Position sensitive CZT detectors for the COBRA neutrinoless double beta decay project

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Neutrinoless double beta decay
The COBRA project
CZT detector development

NEUTRINOLESS DOUBLE BETA DECAY

Beta decay is a well understood process, with lifetimes ranging from milliseconds to years

e.g. $^{14}O \rightarrow ^{14}N + e^{+} + \nu$ $(t_{1/2} = 70.5 \text{ s})$

$^{14}C \rightarrow ^{14}N + e^{-} + \bar{\nu}$ $(t_{1/2} = 5703 \text{ yr})$

The decay energy is shared between the electron and neutrino

Double beta decay is a much rarer process (35 possible nuclei) with much longer lifetimes

e.g. $^{76}Ge \rightarrow ^{76}Se + 2e^{-} + 2\bar{\nu}$ $(t_{1/2} = 1.1 \times 10^{21} \text{ yr})$

Again, the decay energy is shared between the electrons and the neutrinos

An alternative form of double beta decay can be postulated where no neutrinos are emitted (**neutrinoless double beta decay**)

e.g. $^{76}Ge \rightarrow {}^{76}Se + 2e^-$

This time, the decay energy is carried away entirely by the two electrons, so their sum energy is unique (equals the decay Q-value)

Think of this as a two step decay, with the first neutrino interacting with a second neutron in the nucleus

$n \rightarrow p + e^- + \bar{\nu}$ then $\nu + n \rightarrow p + e^-$

But wait….. The first step emits an anti-neutrino, while the second needs a normal neutrino

So $0\nu\beta\beta$ decay could only occur if the neutrino and its antiparticle are the same

Interestingly, there is no experimental evidence against this and indeed theorists have long speculated this might be the case

DIRAC PARTICLE	particle and anti-particle different
MAJORANA PARTICLE	particle and anti-particle same

So $0\nu\beta\beta$ decay could occur and if it does would show the neutrino to be a Majorana particle…….

…which would have an enormous impact on physics

But there is another neat twist

Theory says the decay life-time would depend on three factors

$$T_{1/2} = F(Q) \times \langle \Psi_D | \Psi_P \rangle \times (M_\nu)$$

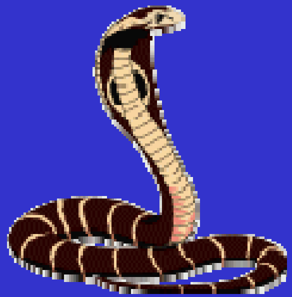
Phase space factor (exactly calculable)

Overlap of nuclear wavefunctions (calculate with shell model)

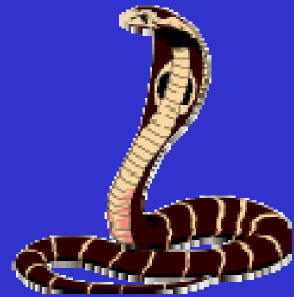
Depends on mass of neutrino

So a measurement of the life-time gives the neutrino mass!

THE COBRA PROJECT



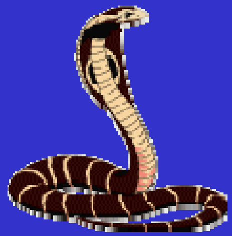
COBRA



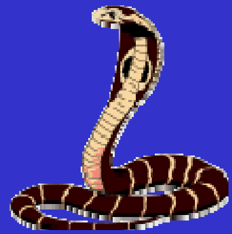
Cadmium telluride **0** neutrino **B**eta **R**esearch **A**pparatus

Recently a group of five UK nuclear and particle groups have come together with Dortmund in the COBRA project to measure $0\nu\beta\beta$ with a sensitivity of ~50 meV

