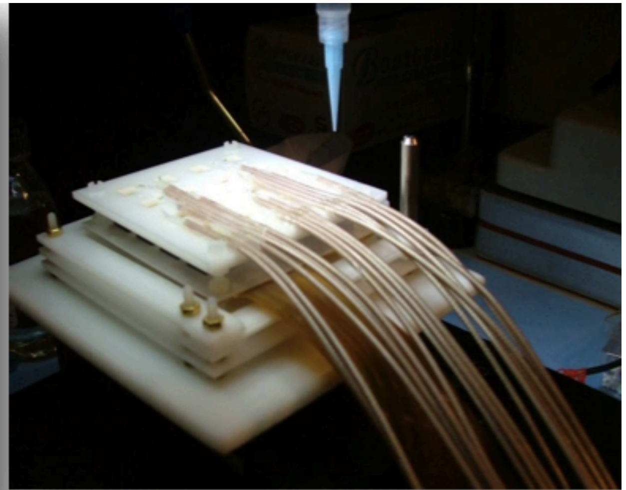
Pulse shapes recorded, efficiency determination

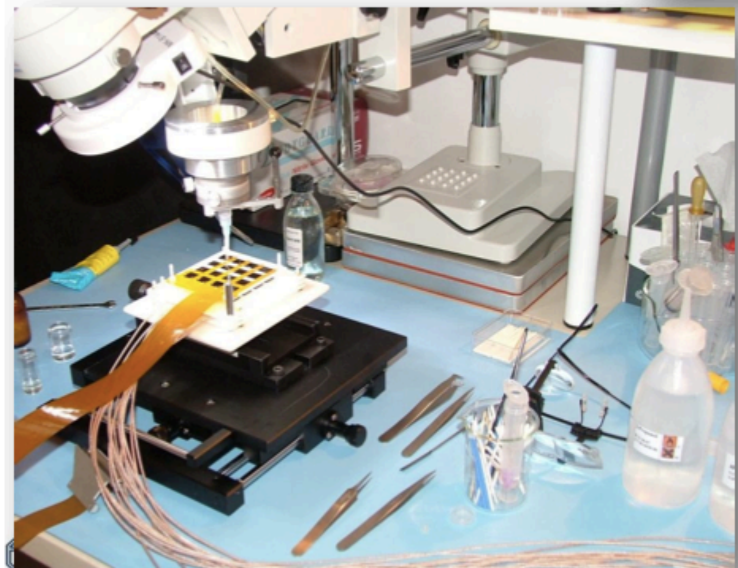


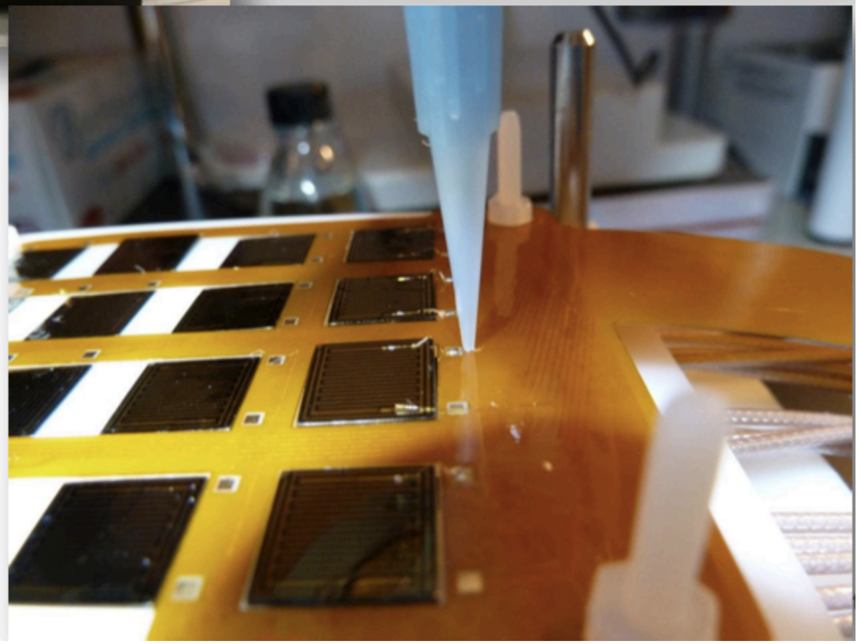
^{137}Cs

Impressions – Contacting at LNGS

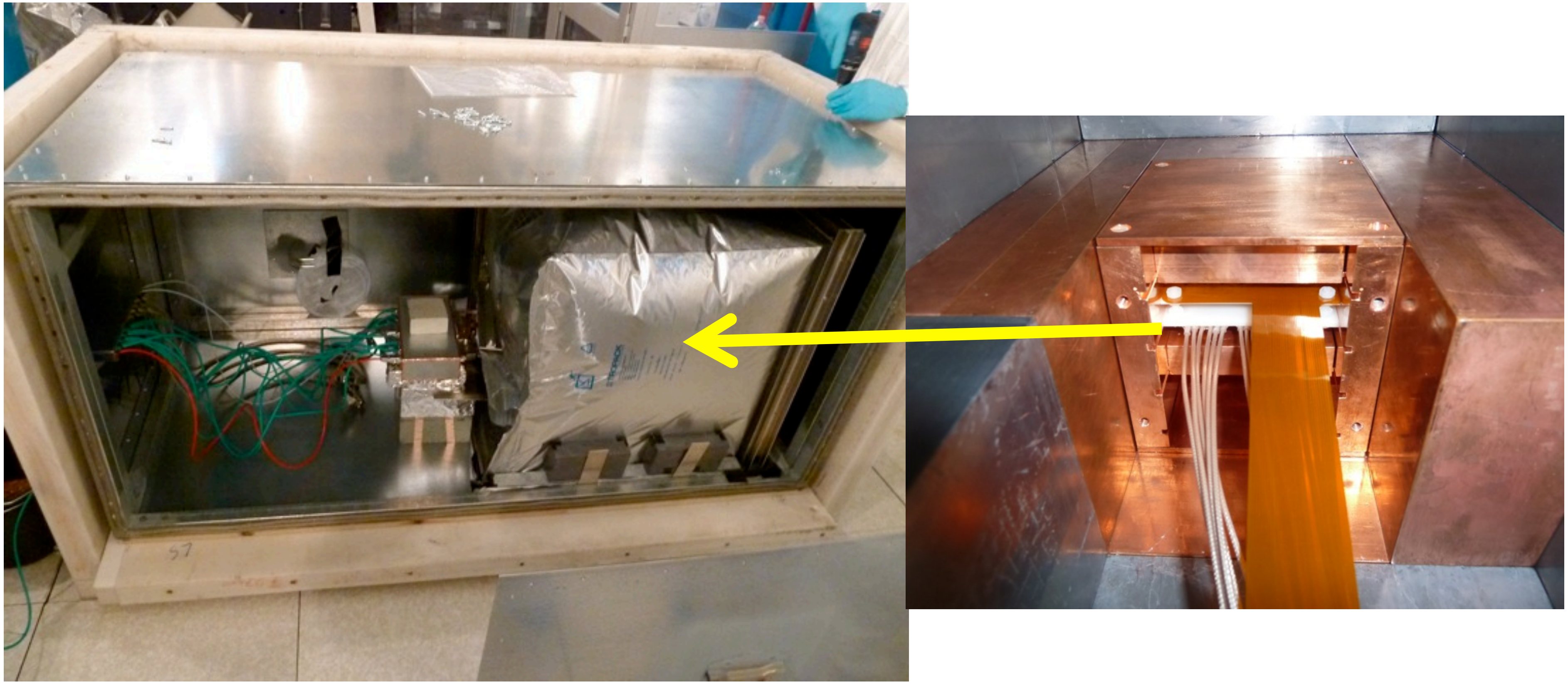








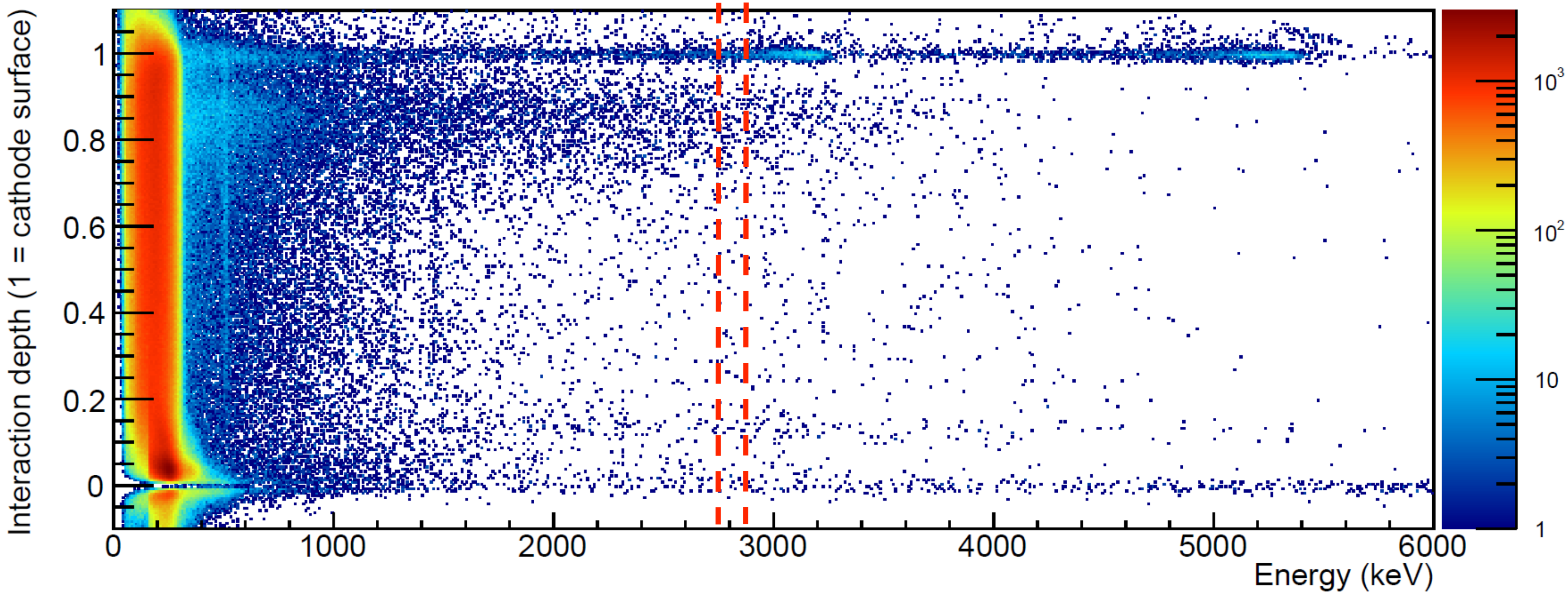
Installation



First layer installed in November 2011, second layer in March 2012,
