COBRA: Status and future plans

Jerrad Martin

on behalf of the COBRA Collaboration

Washington University in St. Louis

McDonnell Center for the Space Sciences

- Neutrinoless Double Beta Decay
- CdZnTe Detectors
- COBRA
    - The Experiment
    - Results
    - Event Tracking
    - Summary and Outlook

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COBRA Collaboration (Zuber et al.)

TU Dresden
TU Dortmund
MRC Freiburg
Univ. Erlangen

Gran Sasso National Laboratory

Washington University in Saint Louis

Czech Technical University Prague

Comenius University in Bratislava

University of Jyväskylä

National University of La Plata

Joint Institute for Nuclear Research

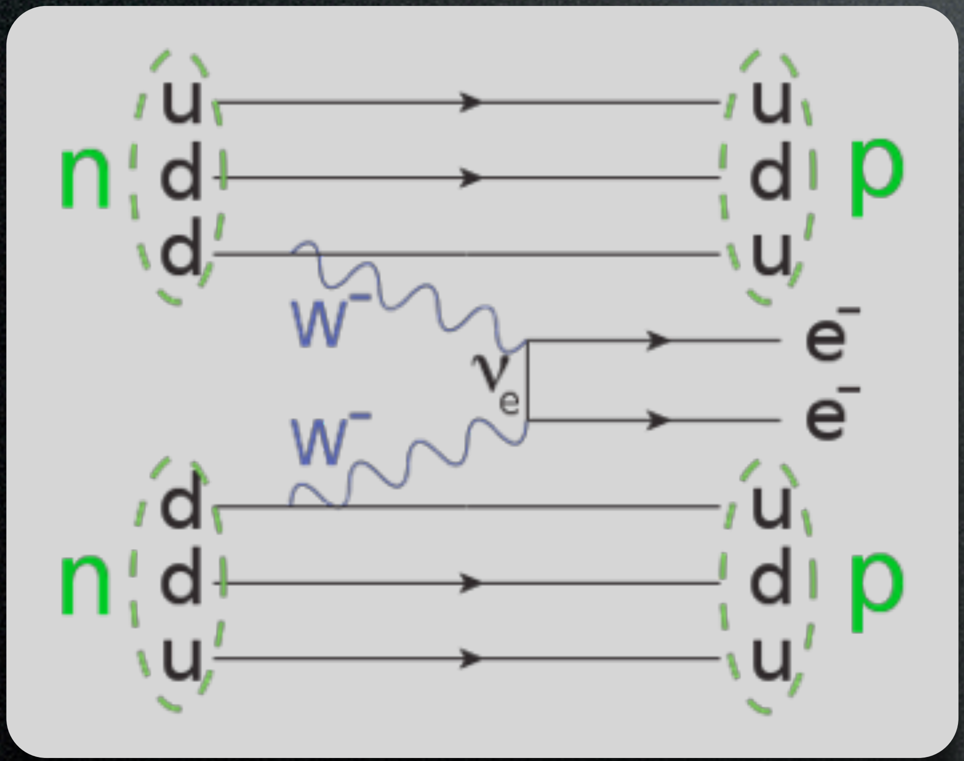
Observer status: University of Hamburg (Germany), Jagiellonian University (Poland), Urbana Champaign (USA), Los Alamos National Laboratory (USA).

Neutrinoless Double Beta Decay

What are the neutrino rest masses?

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu} M^2_{0\nu} \left(\frac{\langle m_\nu \rangle}{m_e} \right)^2$$

Is the neutrino Dirac or Majorana?



May lepton number conservation be broken?

$$(Z, A) \rightarrow (Z+2, A) + 2e^-$$

$$\Delta L = 2$$

Cadmium Zinc Telluride (CZT)

$$T_{1/2} \propto a\varepsilon\sqrt{\frac{Mt}{\Delta EB}}$$

- Source = detector
  - Multiple isotopes
- ^{116}Cd above 2.614 Mev
- Semiconductor
- Maturing technology
- Modular
- Room temperature

Isotope	% Abun	Q (keV)	Mode
Zn-70	0.62	1001	$\beta^-\beta^-$
Cd-114	28.7	534	$\beta^-\beta^-$
Cd-116	7.5	2805	$\beta^-\beta^-$
Te-128	31.7	868	$\beta^-\beta^-$
Te-130	33.8	2529	$\beta^-\beta^-$
Zn-64	48.6	1096	β^+/EC
Cd-106	1.21	2771	$\beta^+\beta^+$
Cd-108	0.9	231	EC/EC
Te-120	0.1	1722	β^+/EC

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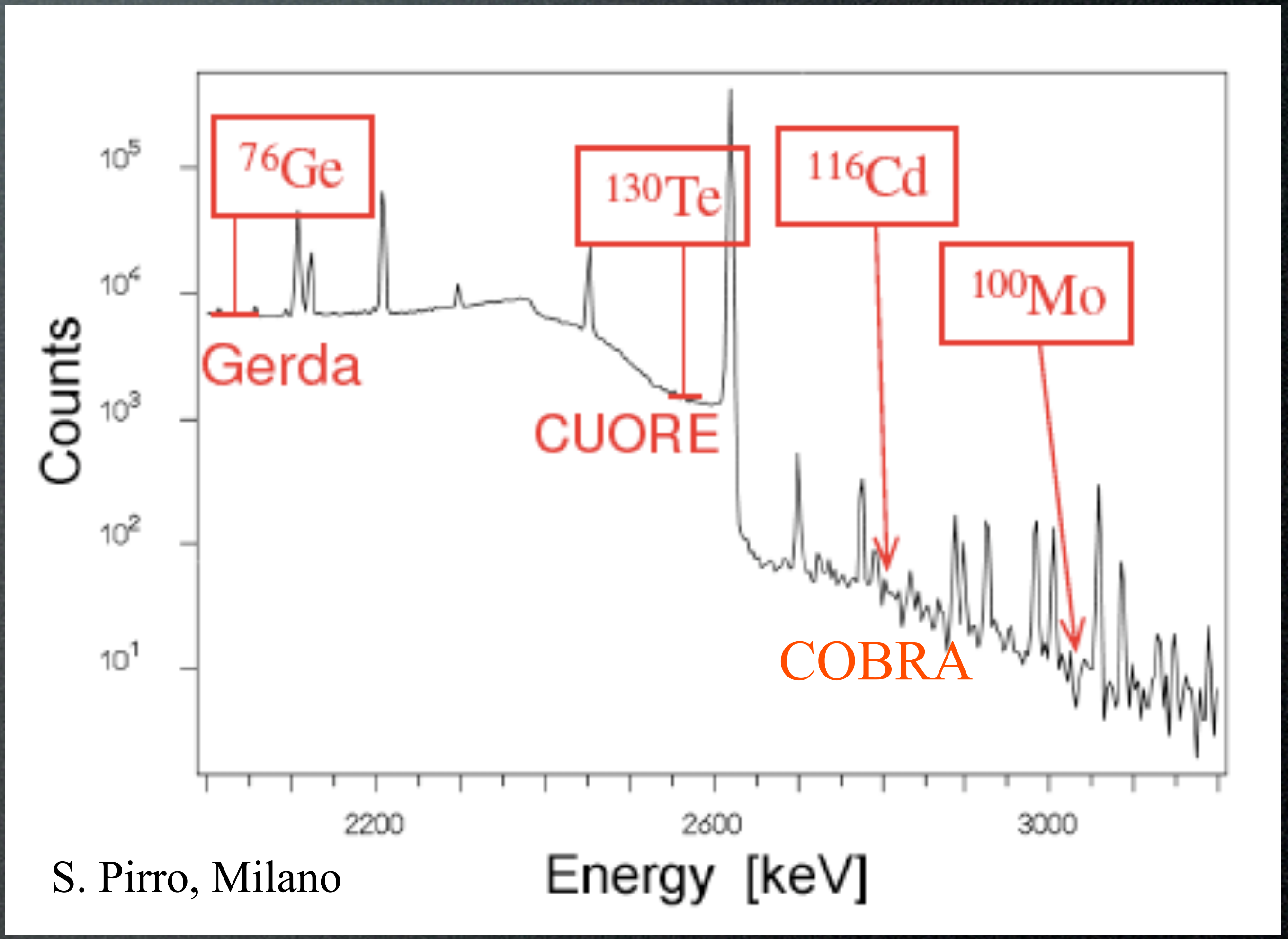

