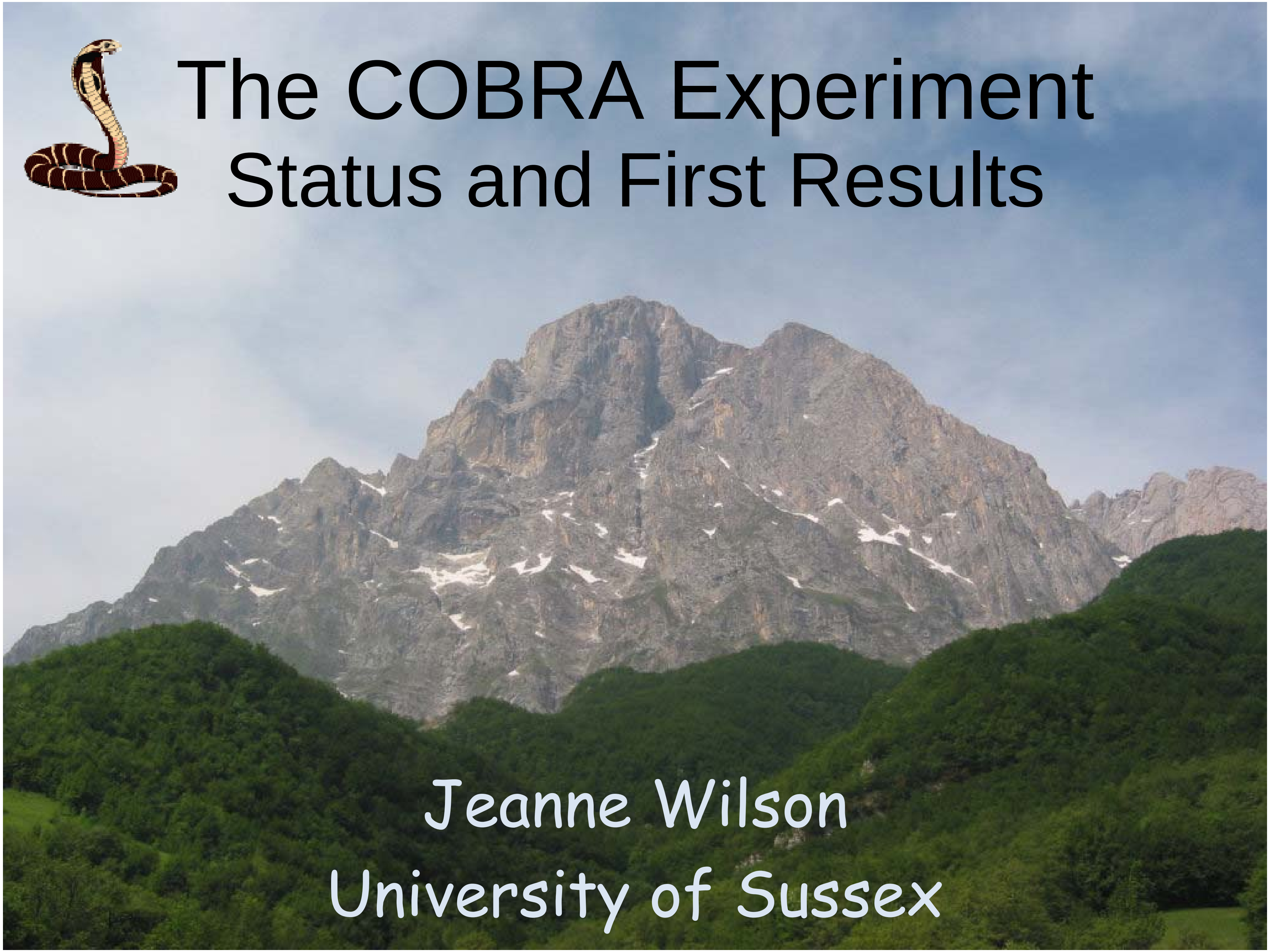
The COBRA Experiment
Status and First Results

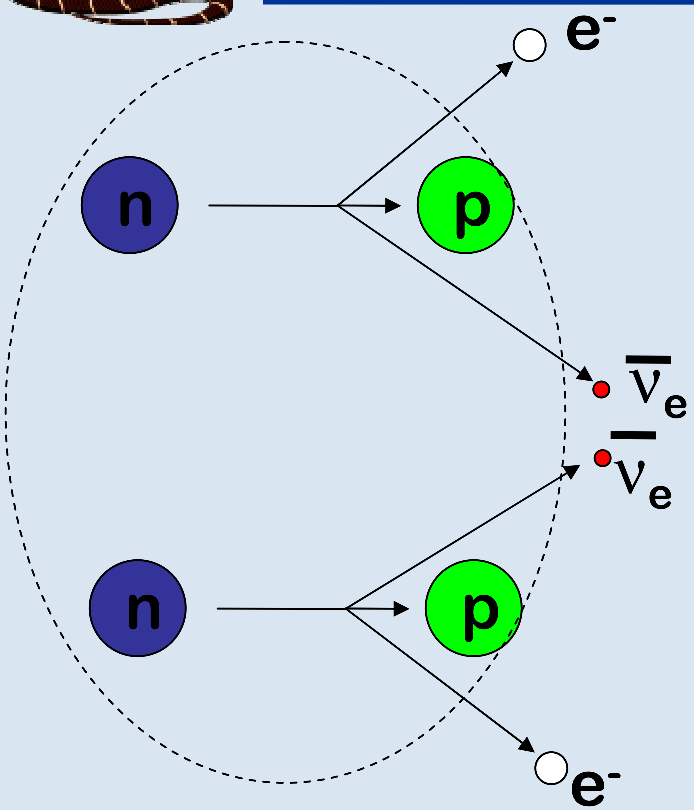


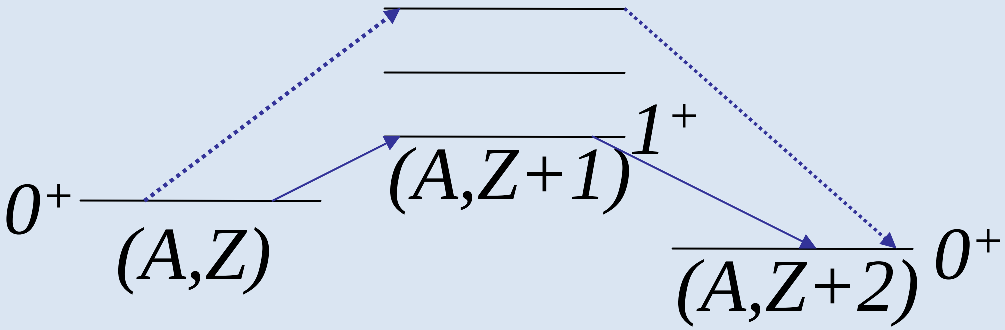
Jeanne Wilson
University of Sussex

C*admium-Telluride* **O***-neutrino double-* **B***eta* **R***esearch* **A***pparatus*