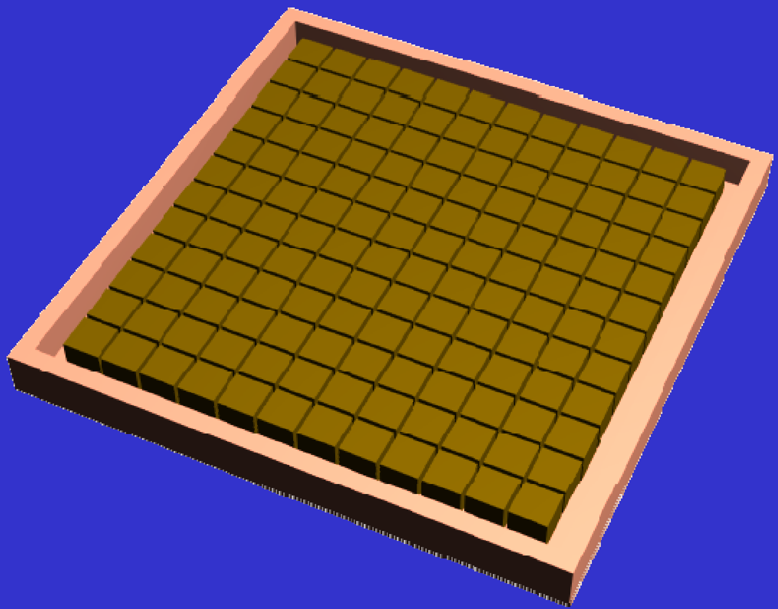
Birmingham, Liverpool and York	Detector knowledge
Dortmund, Sussex and Warwick	Low background

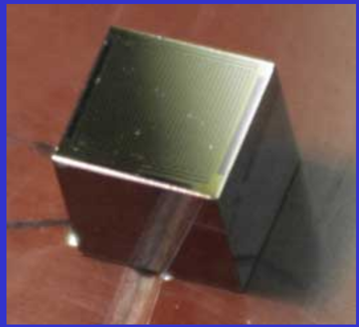


C0BRA



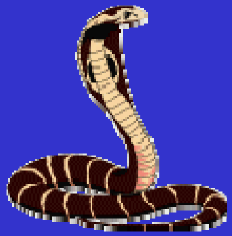
Use large number of CdZnTe Semiconductor Detectors



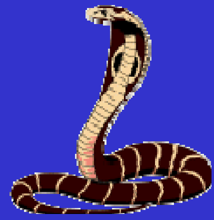


Array of $1 cm^3$ CdTe detectors

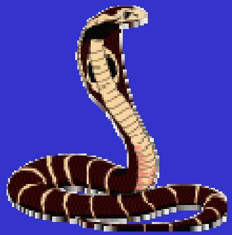
K. Zuber, Phys. Lett. B 519,1 (2001)



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

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

The big problem in any measurement of this type is background

Expecting lifetimes in range of 10^{26} years, so even with 100's of kg of detectors, looking for a few events per year!

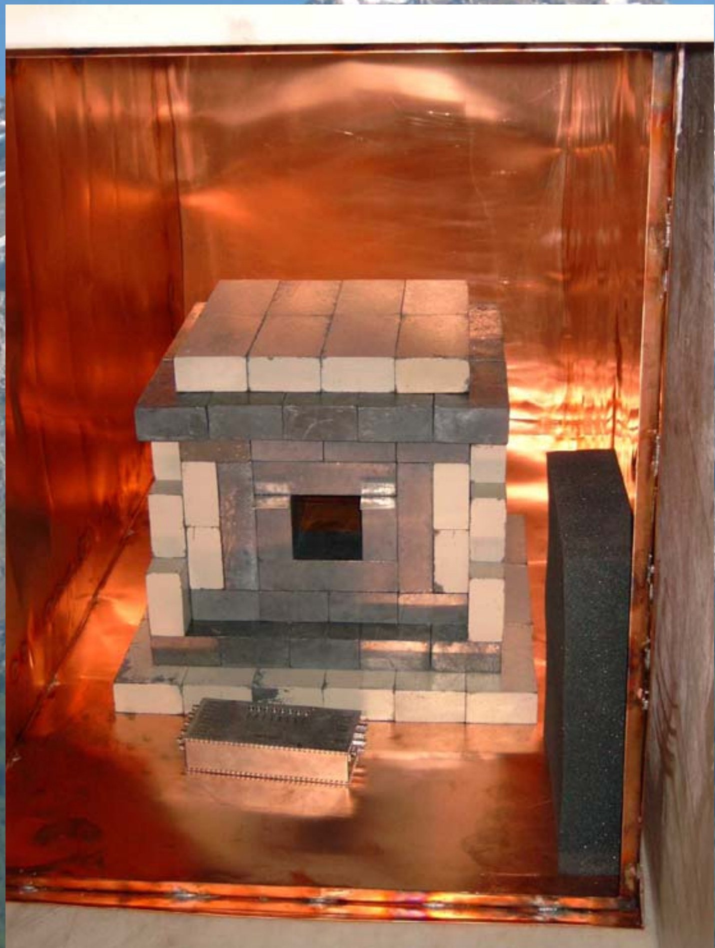
Good energy resolution
(so events in narrow region of spectrum)