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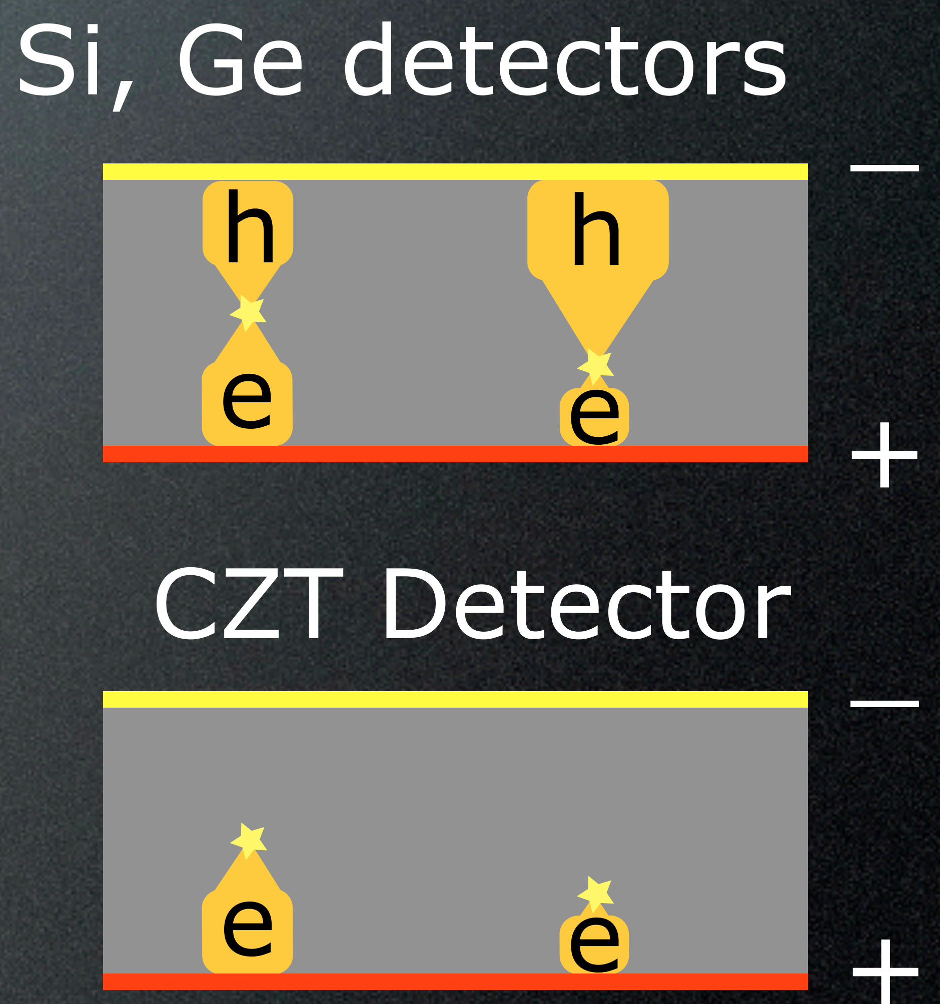

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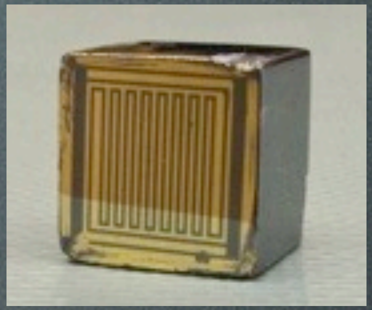
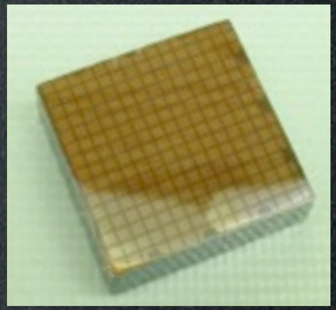


$1x1x1\ cm^3$
Coplanar Grid



$2x2x0.5\ cm^3$
Small pixels

Washington University

Cadmium Zinc Telluride (CZT)

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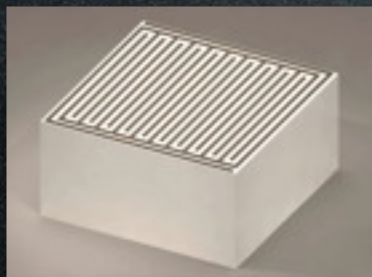
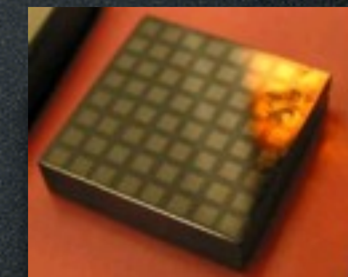
CZT Detectors



(Luke, 1994)

(Barret, Eskin, & Barber, 1995)

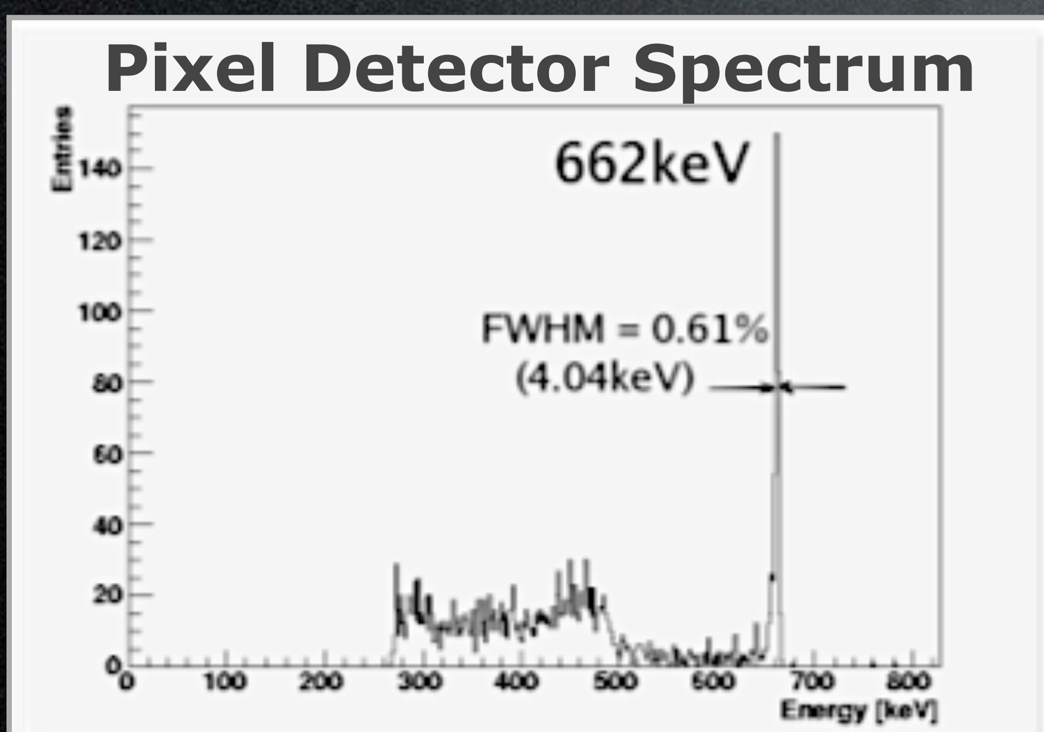


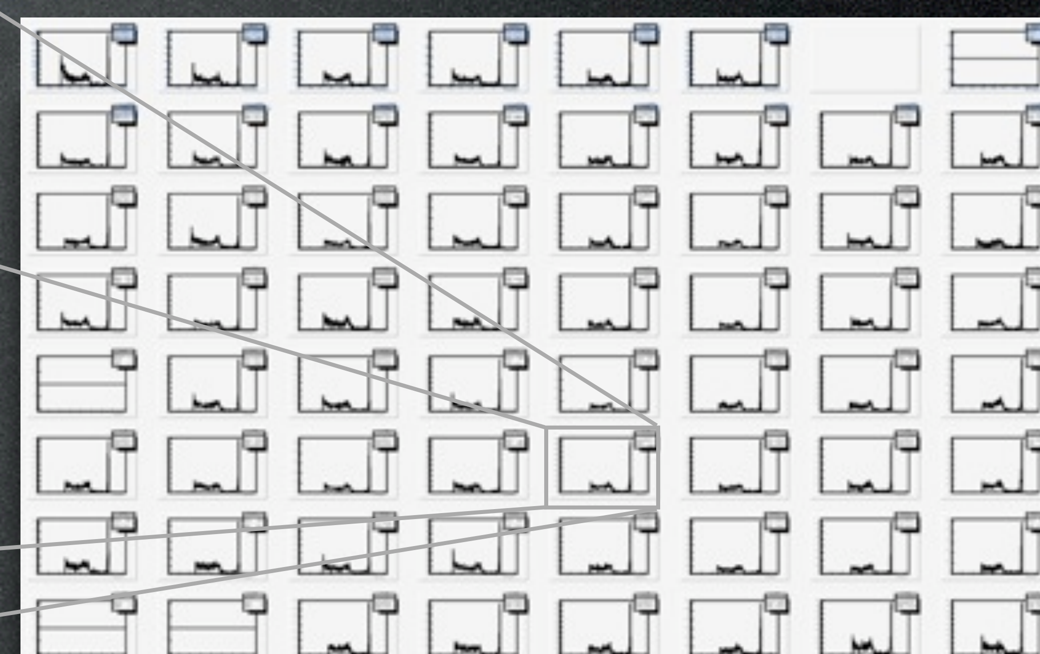
Coplanar Grid CZT

- ✓ Good energy resolution
  - 1.5-5% FWHM
- ✓ Simple 3 channel readout
  - 2 anode, 1 cathode
- ✗ No location of interaction info.