Cadmium-Telluride 0-neutrino double-Beta Research Apparatus

Double Beta Decay

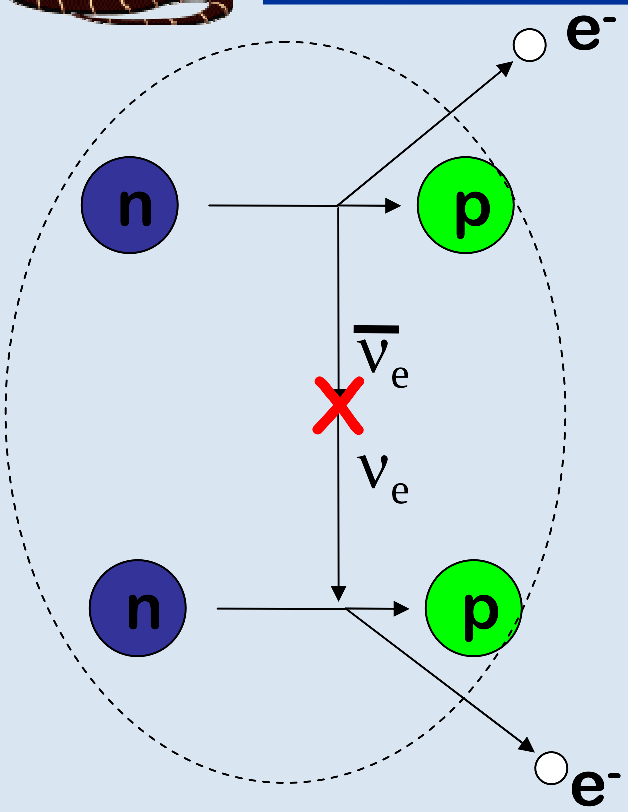


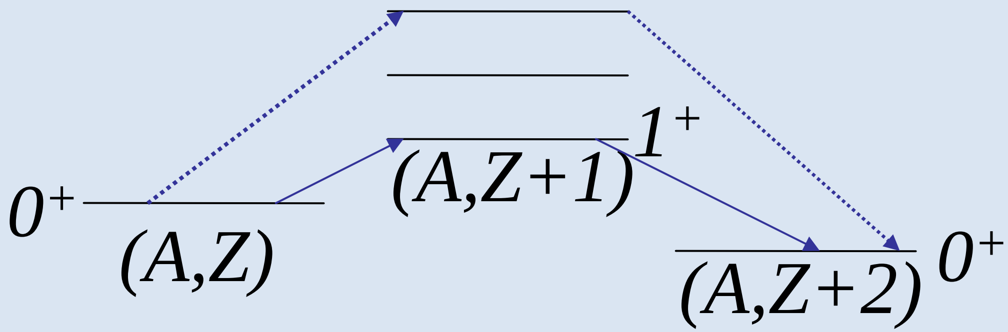


$$(A,Z) \rightarrow (A,Z+2) + 2\,e^- + 2\bar{\nu}_e$$

Only 35 isotopes known in nature

Neutrinoless Double Beta Decay

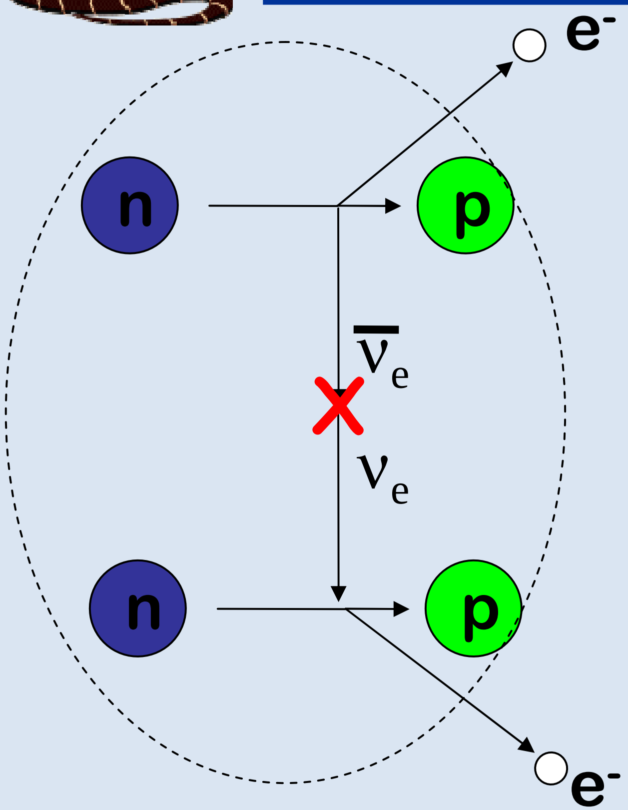


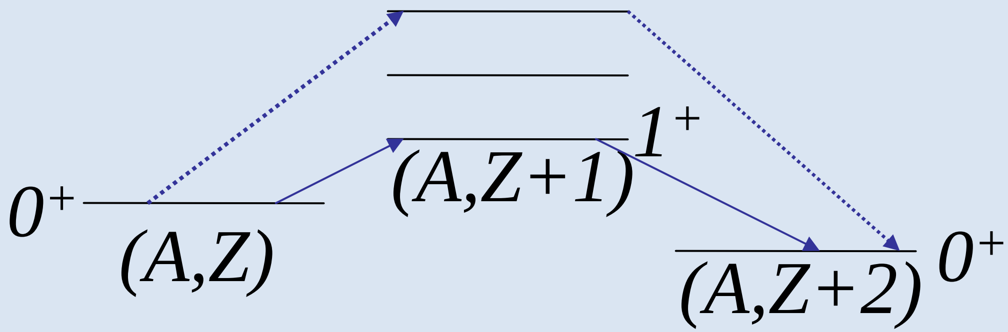


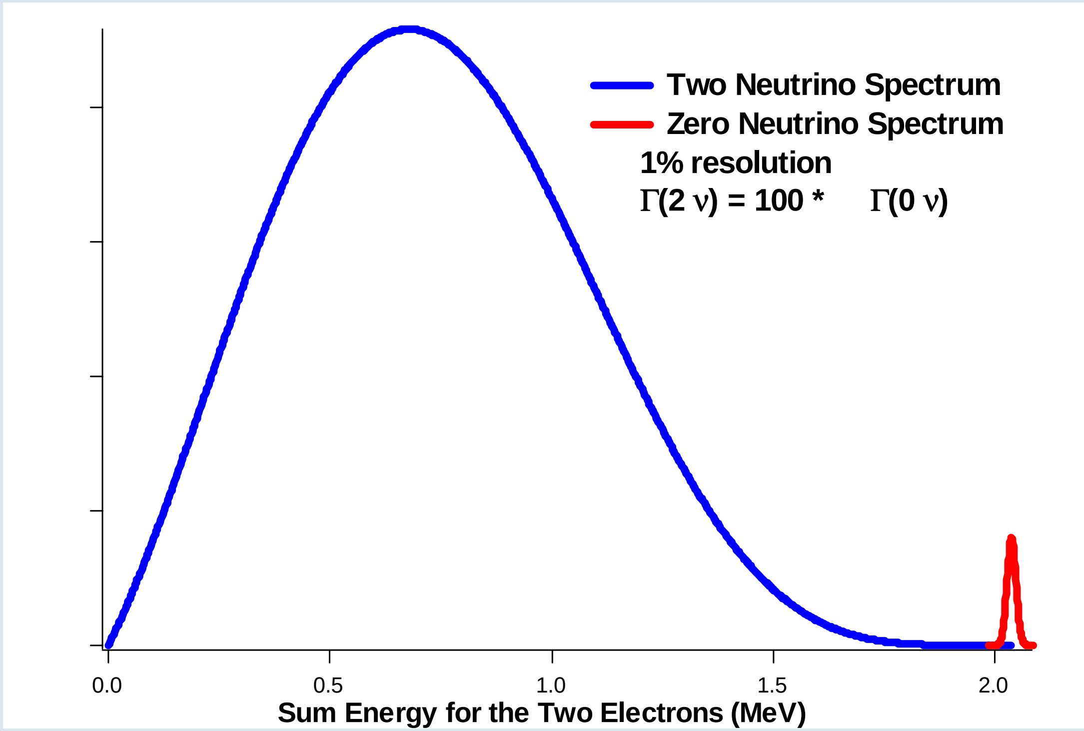
$(A,Z) \rightarrow (A,Z+2) + 2\ e^-$

Requires Massive Majorana Neutrinos

Double Beta Decay

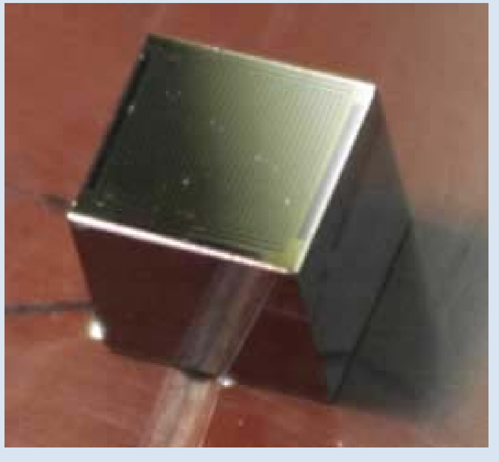




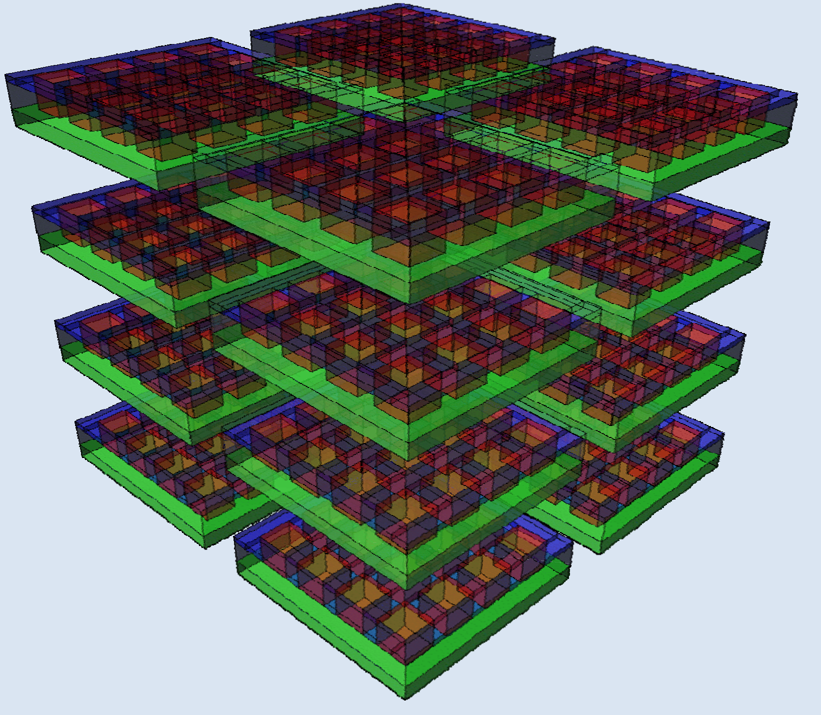