3rd layer in June 2013, last one until end of the year, electronics already in place

Event distribution in detectors

82.3 kg days



Pulse amplitudes provide both energy and interaction depth

improved event reconstruction:
M. Fritts, J. Durst, T. Göpfert, T.Wester and K. Zuber, Nucl. Instrum. Meth. A 708 (2013), pp. 1-6)

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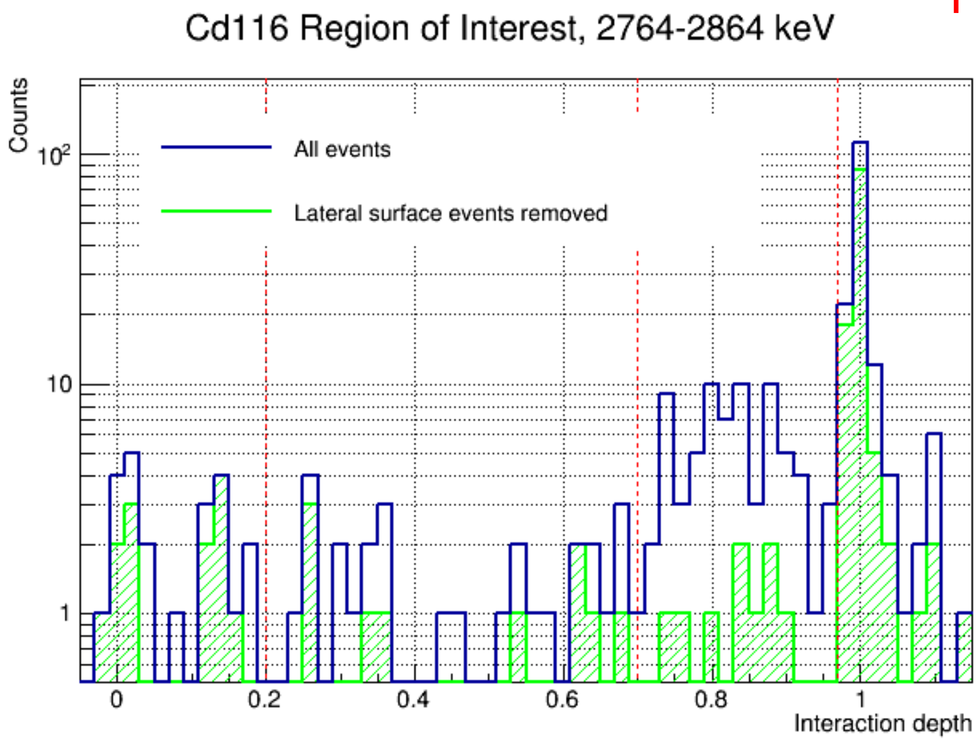
Event distribution signal region