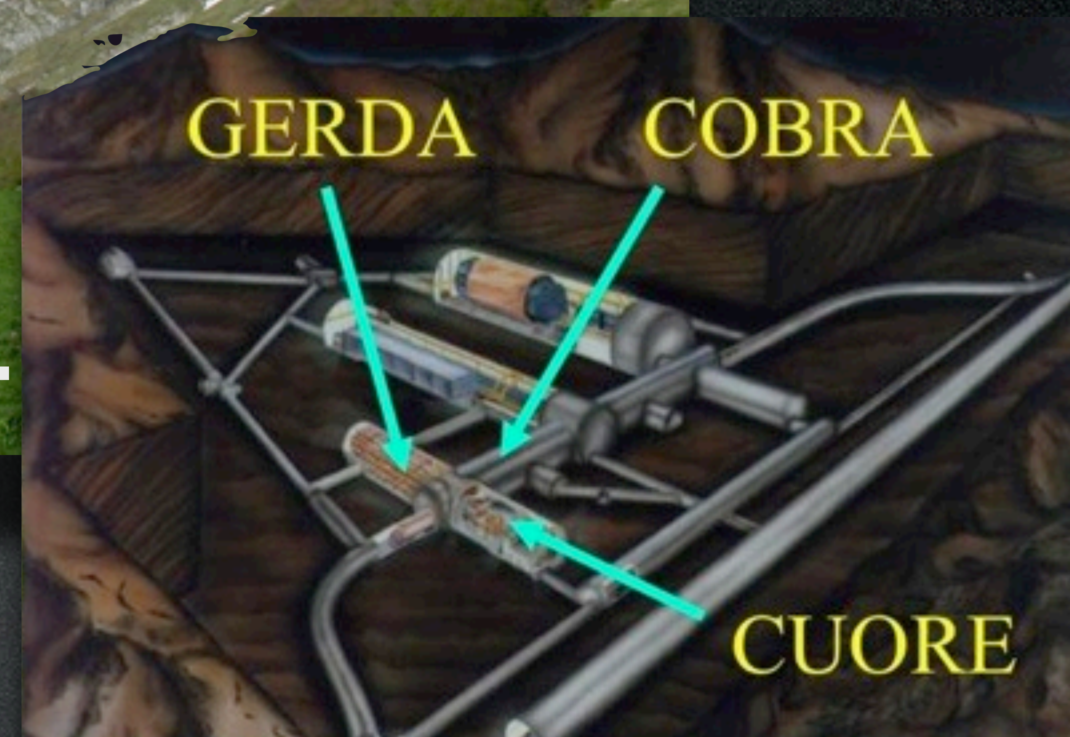
Pixelated CZT

- ✓ Superior energy resolution
- ✗ Complex readout
  - 64 channels or more
- ✓✓ 3D LOI information
  - 2D from pixels, depth from A/C
  - Event tracking
  - ➡ background suppression!





COBRA: The experiment

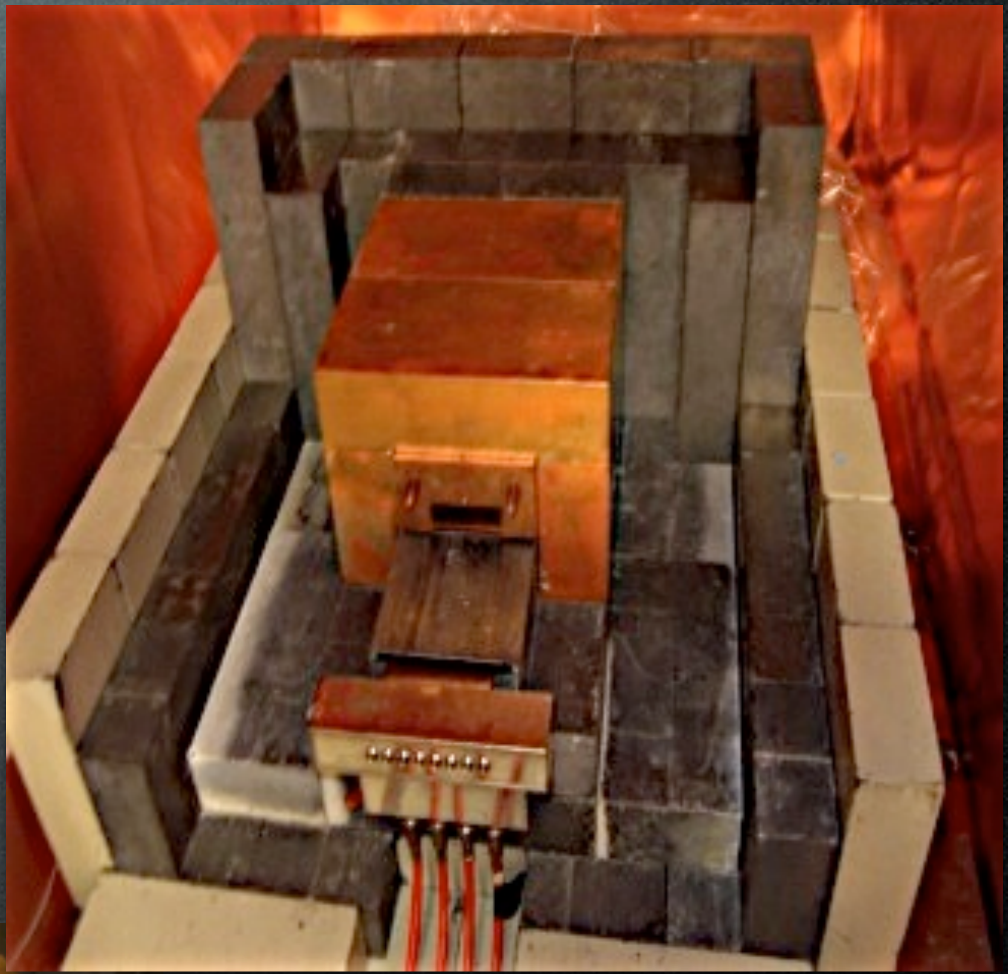


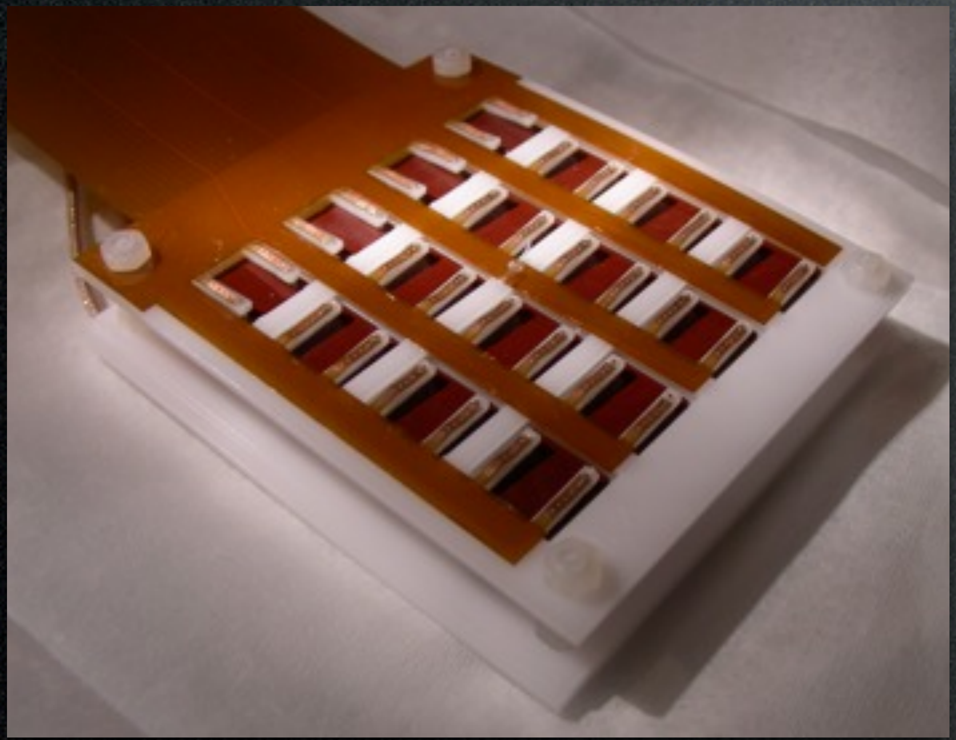
cosmic rays, neutrons and natural decays