Low background
(so no counts in region of signal peak)

Improve detector performance

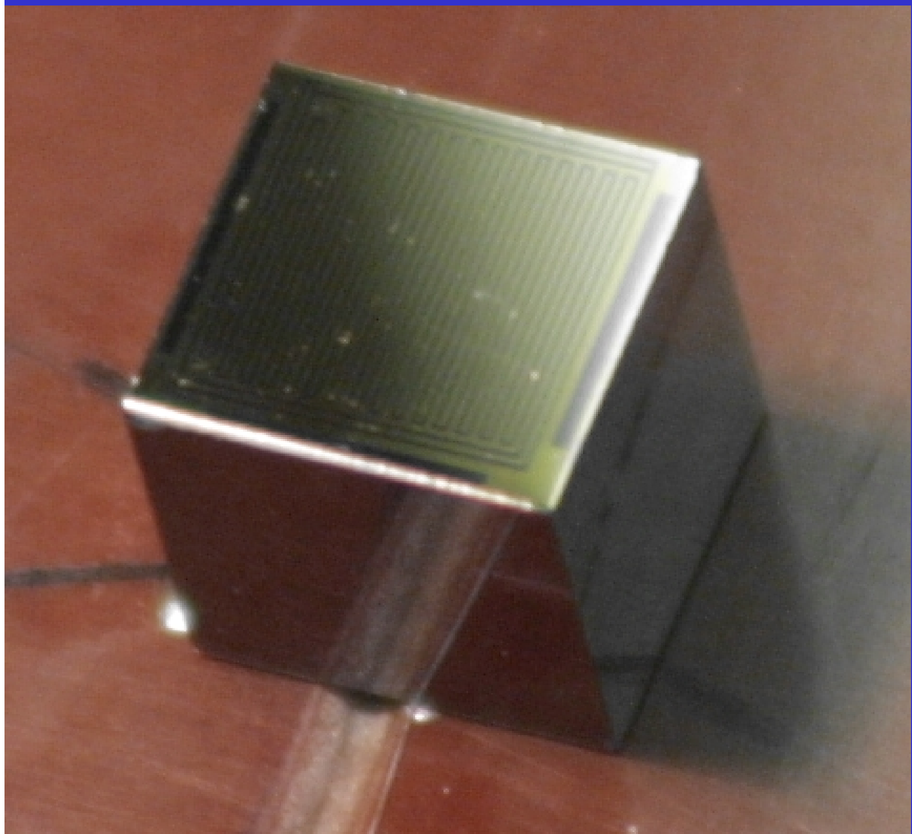
Go underground

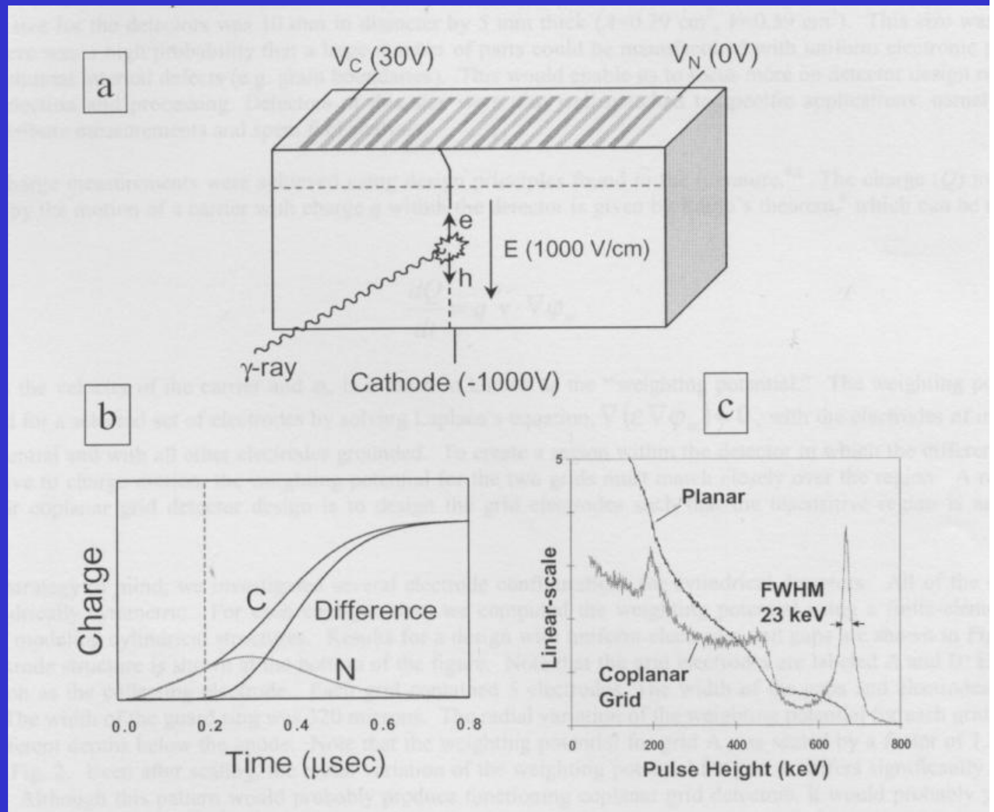
Gran Sasso Installation



CZT DETECTOR DEVELOPEMT

At present COBRA uses 1 x 1 x 1 cm cube detectors from eV Products which use the “Coplanar Grid” approach to avoid the poor resolution arising from charge trapping because of the slow hole transport