Preliminary



Cathode events and lateral wall events dominate

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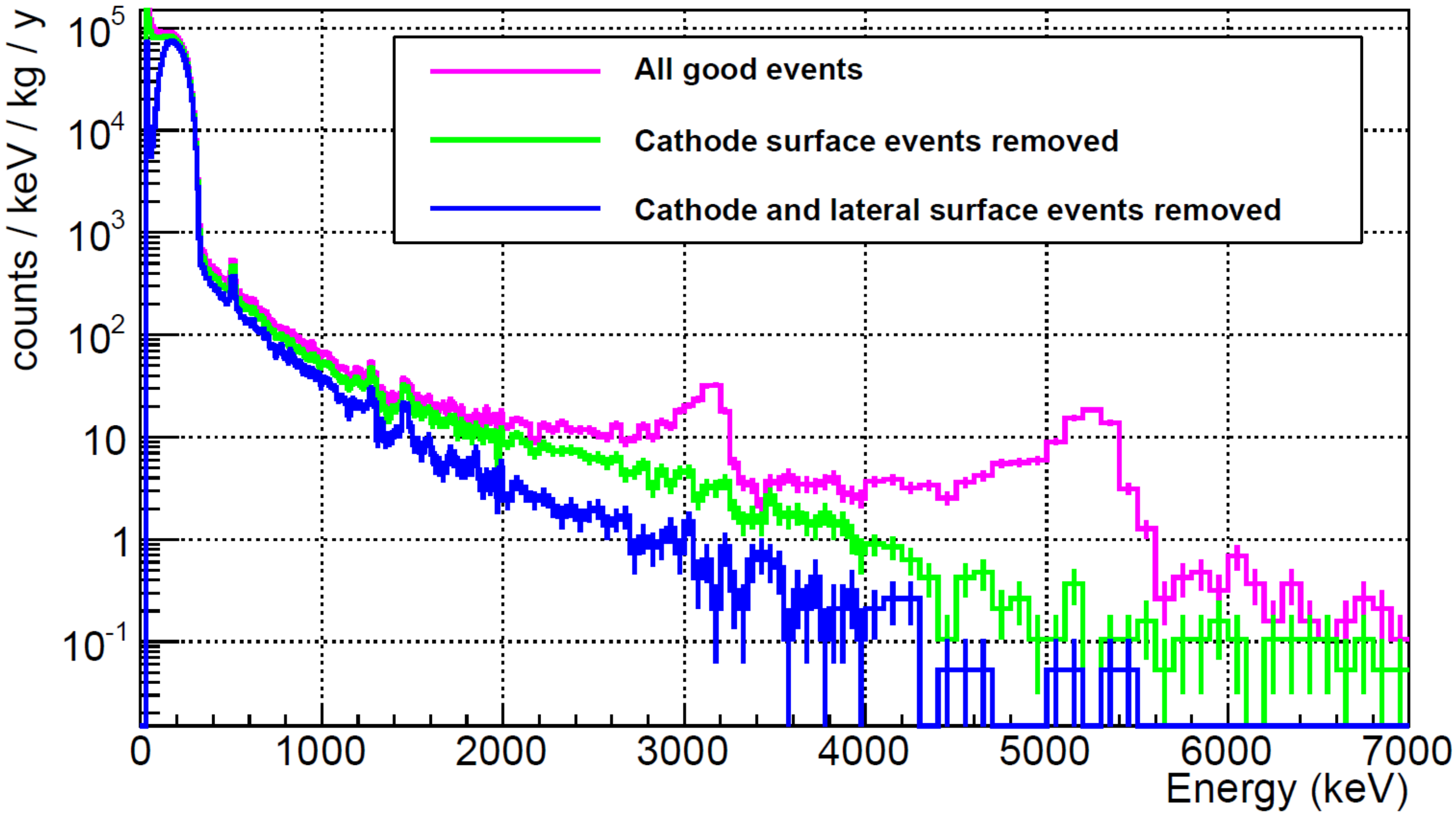
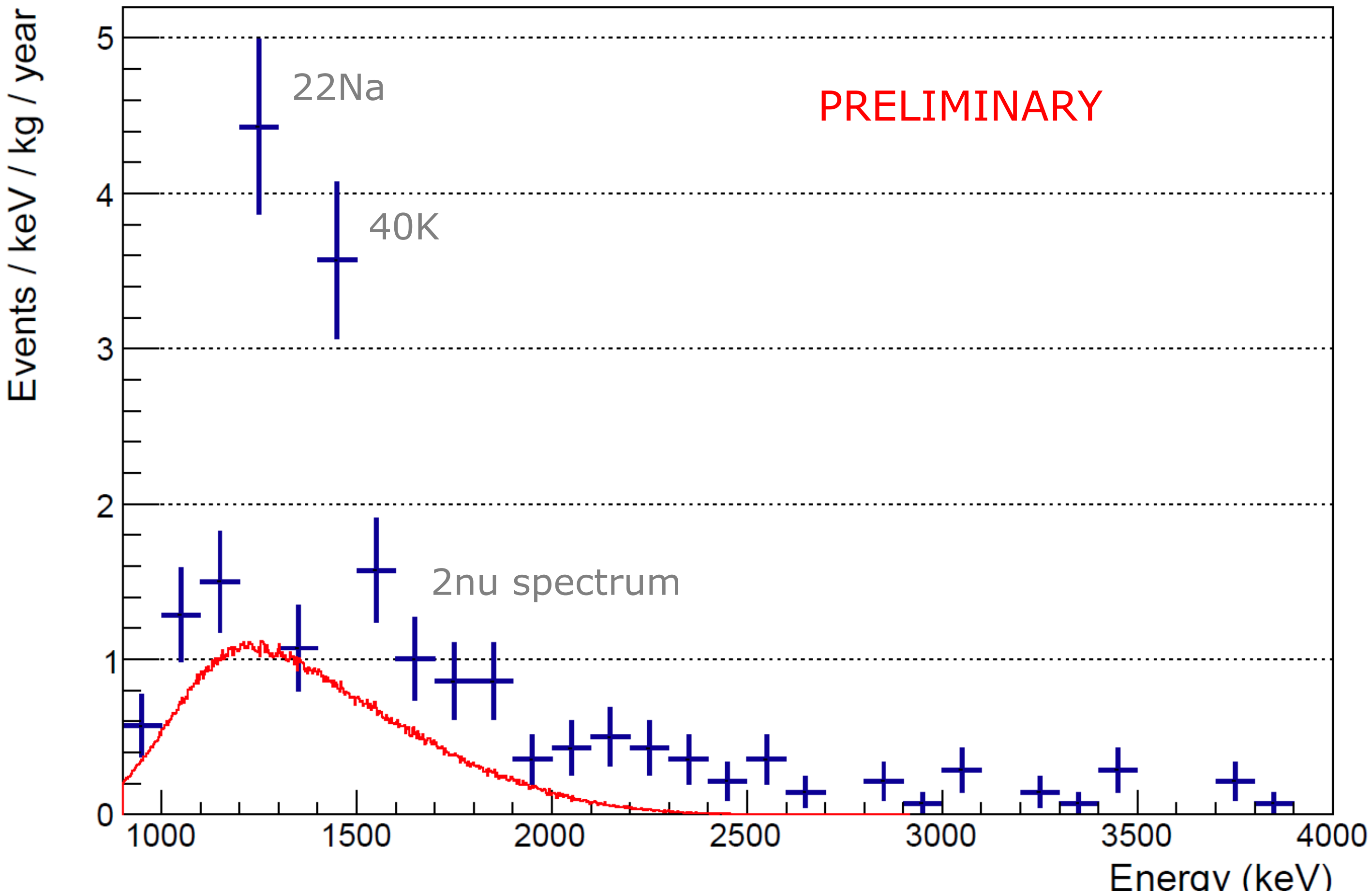
Energy spectrum

COBRA-0ν2β Experiment



Background reduction through identification of surface events

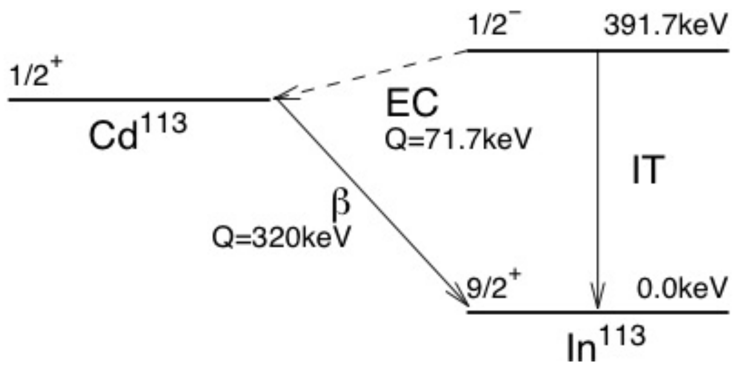
After all cuts

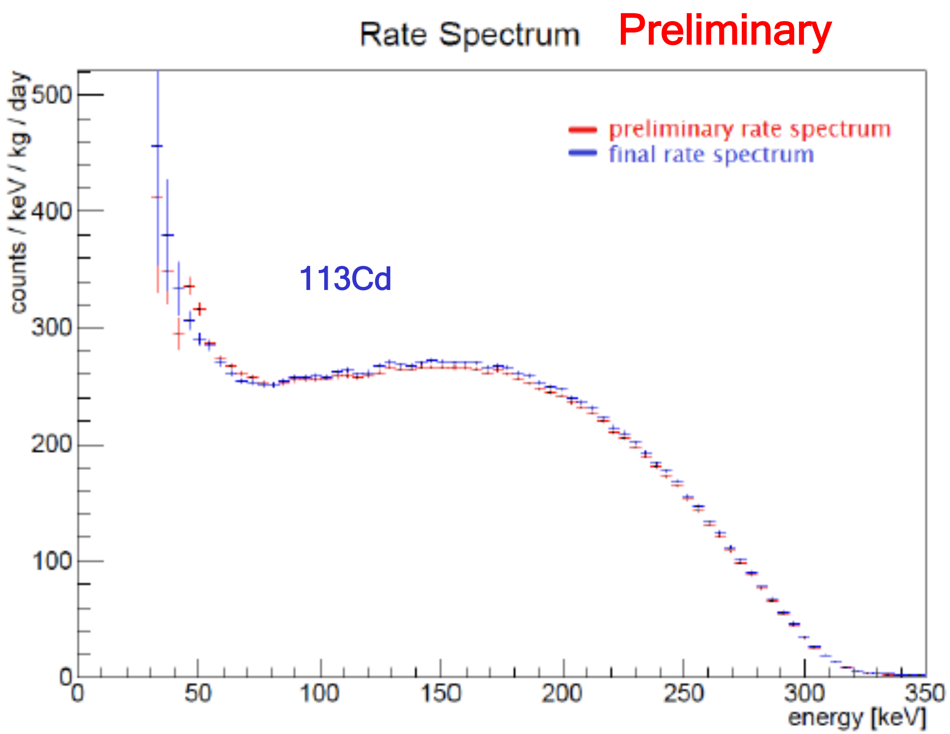


2nu DBD now significant part of the spectrum

Other things – ^{113}Cd

4-fold non-unique beta decay ($1/2^+ \rightarrow 9/2^+$)





Half-life:

$$T_{1/2} = 8.00 \pm 0.11(stat.) \pm 0.24(sys.) \times 10^{15} \text{ years}$$

48 independent measurements of the half-live!