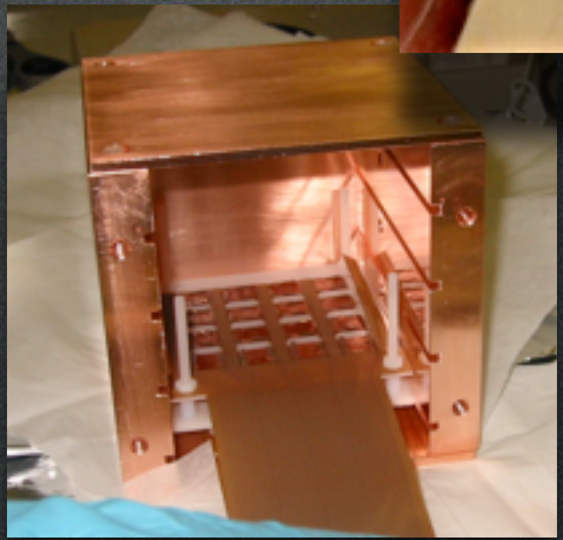
COBRA: The experiment

First Prototype
2x2 1cm^3 detectors
About 8 kg·days at LNGS

Current Generation
4x4 1cm^3 detectors



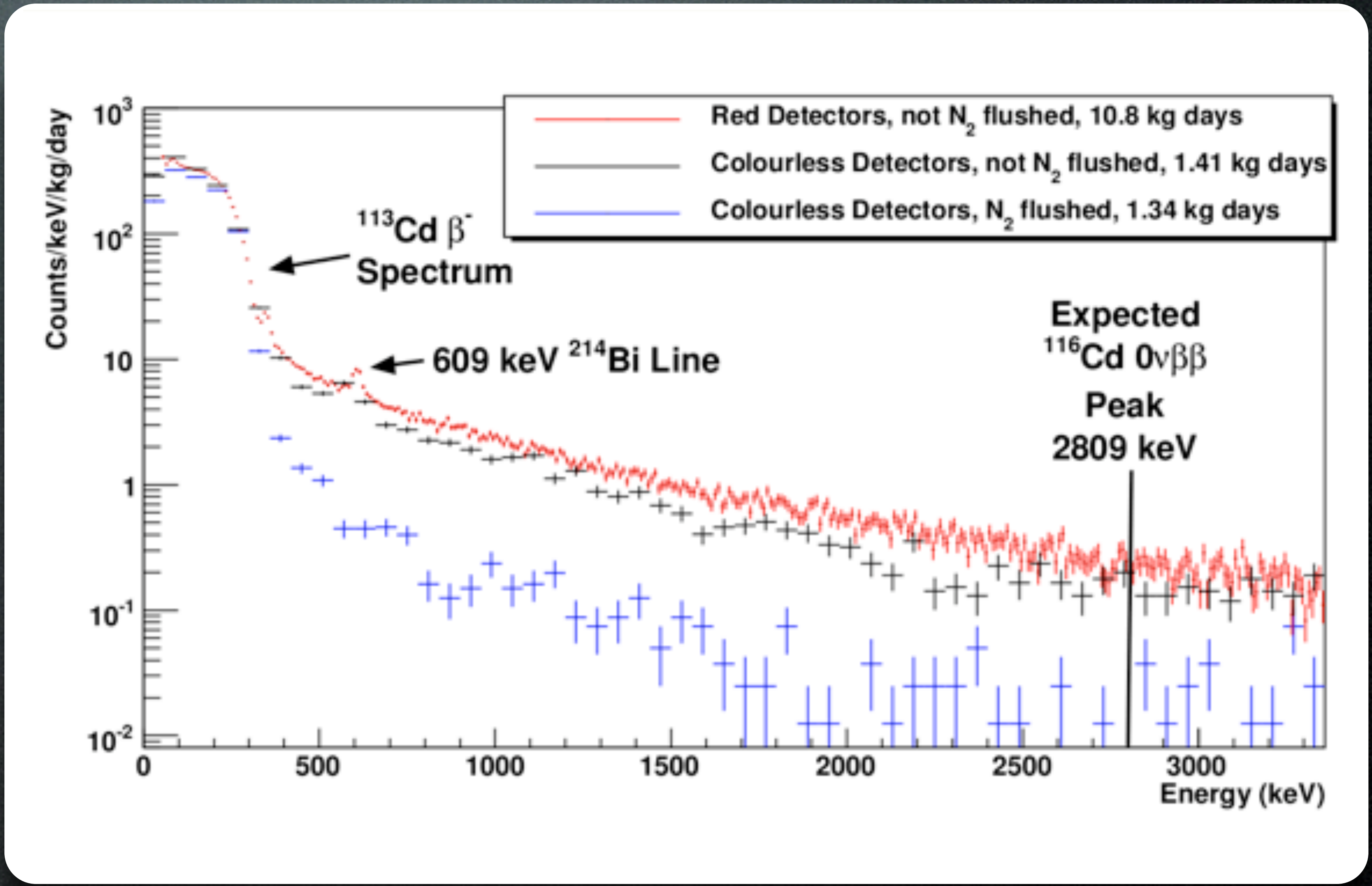




Soon to be 4x4x4...

Background Reduction

- Plastic holders
  - ➡ Delrin
- Wires
  - ➡ Kapton foil
- Radon in the air
  - ➡ N_2 flushing
- Crystal passivation paint
  - ➡ Cleaner paint



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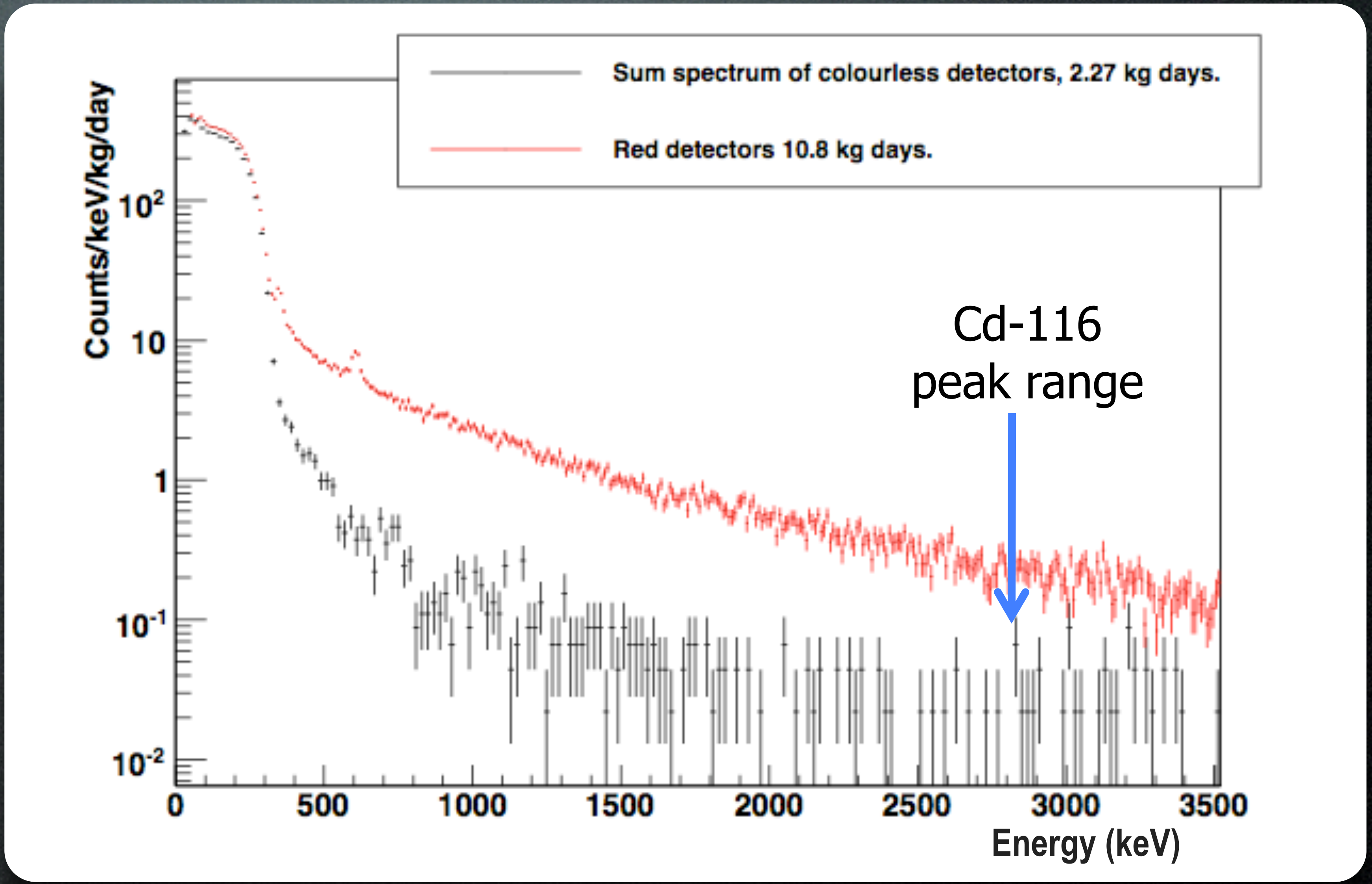