COBRA

A large array of CdZnTe (CZT) Semiconductor Detectors

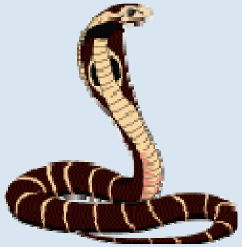


1cm^3 CdZnTe Crystal



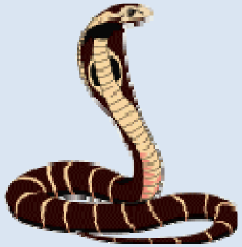
K. Zuber, Phys. Lett. B 519,1 (2001)


Why CZT?



Advantages

- Semiconductor (Good energy resolution, clean)
- Source = Detector
- Room temperature operation



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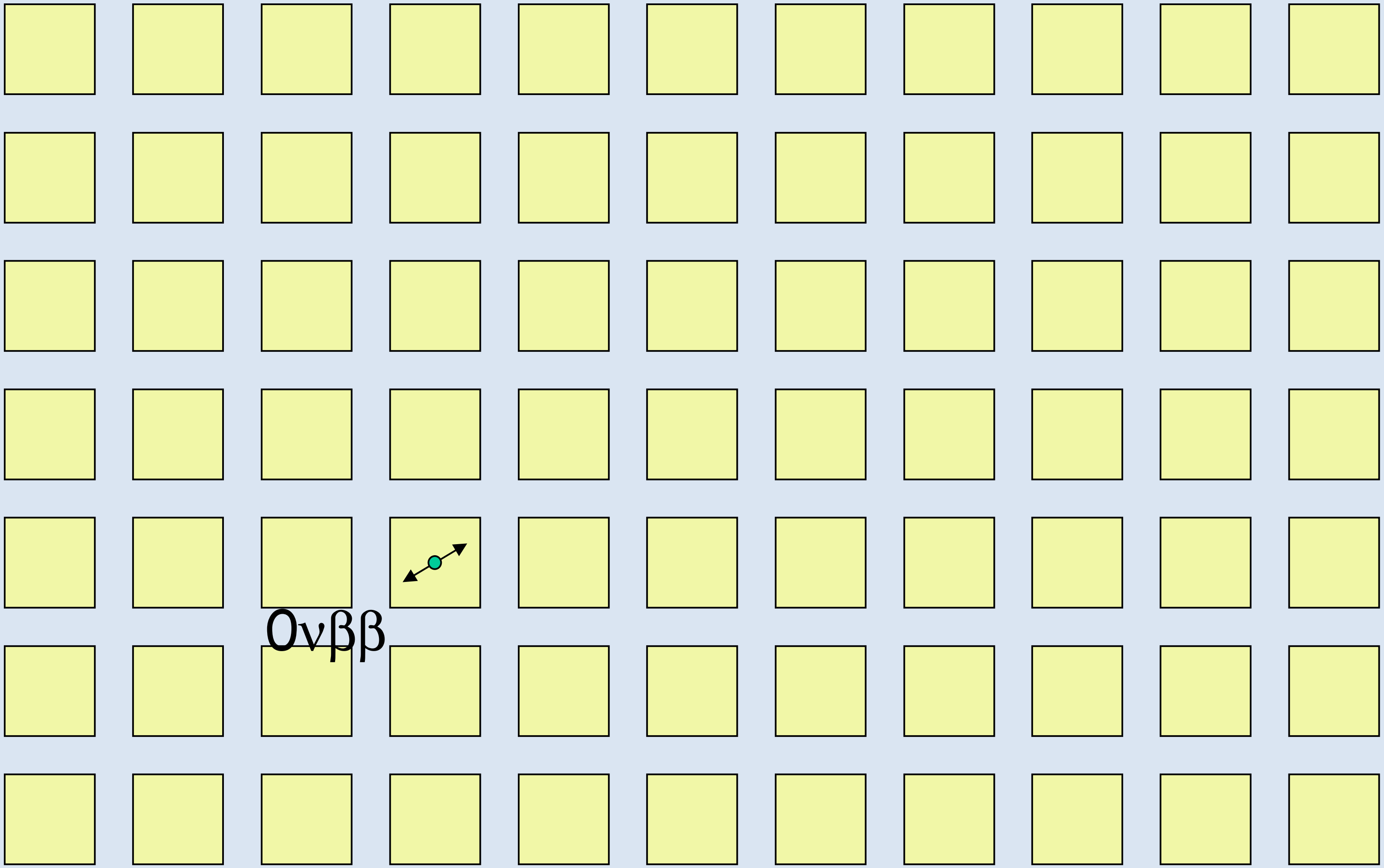
- Modular design

Background Separation



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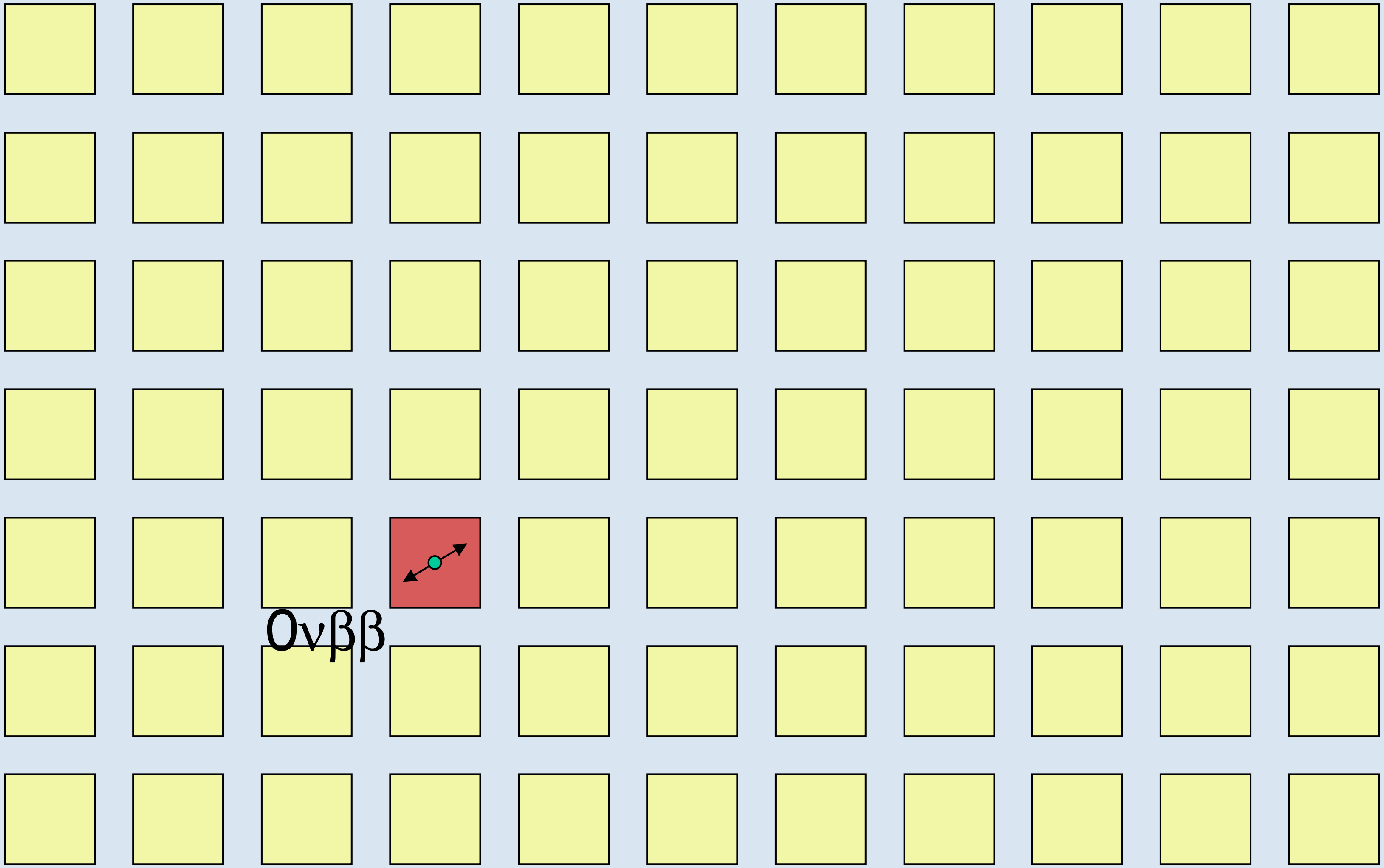