Q-value:

$$322 \pm 0.3(stat.) \pm 0.9(sys.) \text{ keV}$$

J. V. Dawson et al., Nucl. Phys. A 818,264 (2009)

Fits extremely well to AME 2012

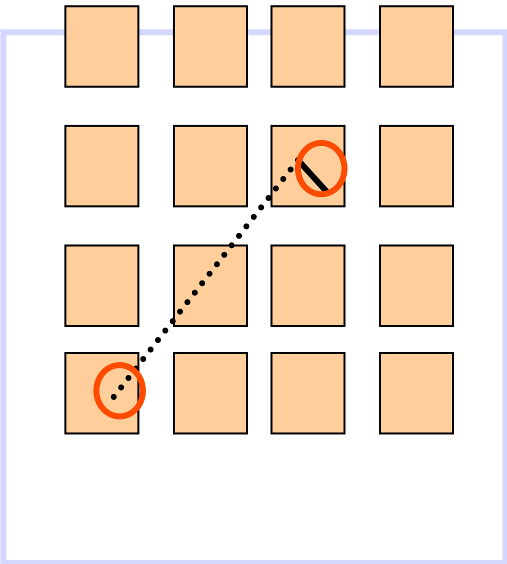
Next: Spectral shape

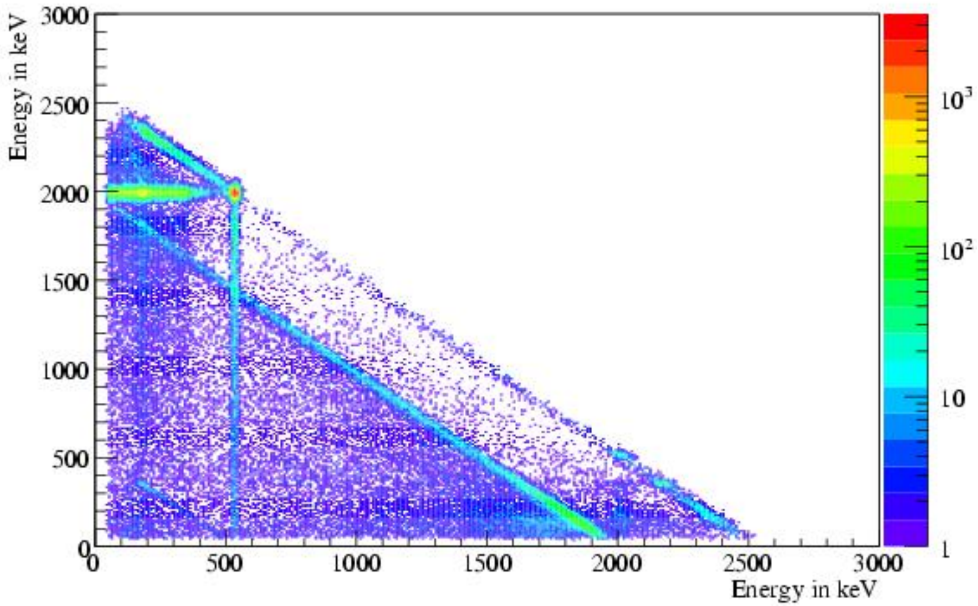
Microscopic calculation:

M. T. Mustonen, M. Aunola, J. Suhonen , PRC 73,054301 (2006)
M. T. Mustonen, J. Suhonen,, PLB 657,38 (2007)

Other things - coincidences

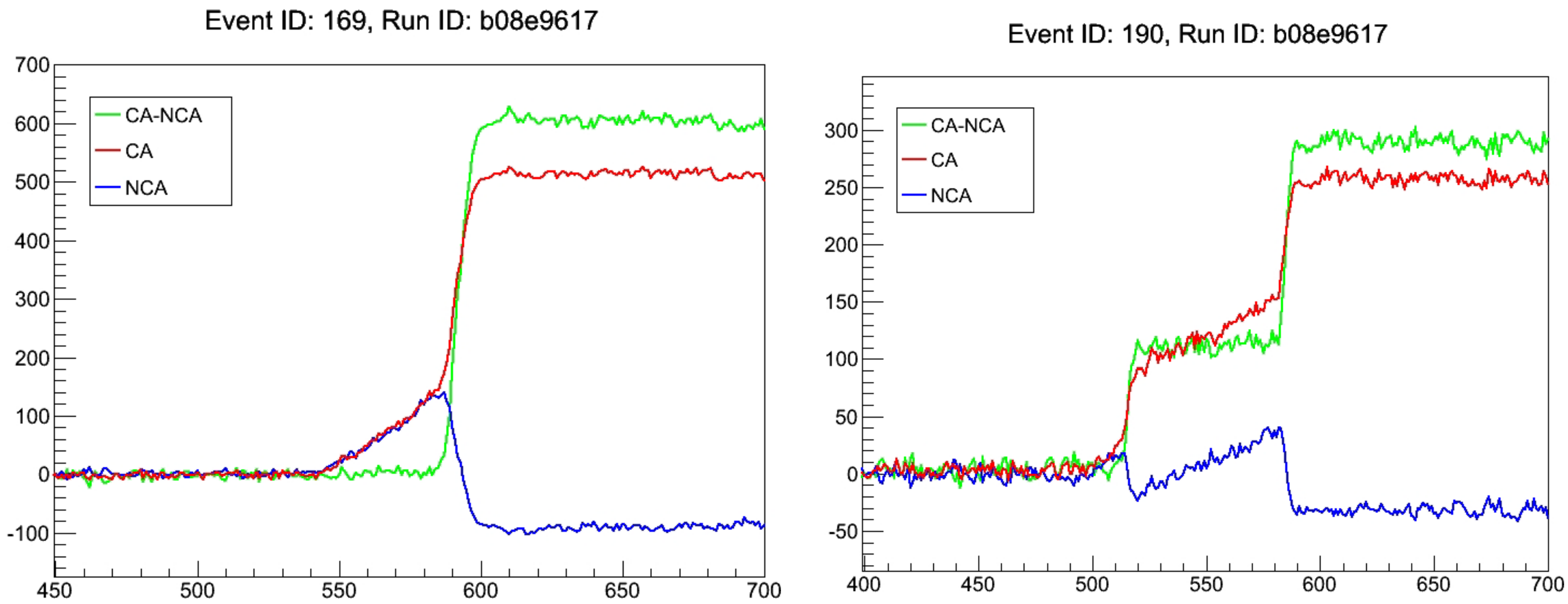
$$^{130}Te \rightarrow {}^{130}Xe^{*} + 2e^{-} + \gamma(536keV)$$





Searches for excited states, beta+ modes, furthermore useful tool for background reduction...