Background fewer than 5 counts/keV/kg/yr at 2.8 MeV

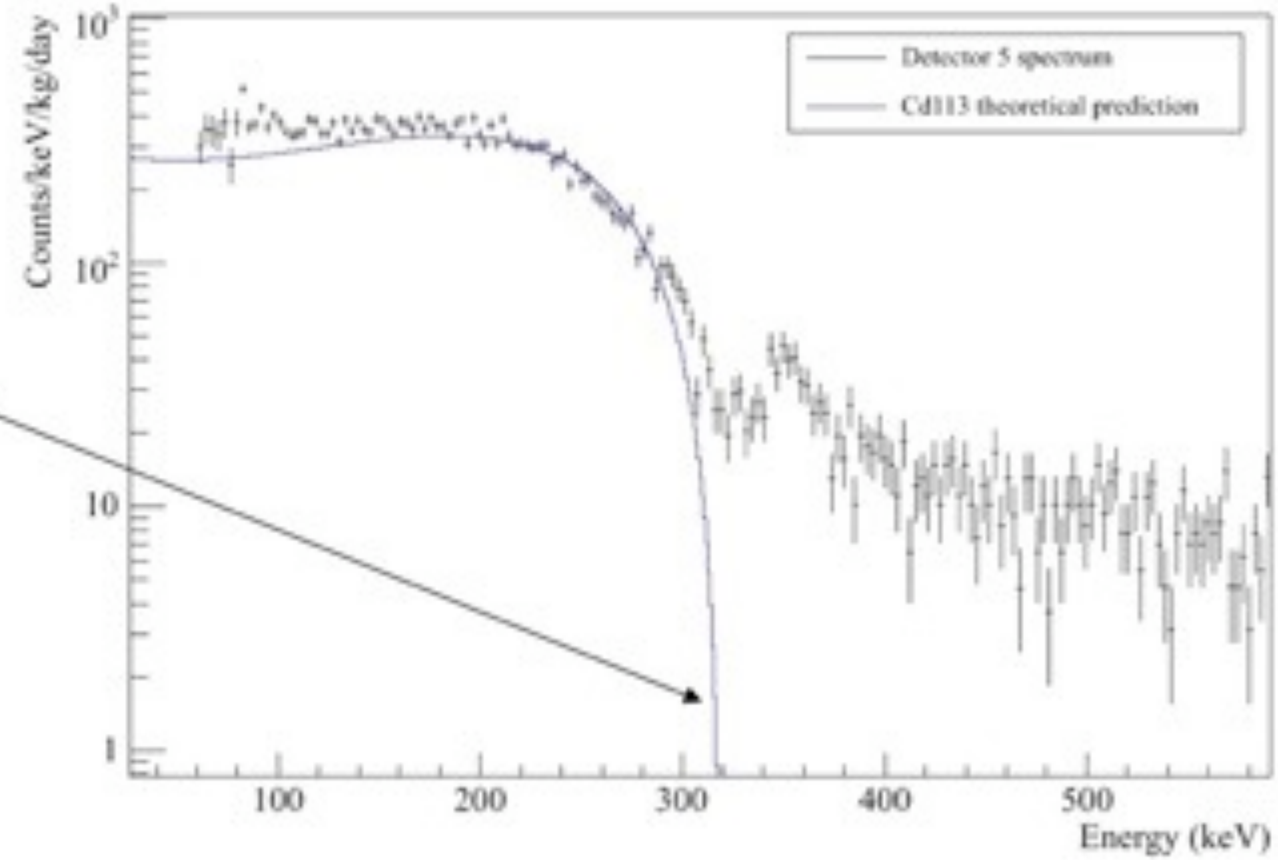
Published Results

4-fold non-unique beta decay of ^{113}Cd

First half-life result published as C. Goessling et al., PRC **72:064328,2005**

(from 2x2 prototype)

First time theoretical model based on nuclear structure calculation (thanks to J. Suhonen)



10 independent measurements from 4x4 system:

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

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

Q-value: $322 \pm 0.3(stat.) \pm 0.9(sys.)$ keV

Published Results

- Six limits above 10^{20} years
- One world best*
  - Three within factor of 3

Isotope and Decay	Fit Range (MeV)	$T_{1/2}$ limit (years) This work	Previous [14]
^{116}Cd to gs	2.2–3.2	9.4×10^{19}	3.14×10^{19}
^{130}Te to gs	2.2–3.2	5.0×10^{20}	9.92×10^{19}
^{130}Te to 536 keV	1.7–2.3	3.5×10^{20}	3.73×10^{19}
^{116}Cd to 1294 keV	1.2–1.8	5.0×10^{19}	4.92×10^{18}
^{116}Cd to 1757 keV	0.9–1.3	4.2×10^{19}	9.13×10^{18}
^{128}Te to gs	0.6–1.3	1.7×10^{20}	5.38×10^{19}
^{116}Cd to 2027 keV	0.5–1.2	2.8×10^{19}	1.37×10^{19}
^{116}Cd to 2112 keV	0.5–1.0	4.7×10^{19}	1.08×10^{19}
^{116}Cd to 2225 keV	0.5–1.0	2.1×10^{19}	9.46×10^{18}
^{130}Te to 1794 keV	0.5–1.2	1.9×10^{20}	3.1×10^{18} [15]
^{130}Te to 1122 keV	1.1–1.7	1.2×10^{20}	1.4×10^{19} [15]
^{114}Cd to gs	0.4–1.0	2.0×10^{20}	6.4×10^{18} [15]

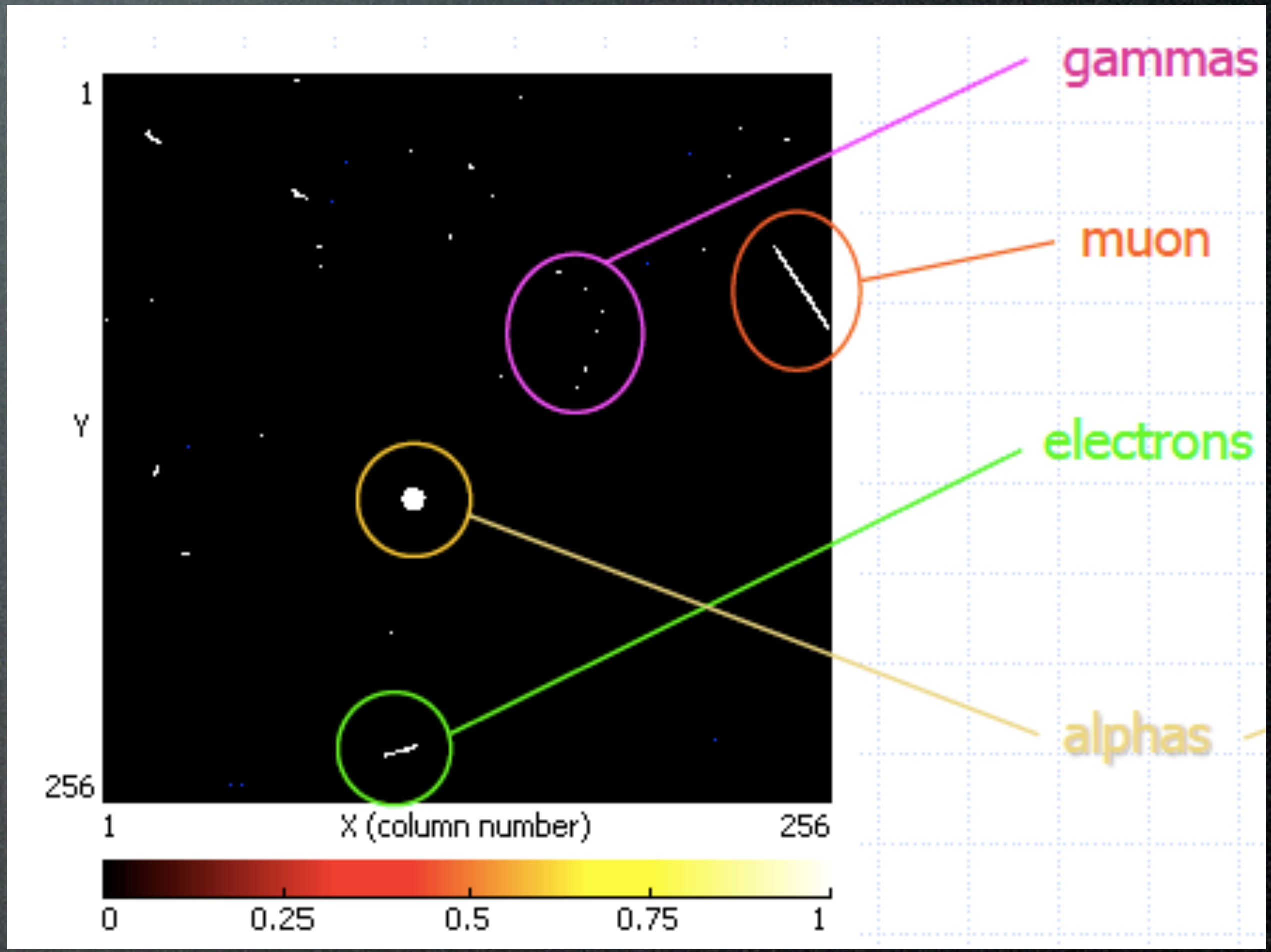
from a total of 18 kg·days of data

Isotope and Decay	Fit Range (MeV)	$T_{1/2}$ limit (years) This work	Previous [14]
^{64}Zn β^+EC to gs	0.5–1.3	1.1×10^{18}	2.78×10^{17}
^{120}Te β^+EC to gs	1.0–2.0	4.1×10^{17}	1.21×10^{17}
^{120}Te 2EC	0.8–2.0	2.4×10^{16}	2.68×10^{15}
^{120}Te 2EC to 1171 keV	0.6–2.0	1.8×10^{16}	9.72×10^{15}
^{106}Cd $\beta^+\beta^+$ to gs.	0.5–2.0	2.7×10^{18}	4.50×10^{17}
^{106}Cd β^+EC to gs	1.5–3.0	4.7×10^{18}	7.31×10^{18}
^{106}Cd 2 EC to gs	2.0–3.0	1.6×10^{17}	5.7×10^{16}
^{106}Cd $\beta^+\beta^+$ to 512 keV	0.6–1.5	9.4×10^{17}	1.81×10^{17}
^{106}Cd β^+EC to 512 keV	0.8–2.0	4.6×10^{18}	9.86×10^{17}