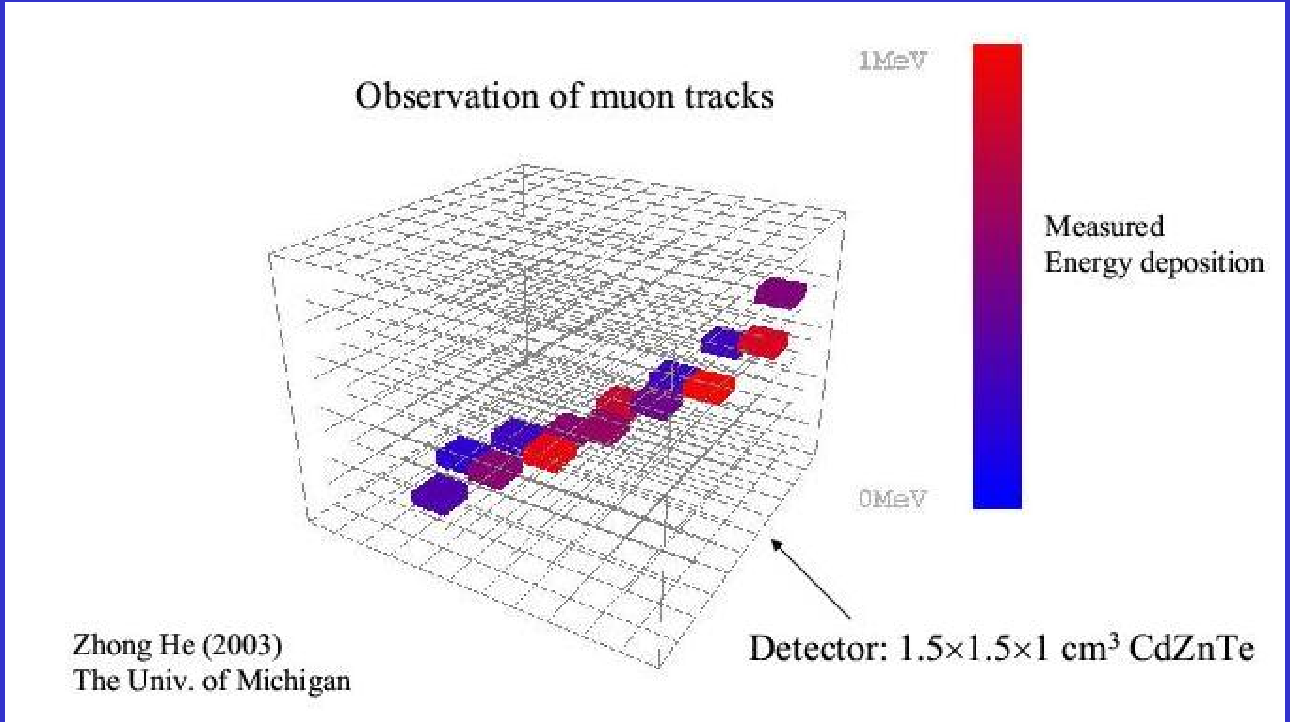


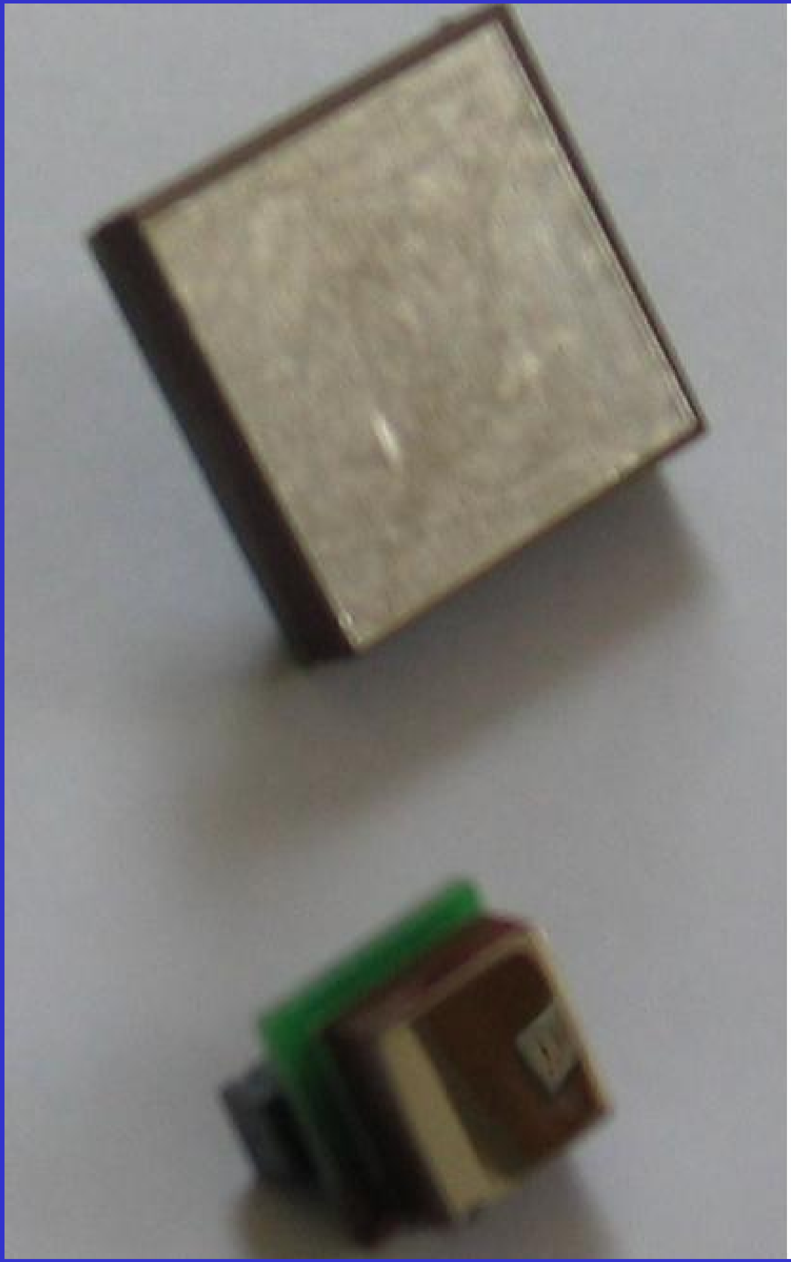
T H Pettyman et al. LANL LA-UR-99-3117

Present work concentrating on learning how to get the best from these detectors:

- electronics (preamps, shaping times etc.)
- cooling (optimum temperature)
- understanding different response to β, γ and α

Just starting to look at advantages of using pixillated detectors





25 x 25 x 5 mm

16 x 16 pixels (1.5 mm)