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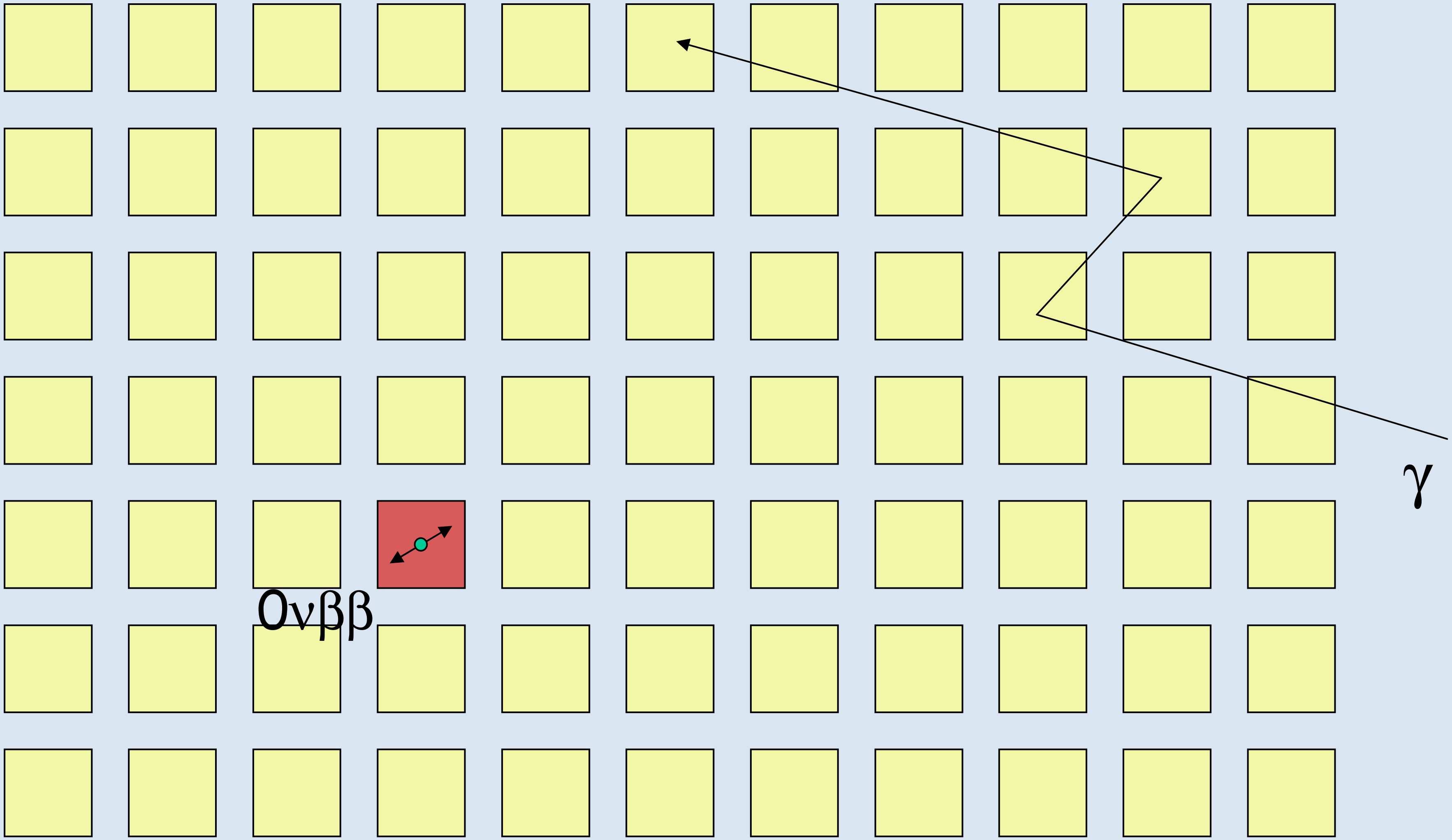

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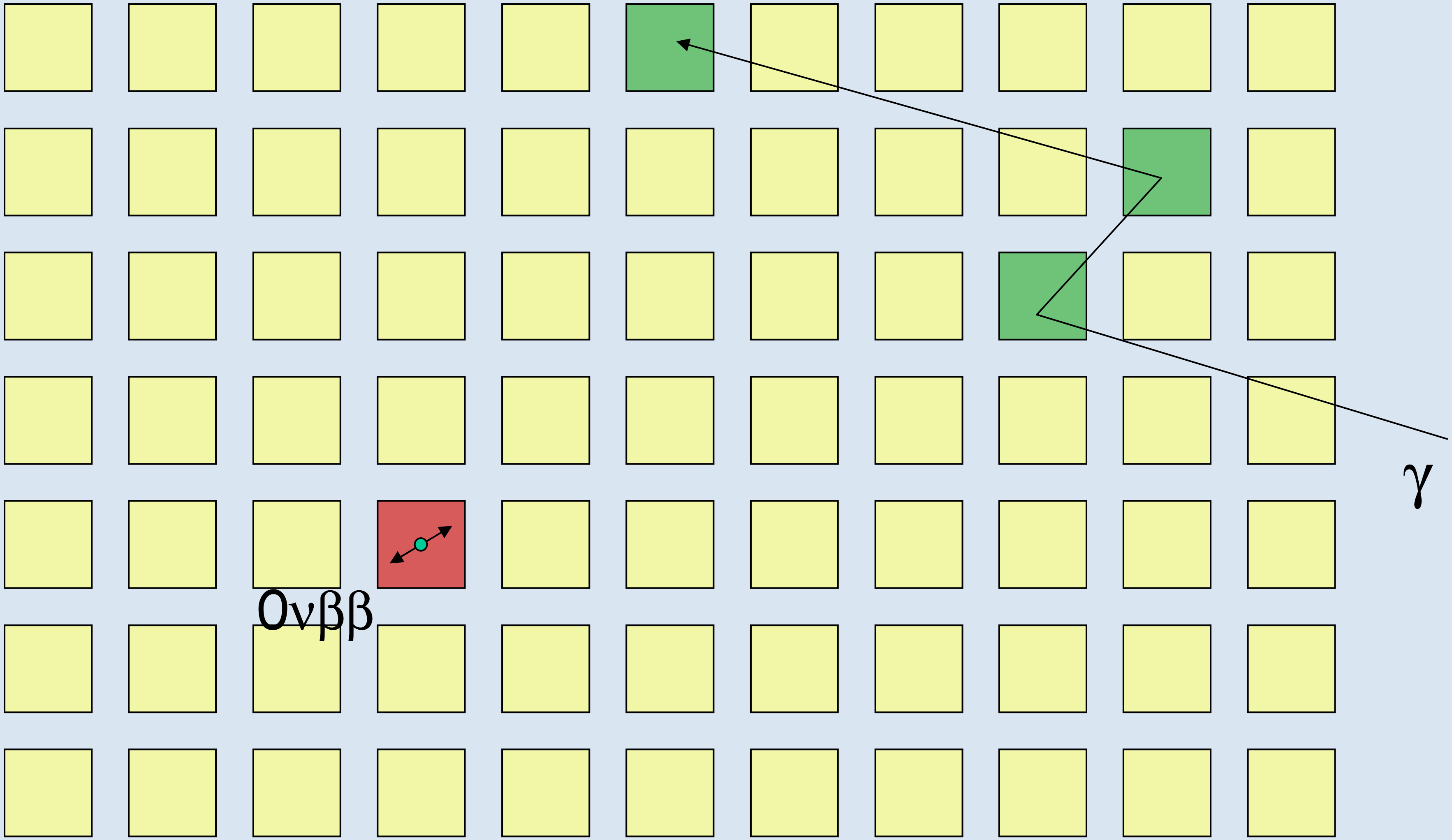

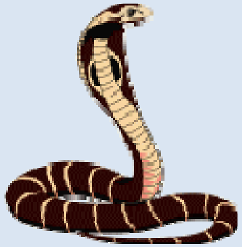

Advantages

- Source = detector
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- Room temperature (safety)
- Modular design (Coincidences)
- Multiple isotopes