J.V. Dawson et al., arXiv:0902.3582

Event Tracking

- Sub-mm spatial resolution
- Differentiate between:
  - alphas
  - muons
  - electrons
  - gammas
- Two options
  - Timepix
  - Custom ASIC system



14x14x0.3mm Si
5.5 µm pixels

Event Tracking

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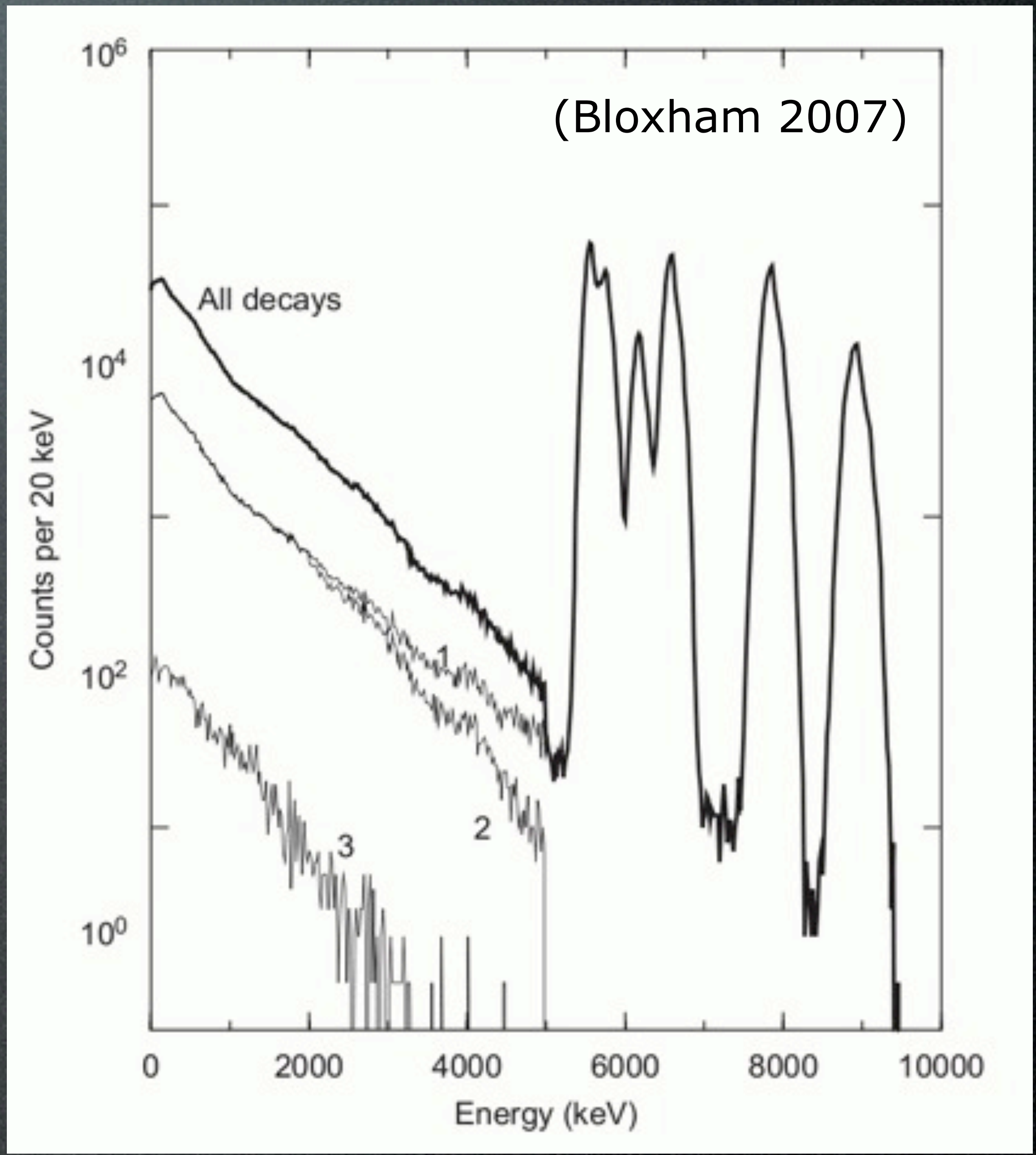
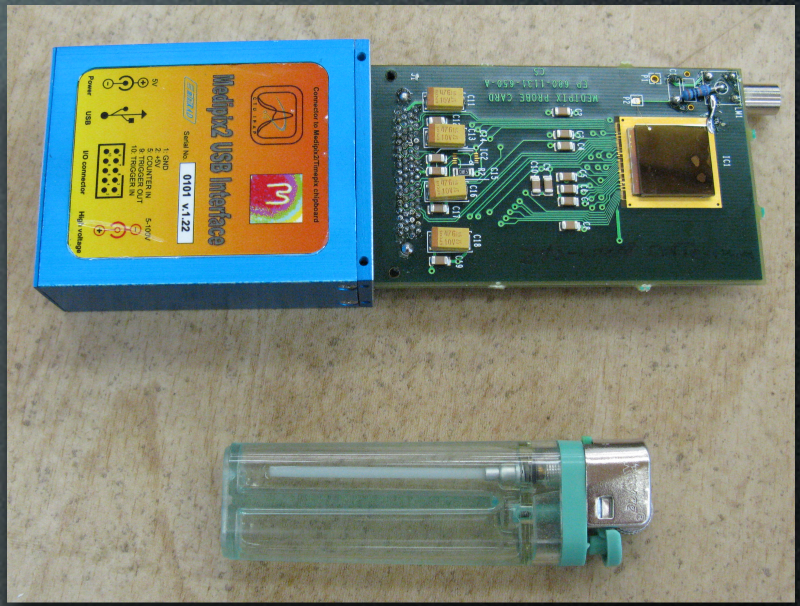
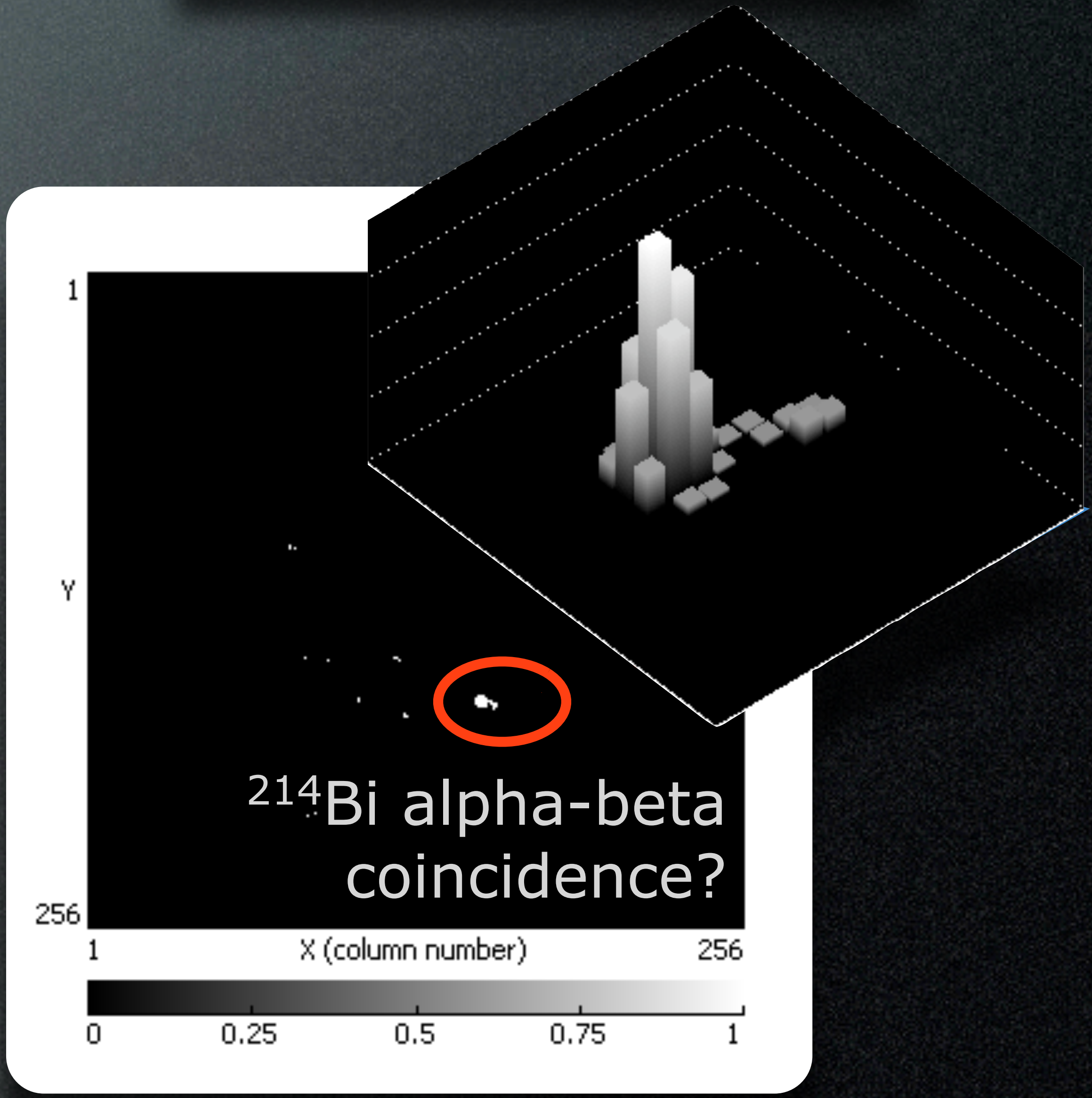