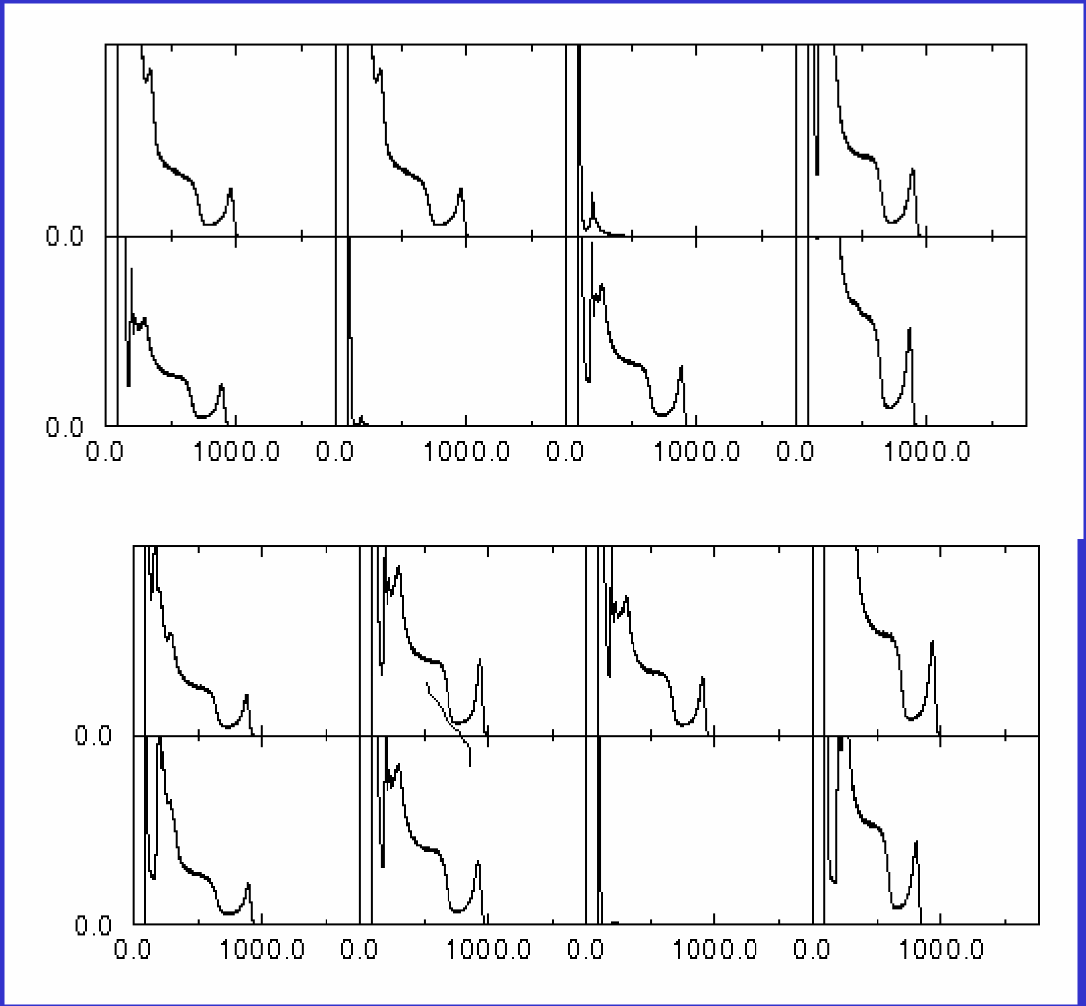
Test of event localisation

10 x 10 x 5 mm

4 x 4 pixels (2.5 mm)