Isotopes

	nat. ab. (%)	Q (keV)	Decay mode
Zn70	0.62	1001	ß-ß-
Cd114	28.7	534	ß-ß-
Cd116	7.5	2805	ß-ß-
Te128	31.7	868	ß-ß-
Te130	33.8	2529	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

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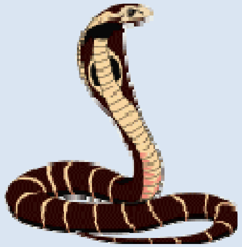
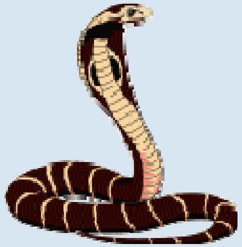
- ^{116}Cd above 2.614 MeV



Advantages

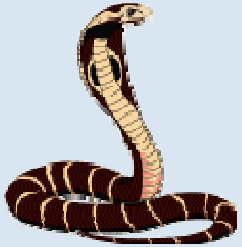
- Source = detector
- Semiconductor (Good energy resolution, clean)
- Room temperature (safety)
- Modular design (Coincidences)
- Multiple isotopes
- ^{116}Cd above 2.614 MeV
- Industrial development of CdZnTe detectors



Backgrounds

The major oppositions to any rare decay experiment:

- Natural radioactivity
- Cosmogenic backgrounds
  - See Ben's talk for more detail
- Neutrons
- Muons
  - See Danielle's poster for more detail
- $2\nu\beta\beta$ decays



Fast Decays – ^{214}Bi

- Can exclude backgrounds through timing coincidence

$$^{214}\mathrm{Bi} \xrightarrow{\beta} {}^{214}\mathrm{Po} \xrightarrow{\alpha} {}^{210}\mathrm{Pb}$$

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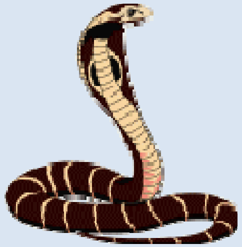
$$^{214}\mathrm{Bi} \xrightarrow{\beta} {}^{214}\mathrm{Po} \xrightarrow{\alpha} {}^{210}\mathrm{Pb}$$

β: endpoint 3.3MeV, accounts for >70% events in 2-3MeV region from ^{238}U chain

α: 7.7MeV alpha
half-life = 164.3μs



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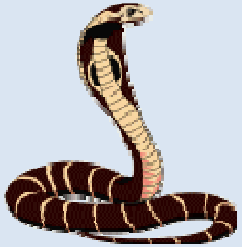
$$^{214}\mathrm{Bi} \xrightarrow{\beta} {}^{214}\mathrm{Po} \xrightarrow{\alpha} {}^{210}\mathrm{Pb}$$

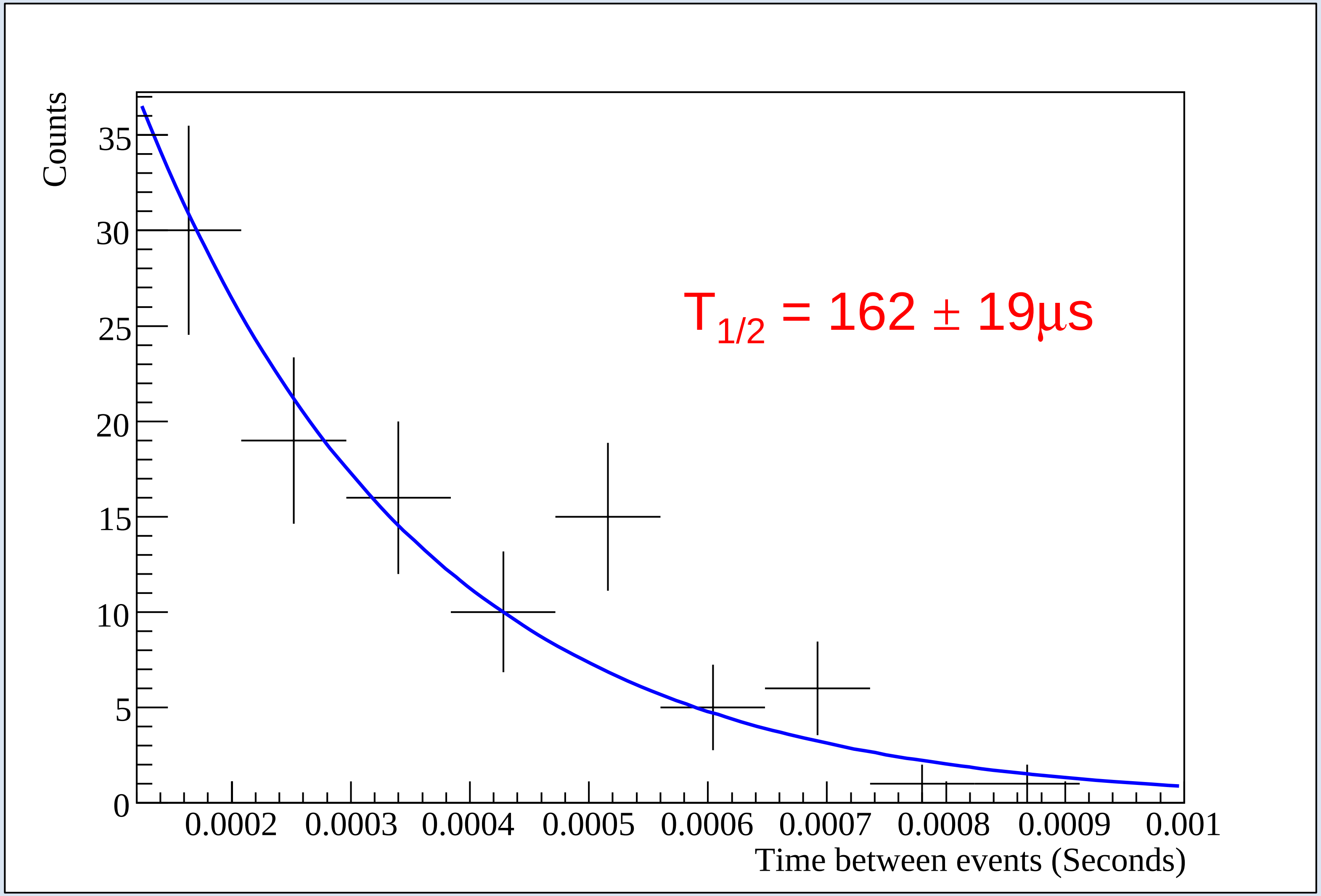
endpoint 3.3MeV, accounts for >70% events in 2-3MeV region from ^{238}U chain

7.7MeV alpha
half-life = 164.3μs

- Cut on events 7-8MeV and $\leq$ 1ms after a <3.3MeV event
- >40% efficiency for tagging ^{214}Bi events in detectors



Fast Decays – ^{214}Bi



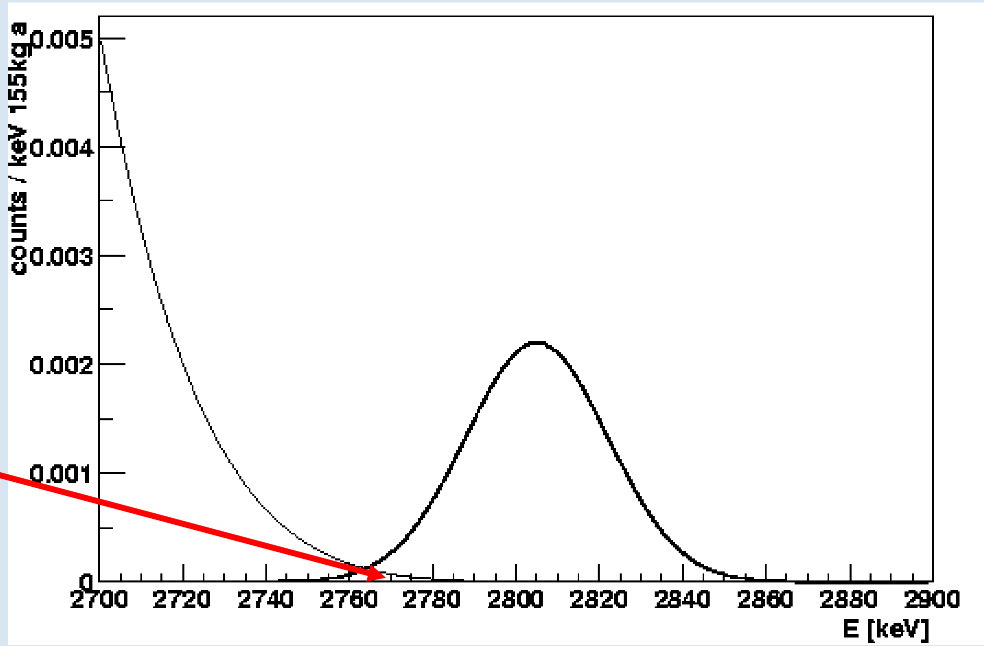
$2\nu\beta\beta$ decays

Fraction of $2\nu\beta\beta$ events in $0\nu\beta\beta$ peak region

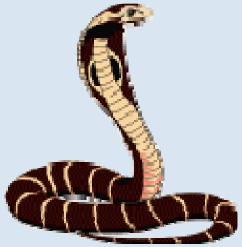
$$F = \frac{8Q(\Delta E/Q)^6}{m_e} = 2.46\times10^{-9}$$