No gammas, quenching/degradation
Smeared at 2.3%

Timepix

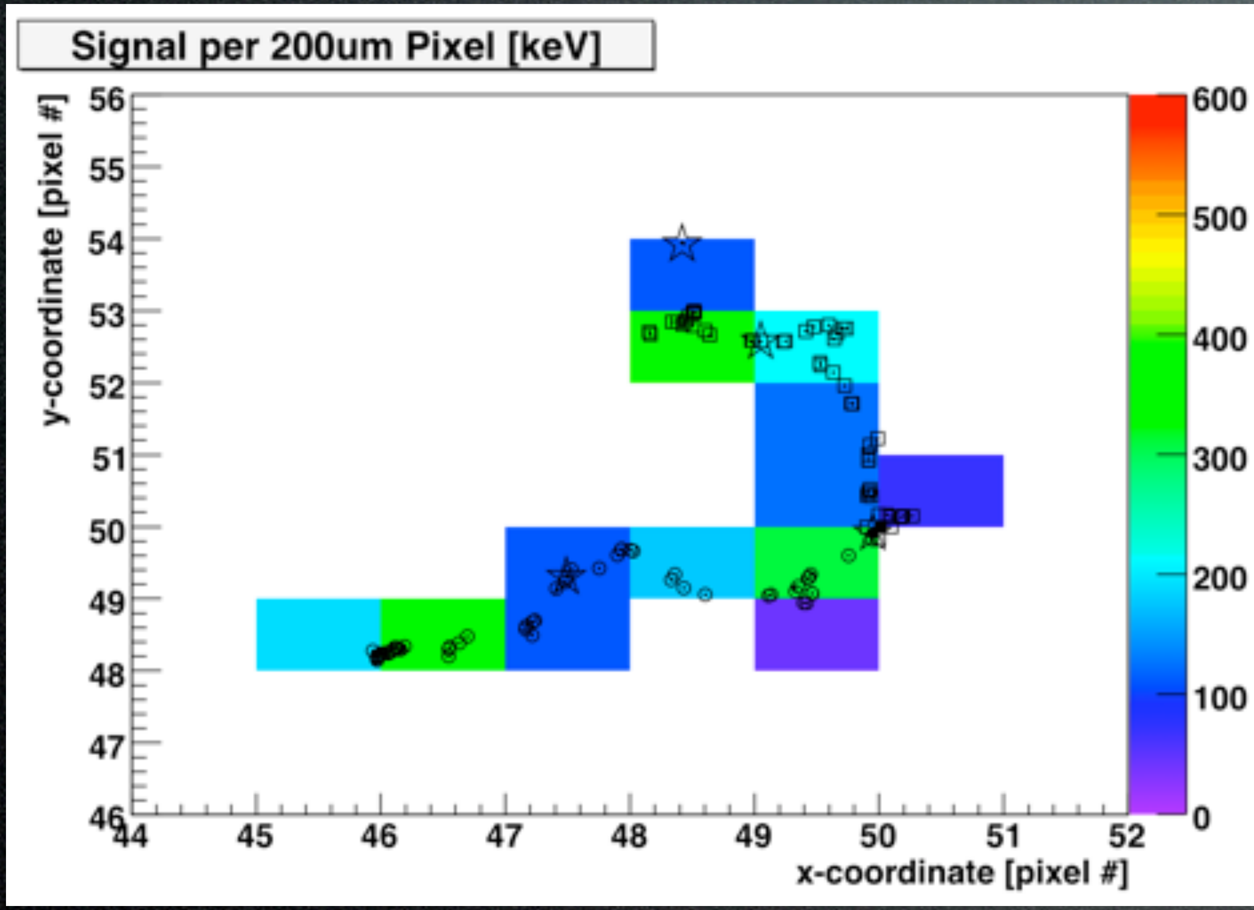
- Medipix chip enhanced with pulse height ADC
- 65,000 channels
- 1.4x1.4 cm^2, direct bonding
- 256x256 5.5μm pixels
- Si: 300 μm thick (data shown)
- CdTe: 1 mm (developing)
- CZT: 10 mm thick???