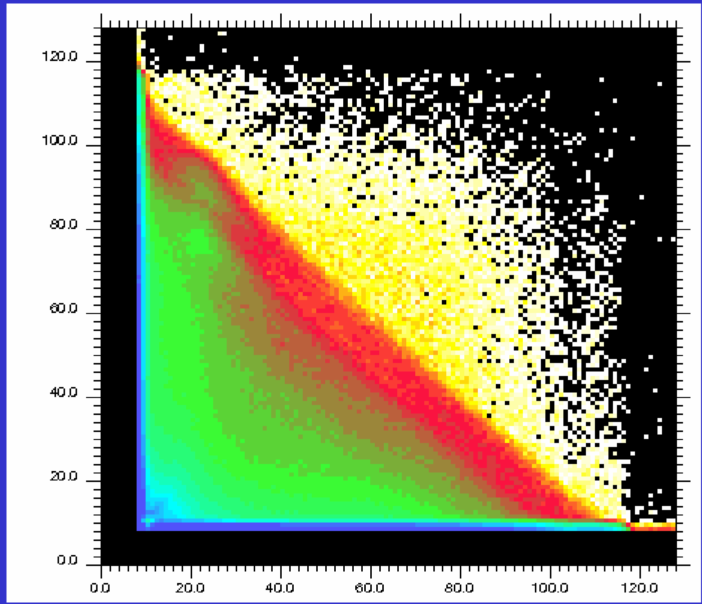
Test of pulse shape information

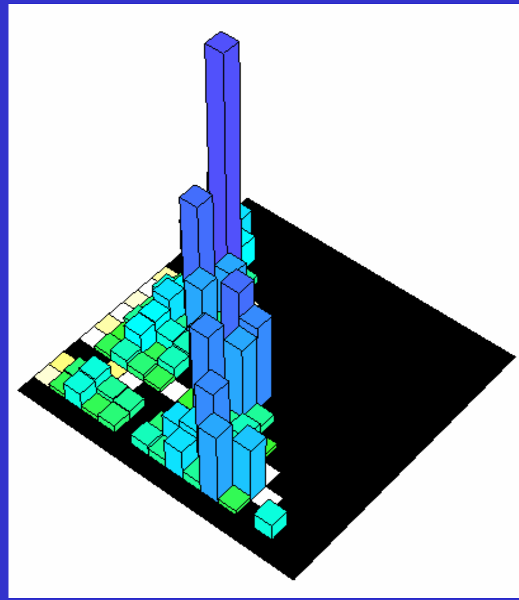
^{137}Cs



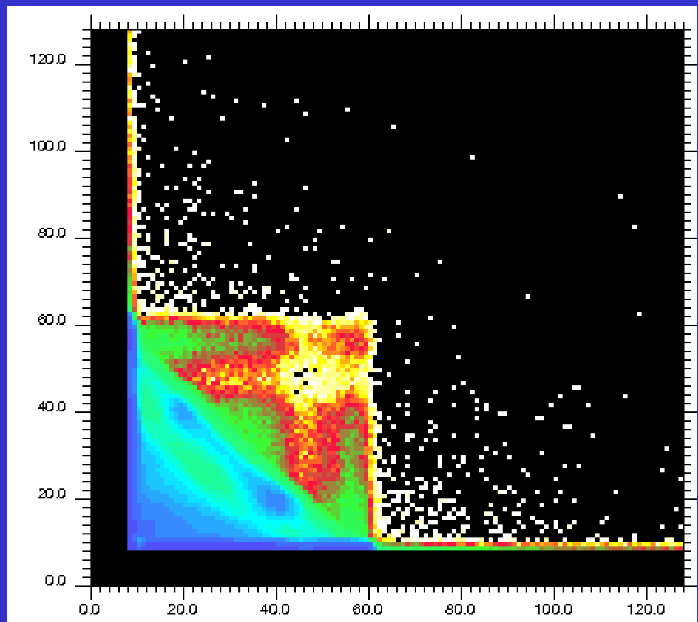
Individual pixel spectra look good, but……..