($\Delta E = 2\%$)

Reduce contribution
by improving resolution

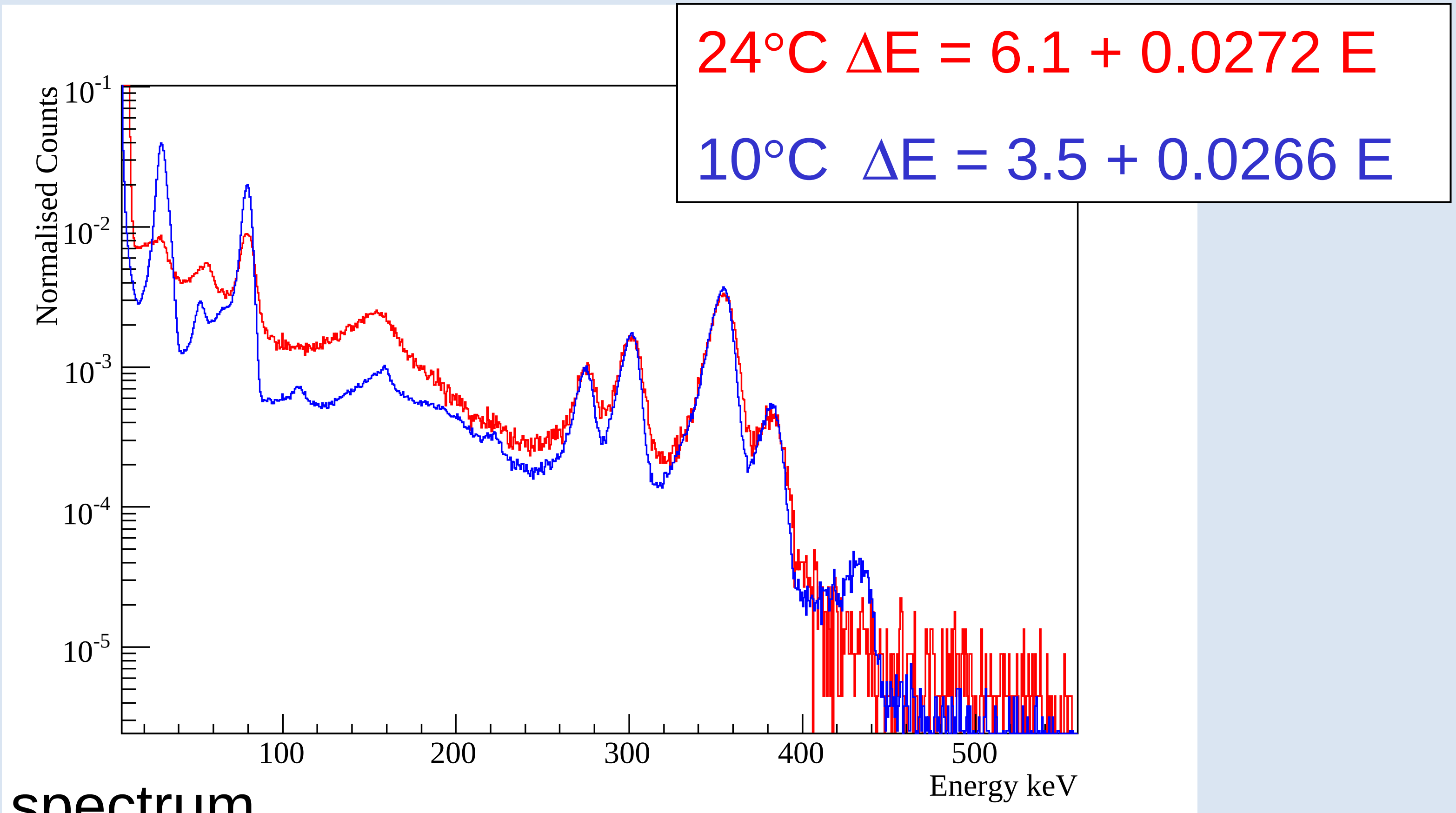


S. Elliott, P. Vogel, Ann. Rev. Nucl. Part. Sci. 2002



Energy Resolution

- Lab tests show modest cooling improves resolution and lowers threshold



^{113}Barium spectrum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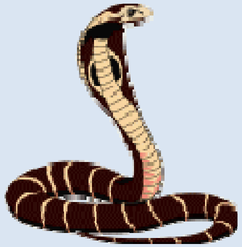
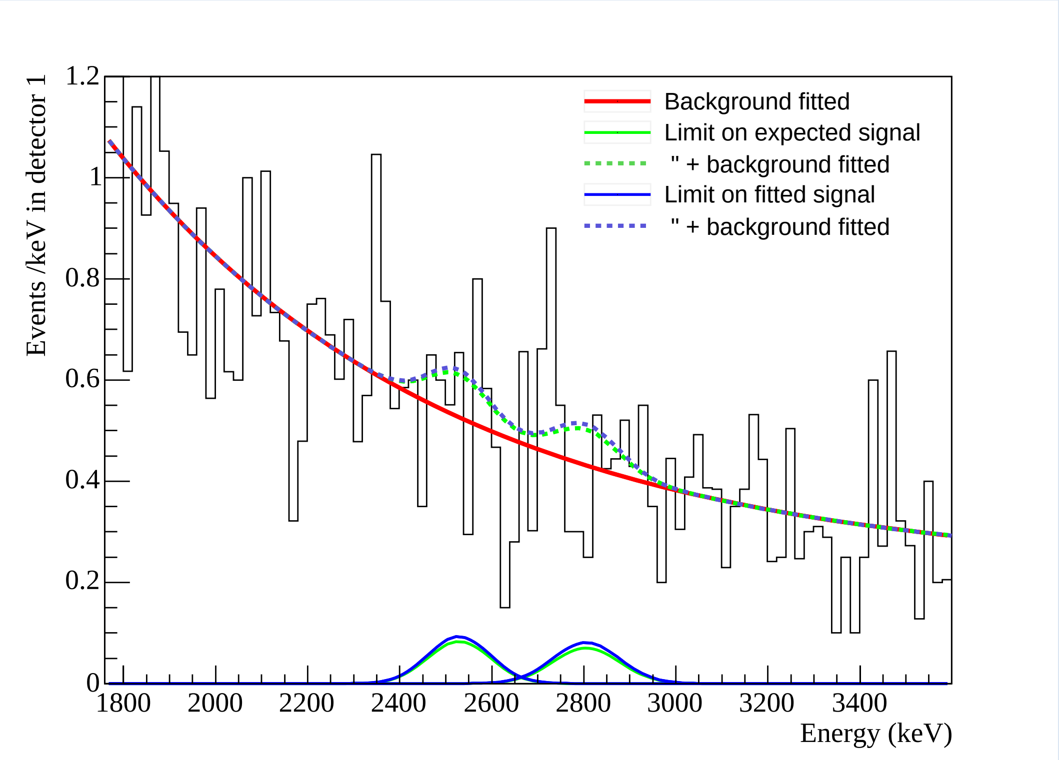


Experimental Status

- Test setup in Dortmund (2002-2003)
- Test set up in Gran Sasso (mar–aug 2003)
- “Old proto-type” 2*2 array in Gran Sasso (aug 2003 – jan 2005)
- “New proto-type” 2*2 array in Gran Sasso (jan 2005 – jan 2006)

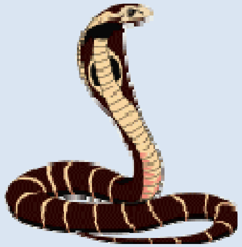
Physics - 0νββ Half life limits



- Maximum Likelihood fit for exponential background gaussian signal to data.
- Allow background to vary between crystals