Outlook - Single site vs multiple site



Not used yet

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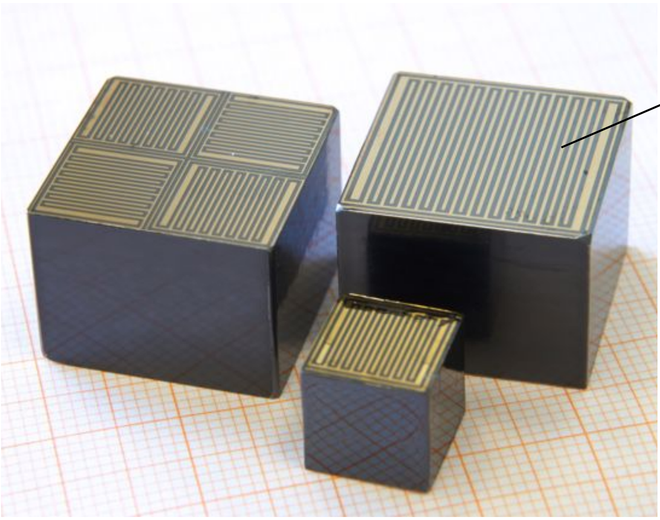
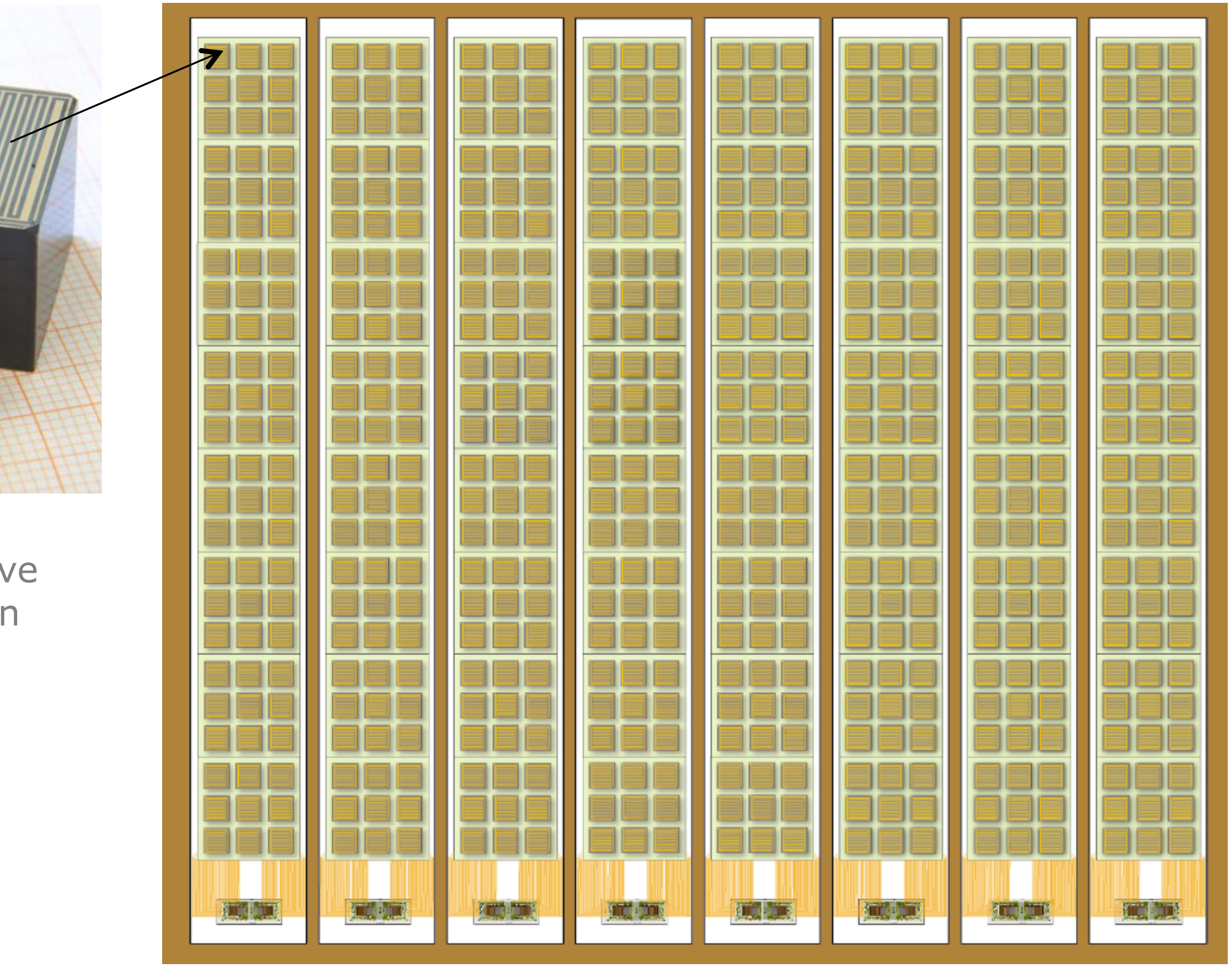
Large scale experiment

Strongly modular design:
-Basic building block : module 3x3 array of 2x2x1.5 cm^3 detector
-1 ladder cointains 8 modules, 1 layer contains 8 ladders, build several layers (towers)



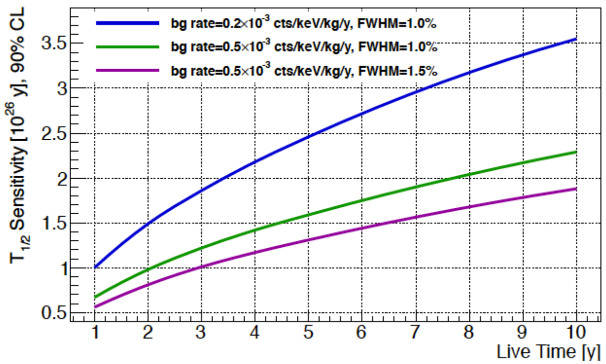


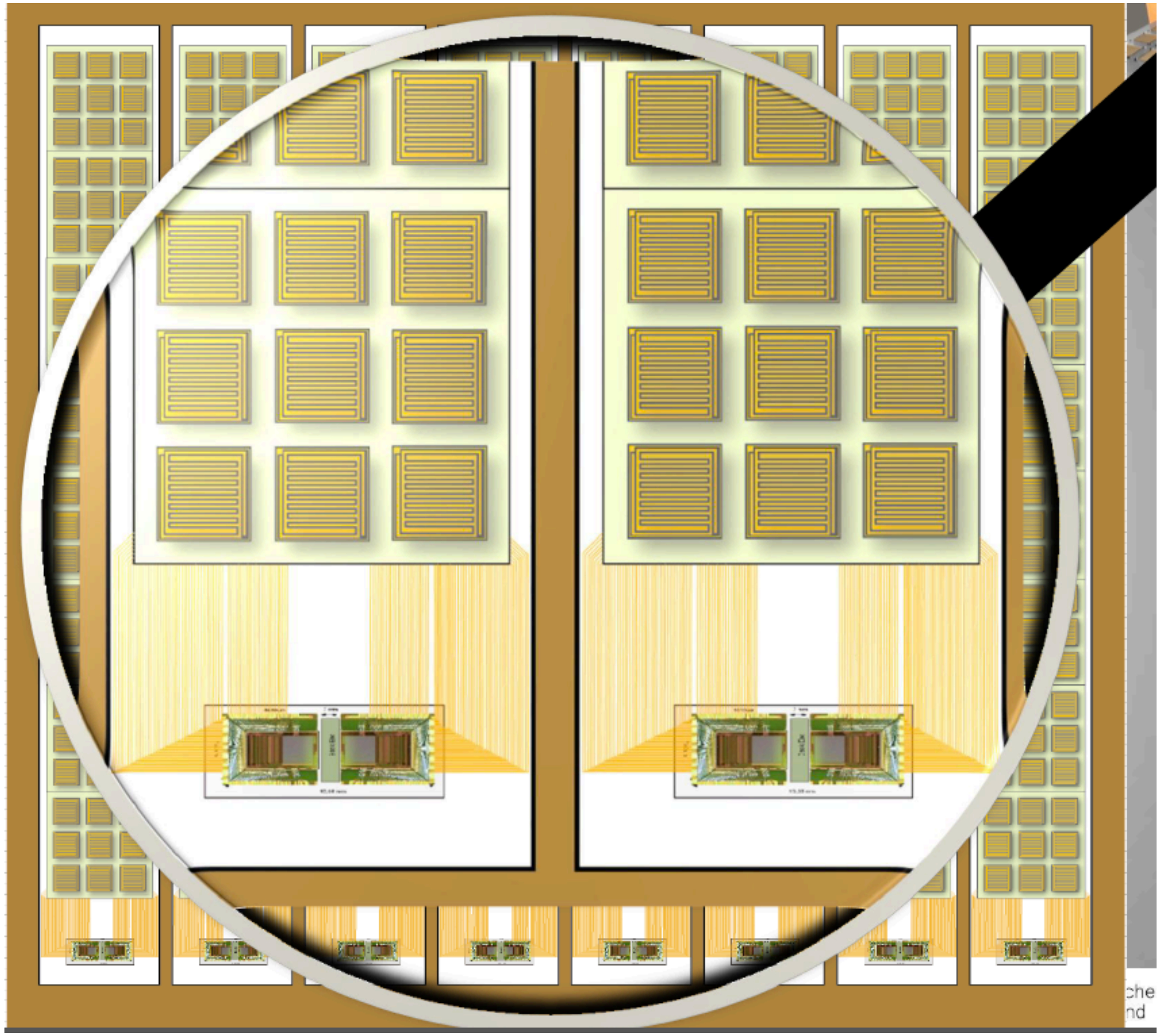
Monte Carlo simulations have shown that never more than 10 detectors will fire