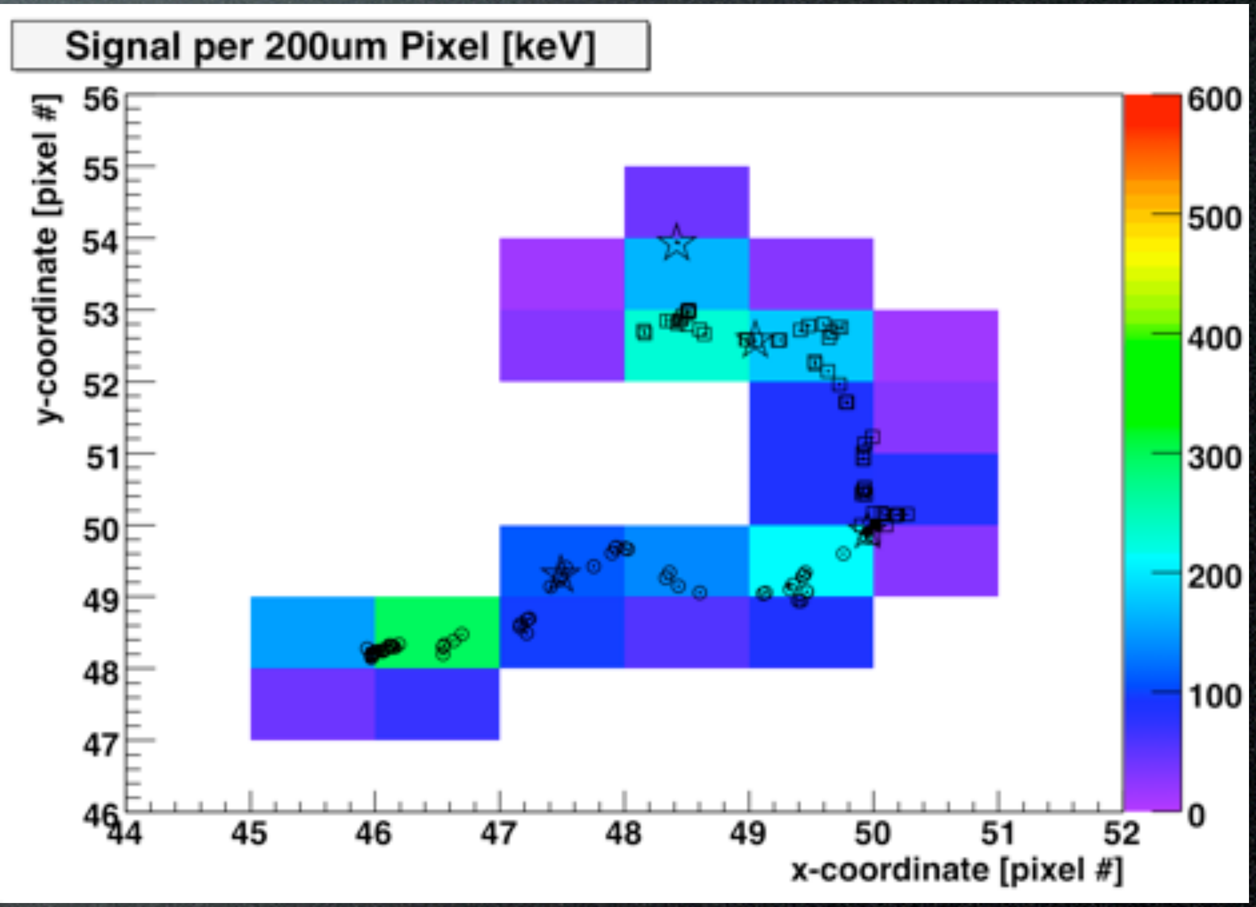


Charge Diffusion

With

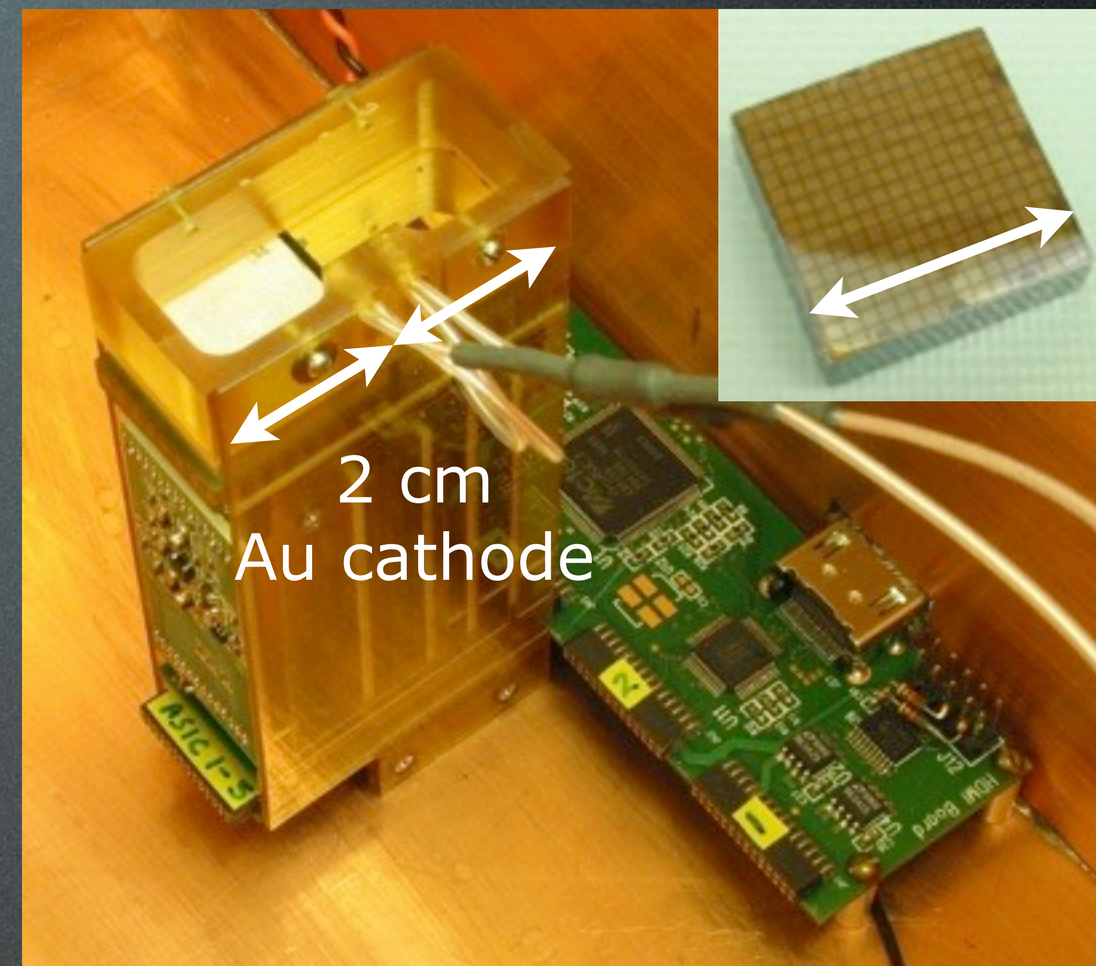


Without



MC Simulated 0νββ event
20x20x5 mm CZT with 200 μm pixels

Pixelated CZT at WUSTL



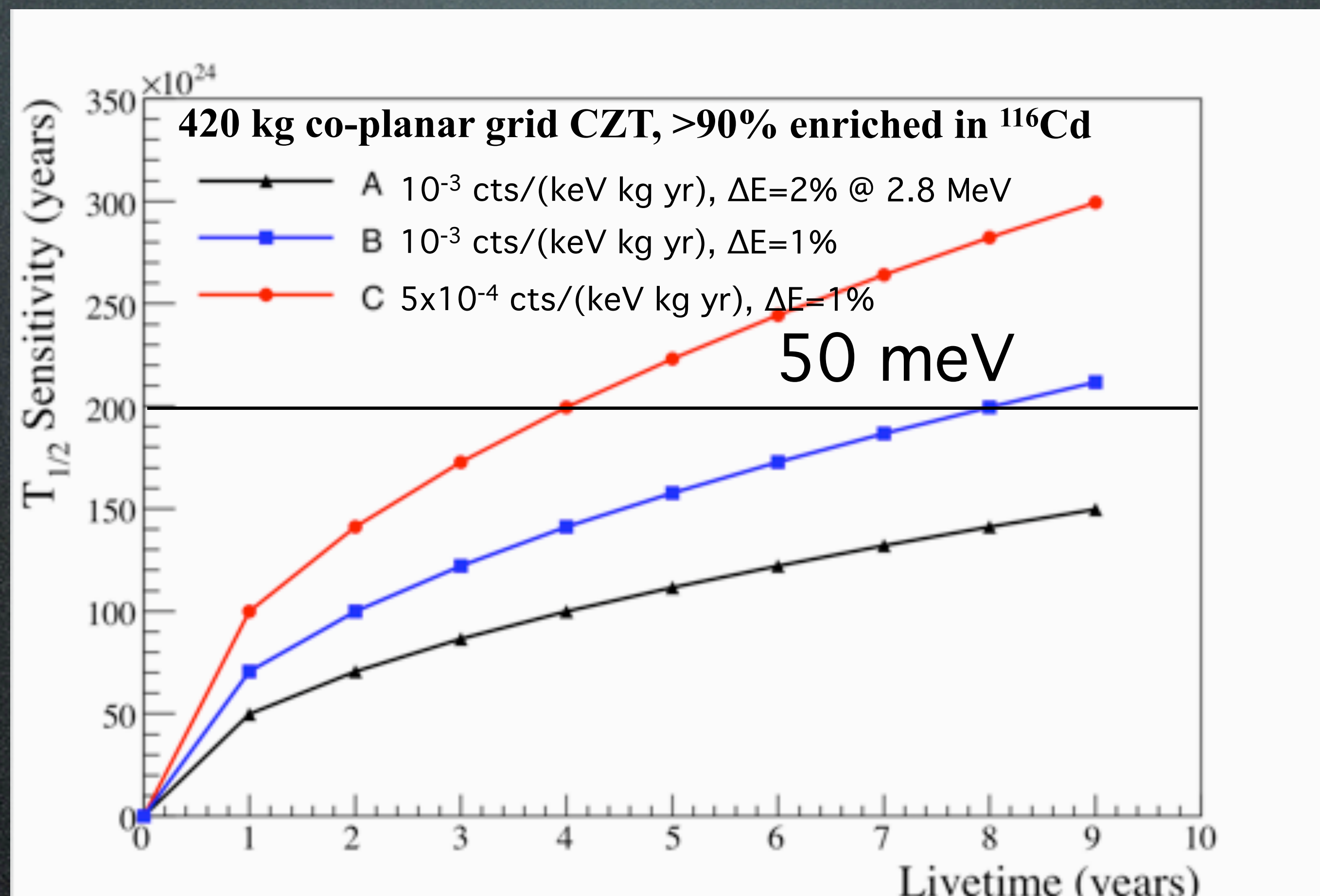
Class-100 Clean Room

- Br Wet Bench
- Photolithograph
- 50-2500 μm pixel pitches
- e-Beam Evaporator

"Mosaic" readout system

- 64 channels, low noise
- Developed at WU
- uses NCI-ASICs (BNL)
- Installation at LNGS: Nov '09

Large Scale Experiment



- 16,000 2x2x1 cm^3 detectors
- 420 kg of 90% ^{116}Cd enriched CZT
- 32×10^6 350 µm pixels

Summary and Outlook

- COBRA is a unique $0\nu\beta\beta$ experiment
- CZT semiconductor detectors
    - Excellent energy resolution
    - ^{116}Cd has Q-value of 2.8 MeV
- Currently running 16 cm^3 of CZT at LNGS
- Currently developing detectors with sub-mm spatial resolution
- New funding expected from DFG this month
- Proposal for large scale experiment: 2012