Isotope	Decay	$T_{1/2}$ limit	
		This work	World Best
$\beta^-\beta^-$ decays			
^{116}Cd	to g.s	1.18×10^{19}	1.7×10^{23} [Dan03]
^{130}Te	to g.s	5.67×10^{19}	1.8×10^{24} [Arn05]
^{130}Te	to 536 keV	4.63×10^{19}	9.7×10^{22} [Ale00]
^{116}Cd	to 1294 keV	4.26×10^{18}	2.9×10^{22} [Dan03]
^{116}Cd	to 1757 keV	8.71×10^{18}	1.4×10^{24} [Dan03]
^{70}Zn	to g.s	1.58×10^{17}	9.0×10^{17} [Dan05]
^{128}Te	to g.s	3.11×10^{19}	1.1×10^{23} [Arn03]
^{116}Cd	to 2112 keV	1.85×10^{19}	6.0×10^{21} [Dan03]
^{116}Cd	to 2225 keV	6.47×10^{19}	$1.0\times10^{20\dagger}$ [Bar90]
$\beta^+\beta^+$ decays			
^{64}Zn	$0\nu\beta^+$EC to g.s.	$\mathbf{5.07\times10^{18}}$	2.4×10^{18} [Dan05]
^{64}Zn	0νECEC to g.s.	$\mathbf{9.52\times10^{16}}$	7.0×10^{16} [Dan05]
^{120}Te	$0\nu\beta^+$EC to g.s.	$\mathbf{4.89\times10^{16}}$	2.2×10^{16} [Kie03]
^{120}Te	0νECEC to g.s.	$\mathbf{1.91\times10^{15}}$	-
^{120}Te	0νECEC to 1171keV	$\mathbf{3.84\times10^{15}}$	-
^{106}Cd	$0\nu\beta^+\beta^+$ to g.s.	3.57×10^{17}	2.4×10^{20} [Bel99]
^{106}Cd	$0\nu\beta^+$EC to g.s.	2.48×10^{19}	3.7×10^{20} [Bel99]
^{106}Cd	0νECEC to g.s.	5.34×10^{16}	1.5×10^{17} [Nor84]
^{106}Cd	$0\nu\beta^+\beta^+$ to 512keV	7.45×10^{16}	1.6×10^{20} [Bel99]
^{106}Cd	$0\nu\beta^+$EC to 512keV	1.93×10^{18}	2.6×10^{20} [Bel99]

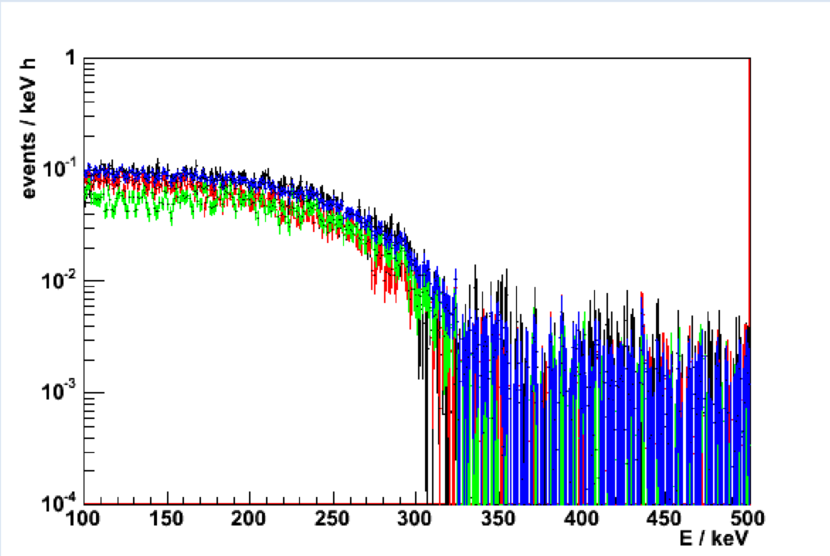
Table 1: 90% C.L.s obtained for various decays with conservative systematic uncertainties applied, compared to the world best limits. New world best values from COBRA are in bold.

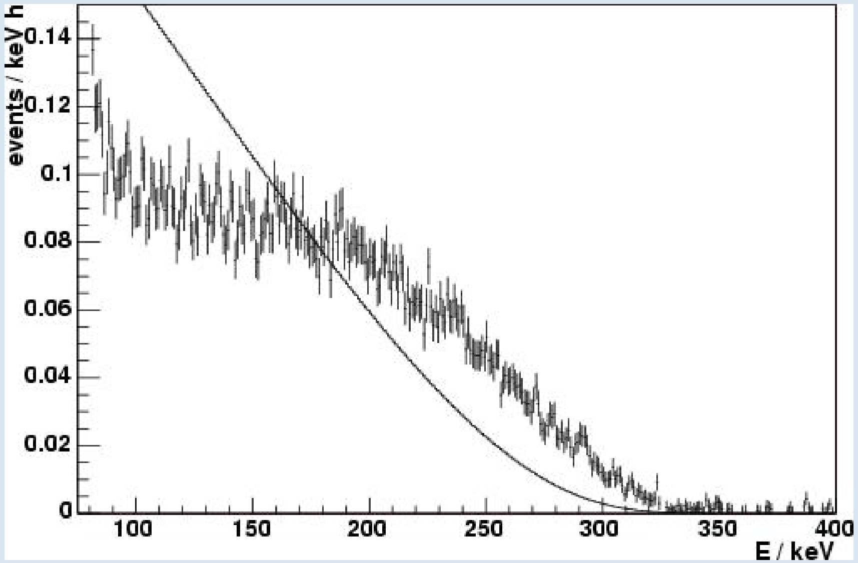


Physics – ^{113}Cd

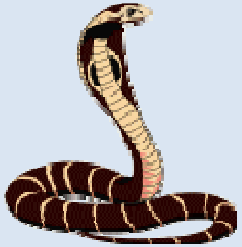
One of only three 4-fold forbidden β-emitters known in nature. $S^p\ \tfrac{1}{2}^+ \Rightarrow \tfrac{9}{2}^+$

$$T_{1/2} = (8.2 \pm 0.2\ (\text{stat.}) \pm^{0.2}_{1.0}\ (\text{sys}))\ 10^{15}\ \text{yrs}$$





C. Goessling et al. Physical Review C, 2005, 72, 064328



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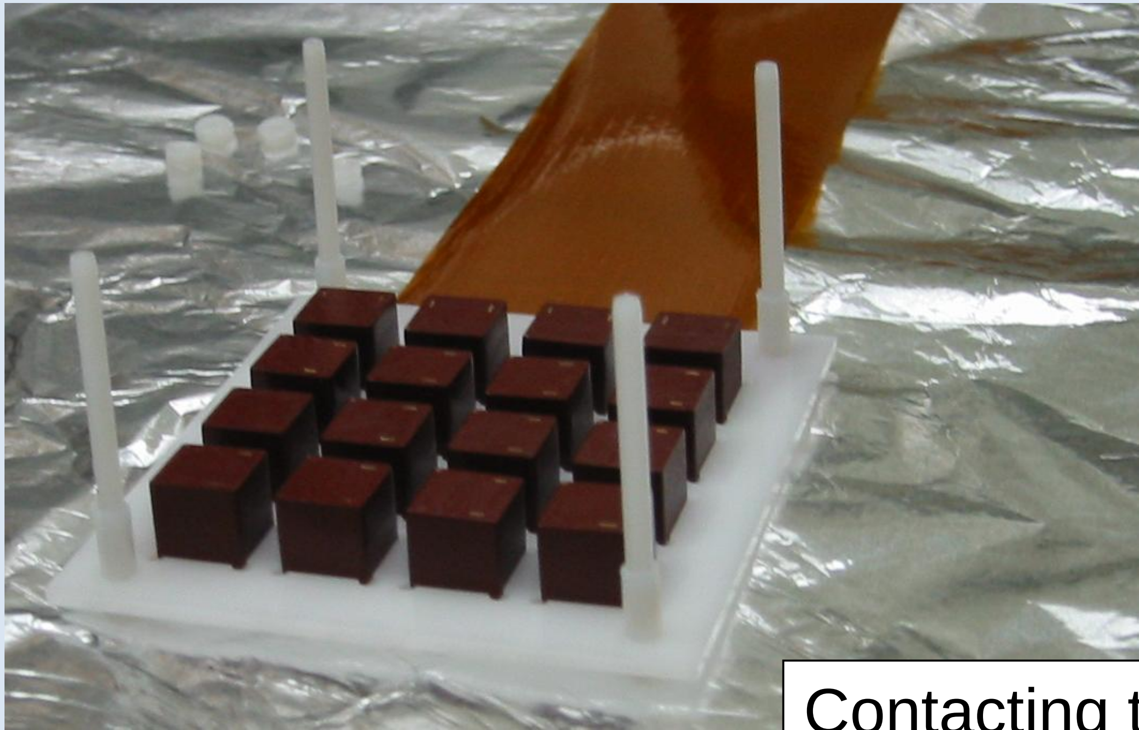
- “New proto-type” 2*2 array in Gran Sasso (jan 2005 – end 2006)
- 64 array (NOW)