Large scale experiment

ASICs and FPGA readout

A total of about 10000 detectors is needed





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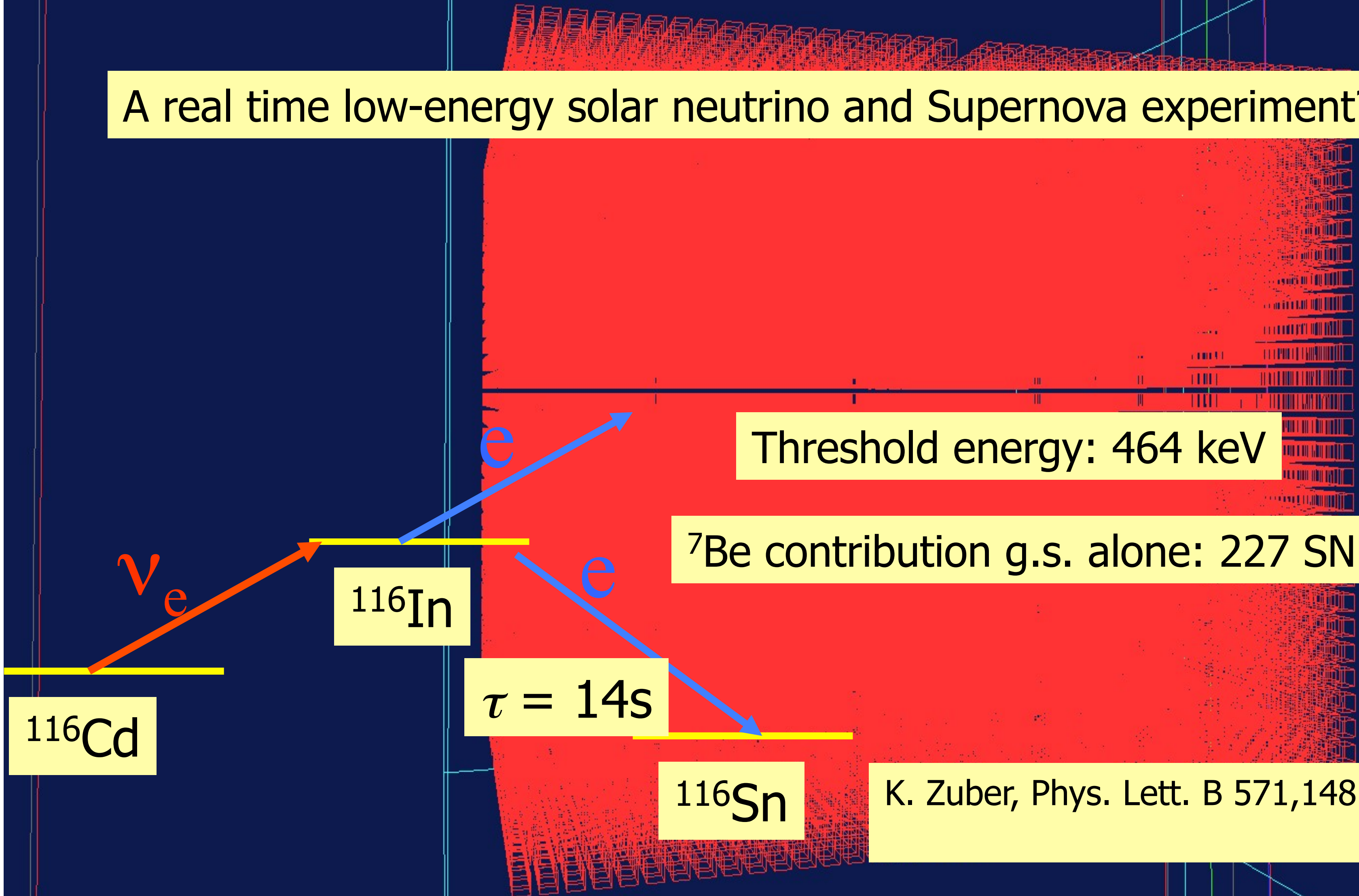
A REAL large scale experiment

A real time low-energy solar neutrino and Supernova experiment?



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

Supernova detection

NC interactions:

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

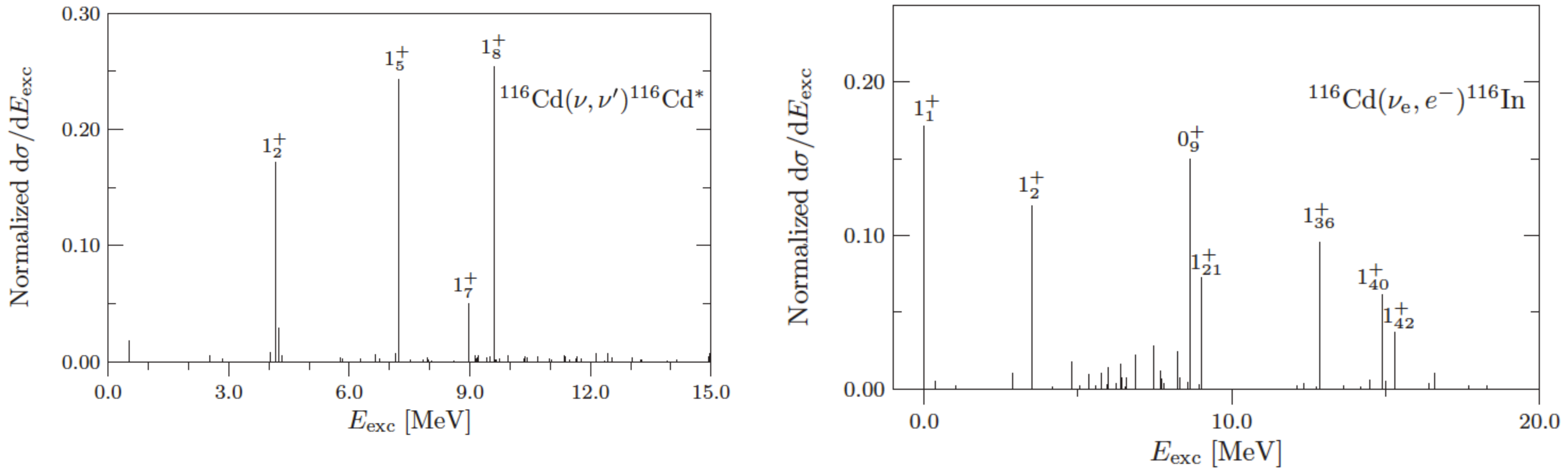
$$\bar{\nu}_l + {}^{116}\mathrm{Cd} \rightarrow {}^{116}\mathrm{Cd}^* + \bar{\nu}_l',$$

CC interactions:

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

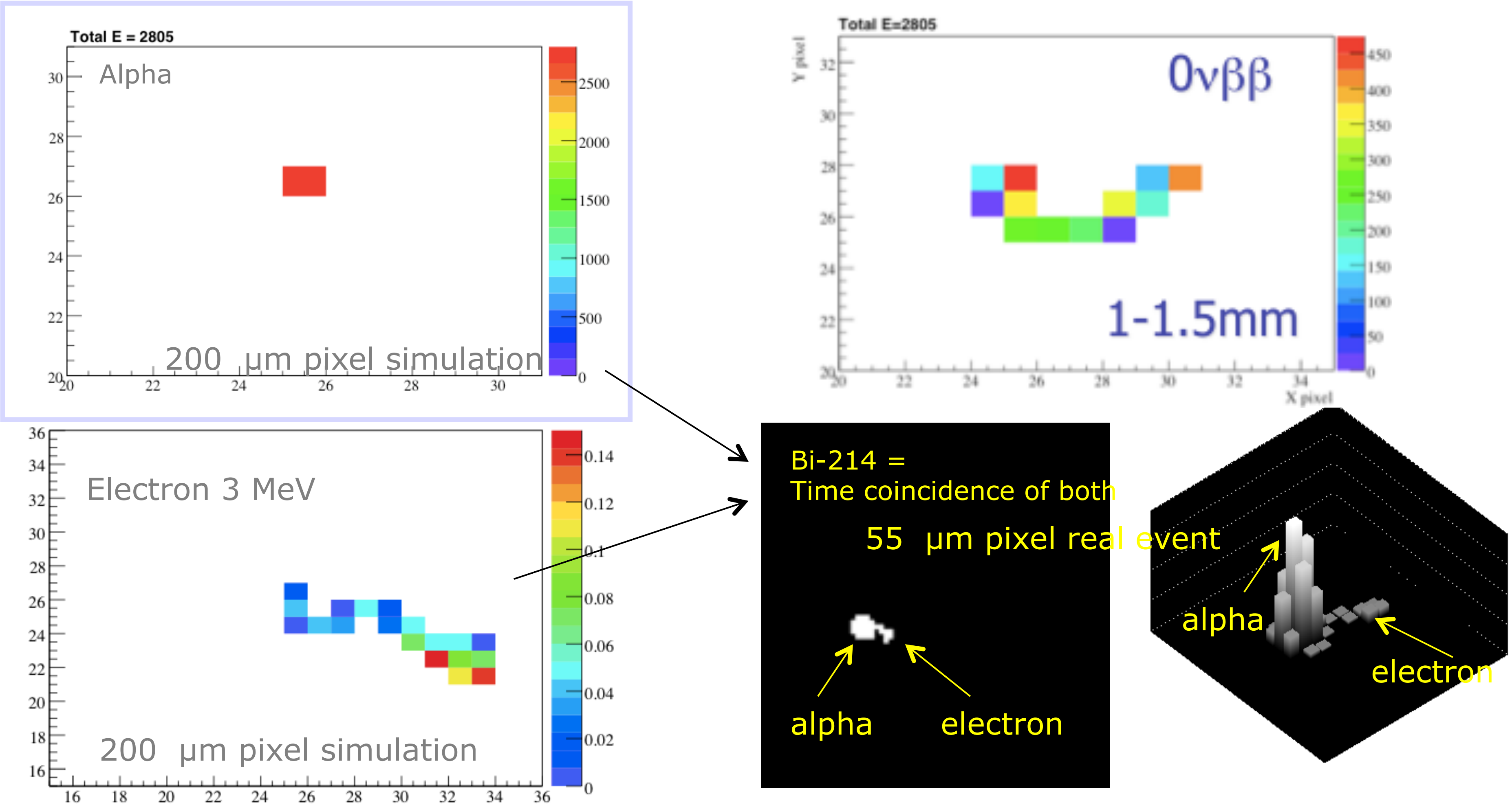
$$\bar{\nu}_l + {}^{116}\mathrm{Cd} \rightarrow {}^{116}\mathrm{Ag} + l^+$$

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



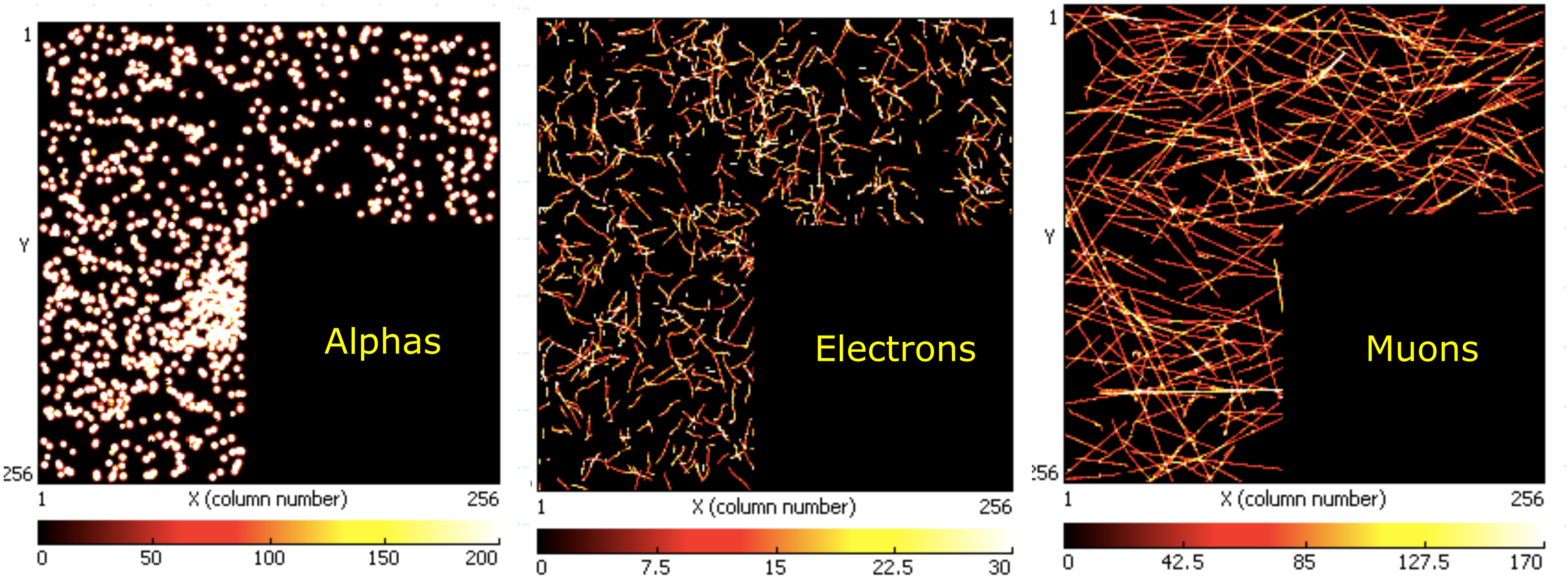
The pixel option

Idea: Massive background reduction by particle identification



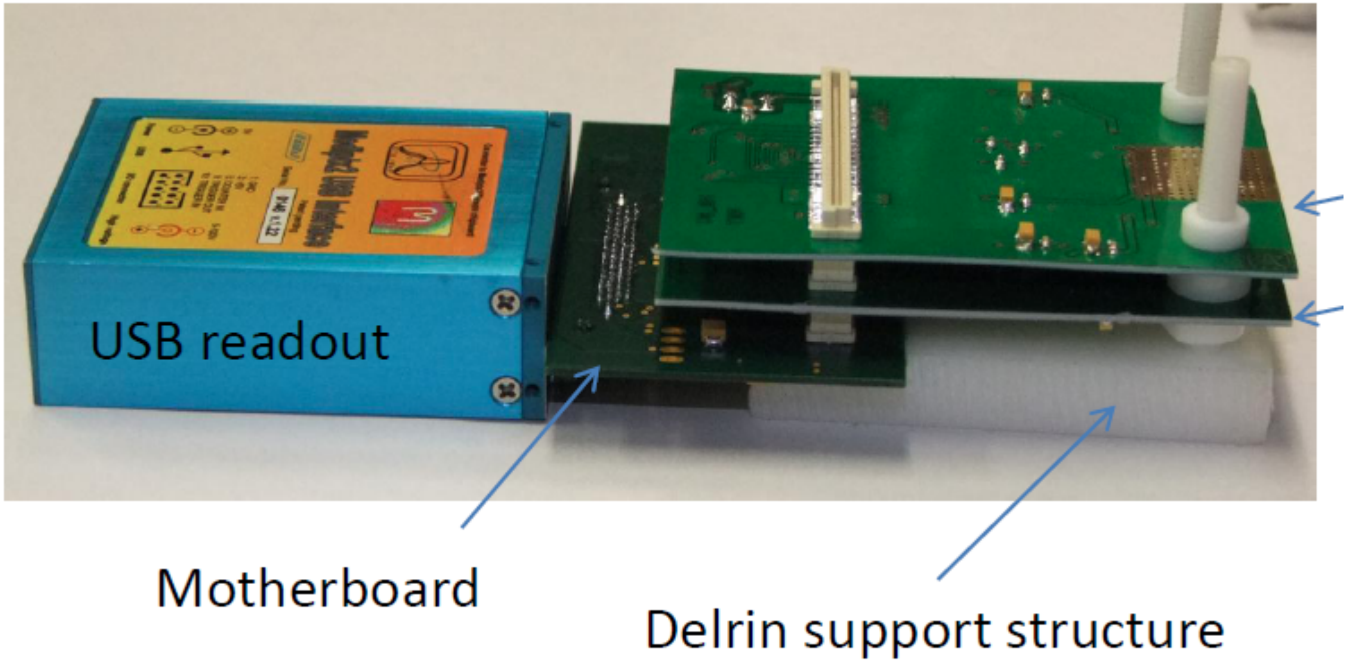
Setup at Gran Sasso Lab

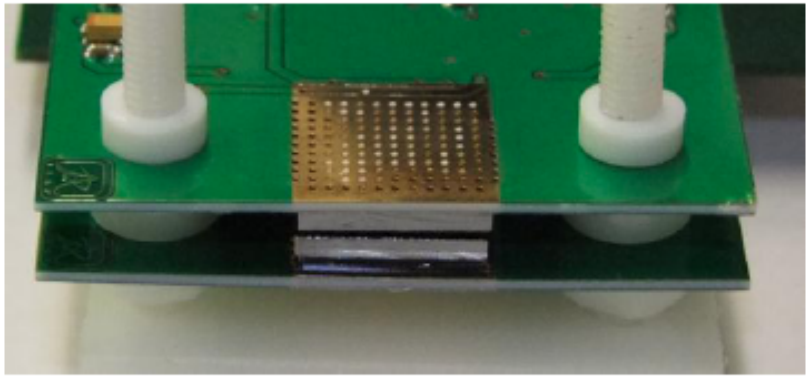
256x256 pixels, 55μm



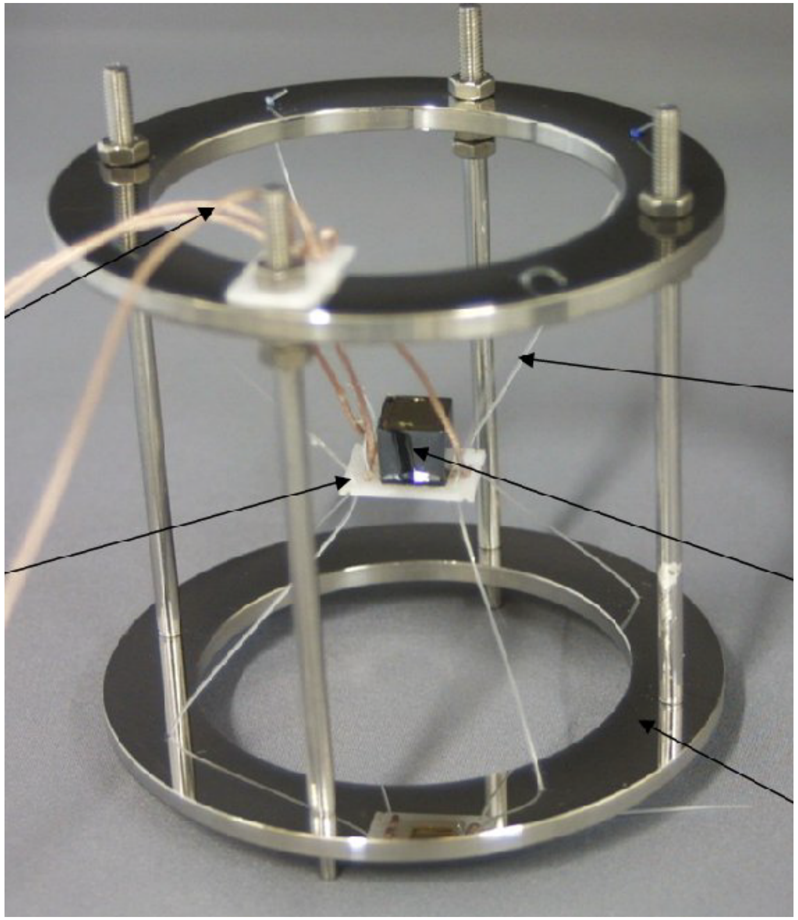
According to simulations particle identification due to pixels should reduce background by 3 orders of magnitude

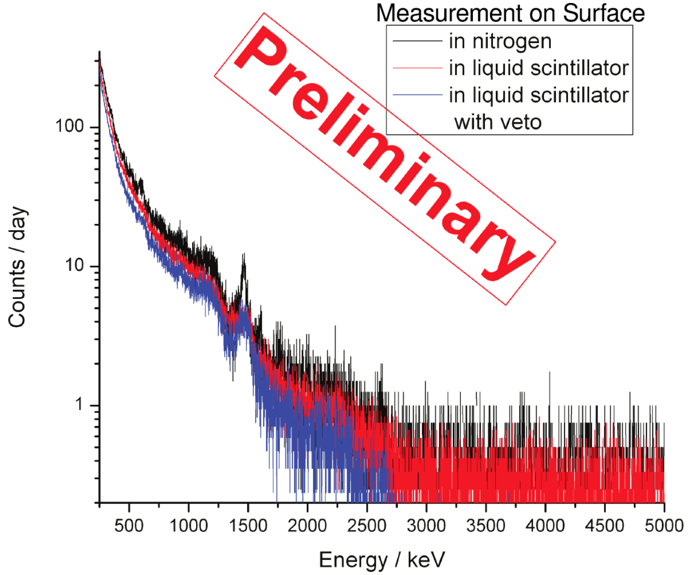
2 pixel system at LNGS

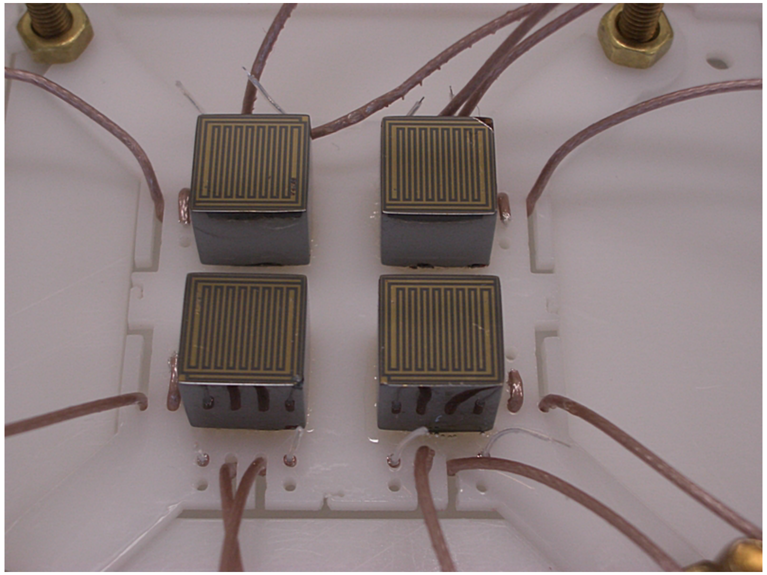




CZT in LSci




Measurement on Surface
in nitrogen
in liquid scintillator
in liquid scintillator with veto
Preliminary
Counts / day
100
10
1
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Energy / keV



Summary

- COBRA is still a rather new approach to double beta using room temperature semiconductors aiming to search for DBD of Cd-116

- After moving to former HdM cabin, currently a major upgrade is ongoing to 64 detectors installation finished by end of the year, exploration of larger detectors (20x20x15 instead of 10x10x10) has started
- Default for a large scale setup of about 10000 detectors are 2x2x1.5 cm^3 detectors, more detailed design/simulation ongoing

- Pixel option very attracting and unique (semiconductor tracker, solid state TPC), but much more complex.

Join the Party!