…..and beyond

The 64-Array

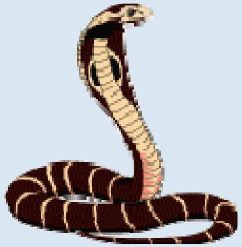
- 0.42 kg CdZnTe
- Cooling – N_2 flushing
- Wire calibration sources

The 64-Array



Contacting the first layer

- Explore coincidences
- Improve on exisiting half-life limits
- Access to 2ν2EC

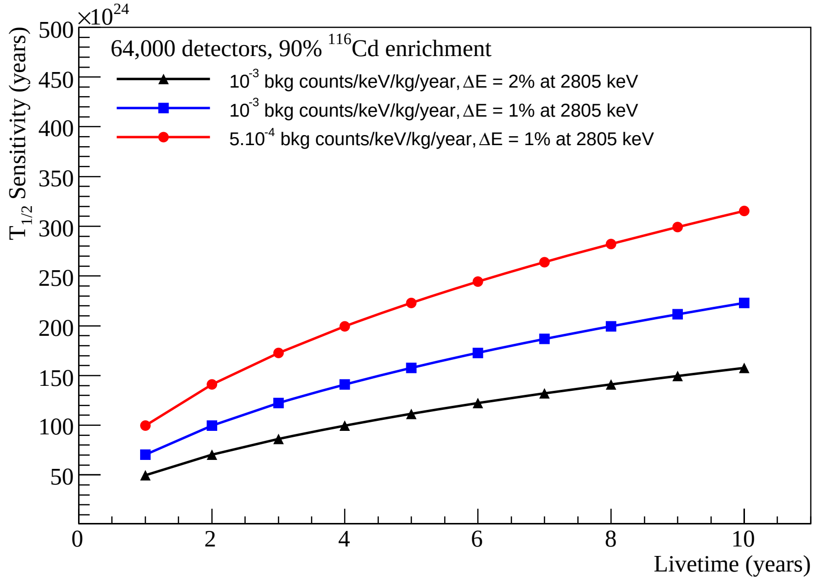


Summary and Outlook

- CdZnTe has many advantages
- Physics results even with small mass
- Installation and comissioning of 64 detector array (about 0.5 kg) underway

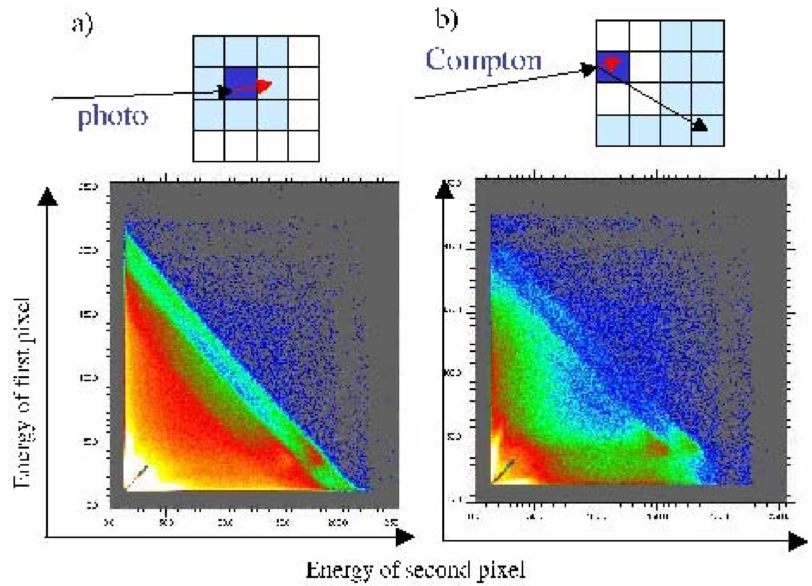

Sssspare ssslidesss

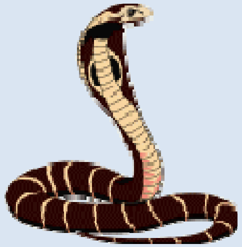
The future



- 64,000 detectors
- 90% enriched in ^{116}Cd

- Pixellisation of detectors
- Background suppression
- Signal identification





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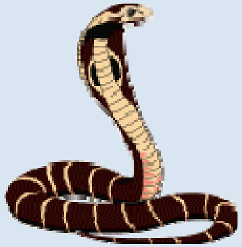
- Source = detector
- Semiconductor (Good energy resolution, clean)
- Room temperature (safety)
- Modular design (Coincidences)
- Multiple isotopes
- ^{116}Cd above 2.614 MeV
- Industrial development of CdZnTe detectors
- Tracking ("Solid state TPC")

Surface contamination

- Coating required for passivation – stable operation of crystals.

- Found to contain ‘high’ levels of U, Th, K
- New clear paint developed by EV-products
- Alternative suppliers - alternative passivation techniques



C. Goessling et al. nucl-ex/0508016

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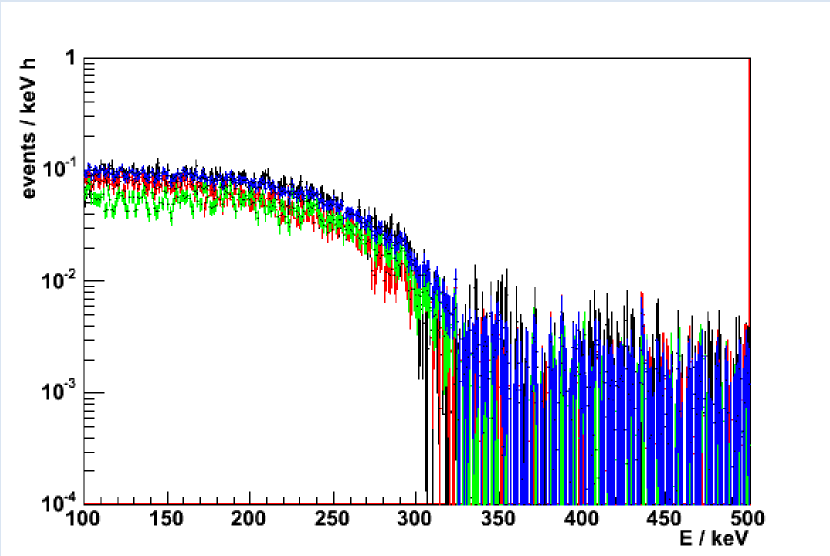

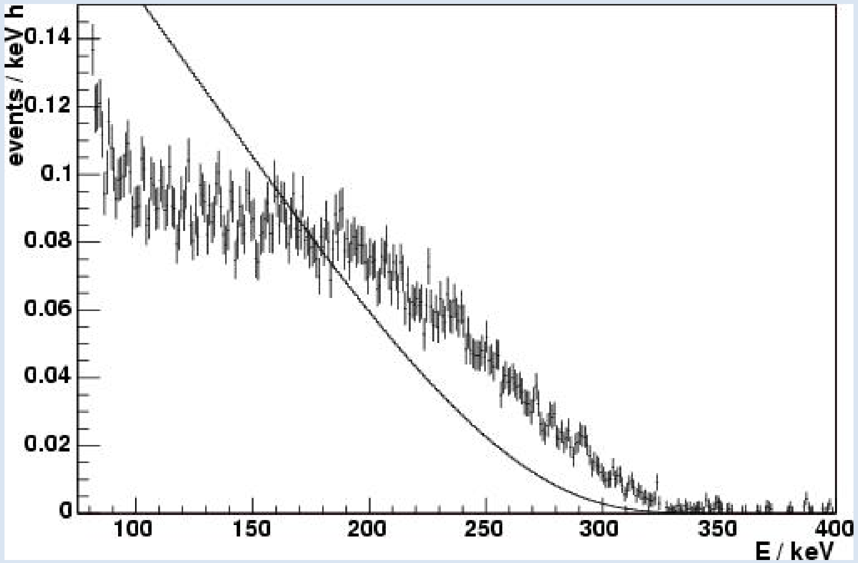

$T_{1/2} = (7.7 \pm 0.3)\ 10^{15}$ yrs — Danevich et al. 1996

$T_{1/2} = (9.0 \pm 0.5 \pm 1.0)\ 10^{15}$ yrs — Allessandrello et al. 1994