^{60}Co


120.0
100.0
80.0
60.0
40.0
20.0
0.0
0.0
20.0
40.0
60.0
80.0
100.0
120.0



^{137}Cs


120.0
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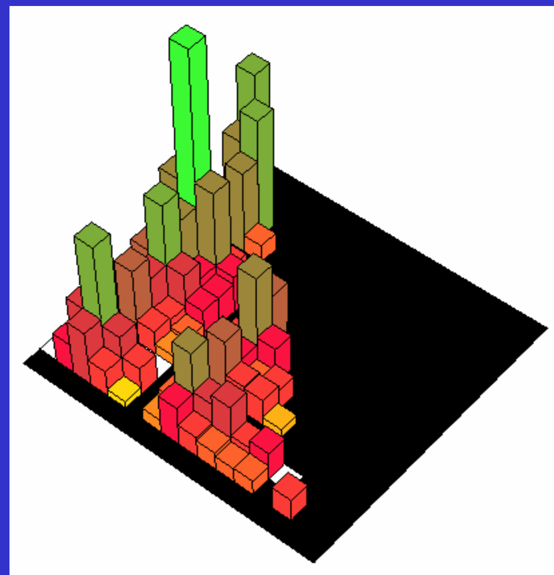
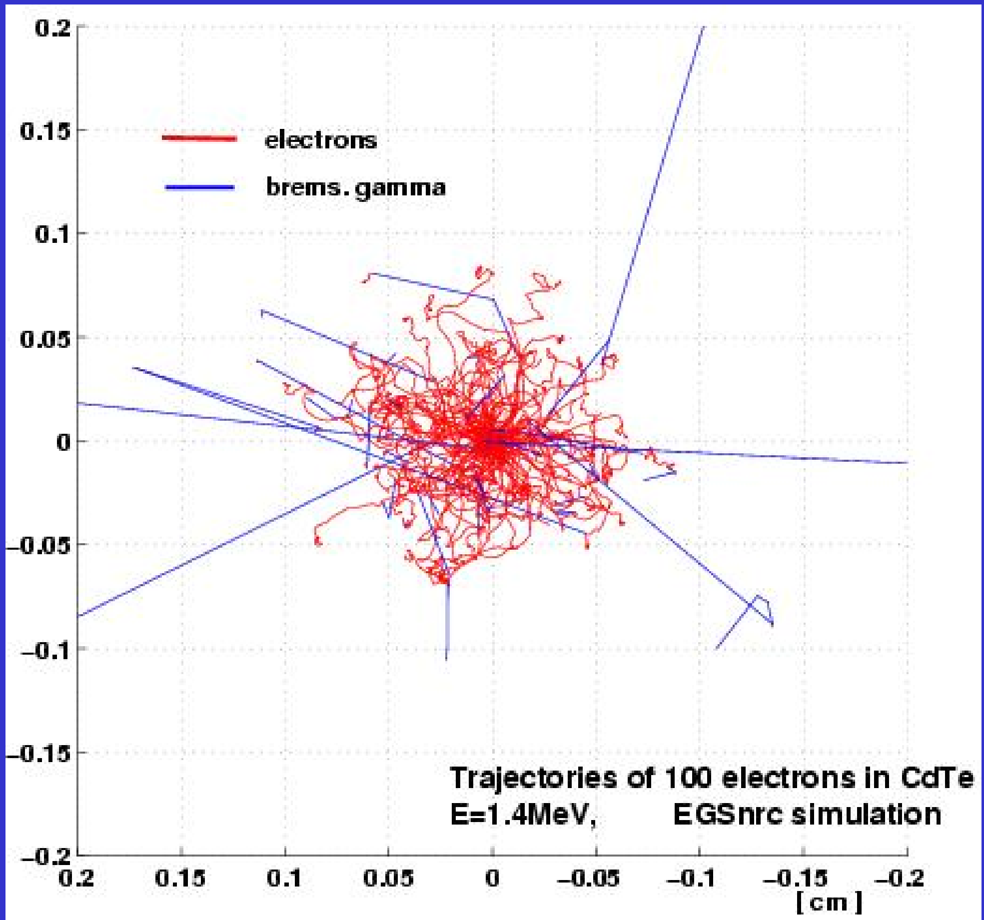


At first sight this appears bad, but it is potentially good news

While gammas tend to Compton scatter between pixels, betas will dump their energy in a small volume (single pixel?)



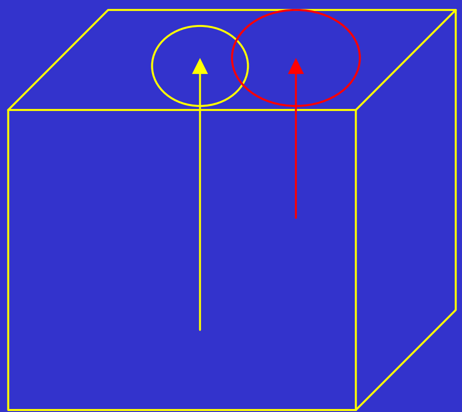
Next step is to check these simulations by implanting radioactive nuclei into the detector and recording the decays

Next step will be to look at what additional information can be obtained by using digital encoding to record the waveform

Can we distinguish between α, β and γ based on rise time?

For same energy, α and β produce different plasma density on ionisation trail – takes longer for the electric field to start separating

Can the mirror charge on adjacent pixels reveal the event depth ?



Pattern and time evolution of mirror charge induced on adjacent pixels will depend on the depth of the interaction point

Present Status

64 detector prototype array using co-planar grids being installed at Gran Sasso and will be taking test data by the end of the year.

Starting to look at using pixillated detectors to provide additional ways of reducing background

Need to check simulations with measurements on a real detector (implant radioactive nuclei into detector and record decays)

Then need to see if we can pick up additional information on the event topology by looking at mirror charges on adjacent electrodes.

And finally, face the technological challenge of instrumenting 64,000 such detectors!

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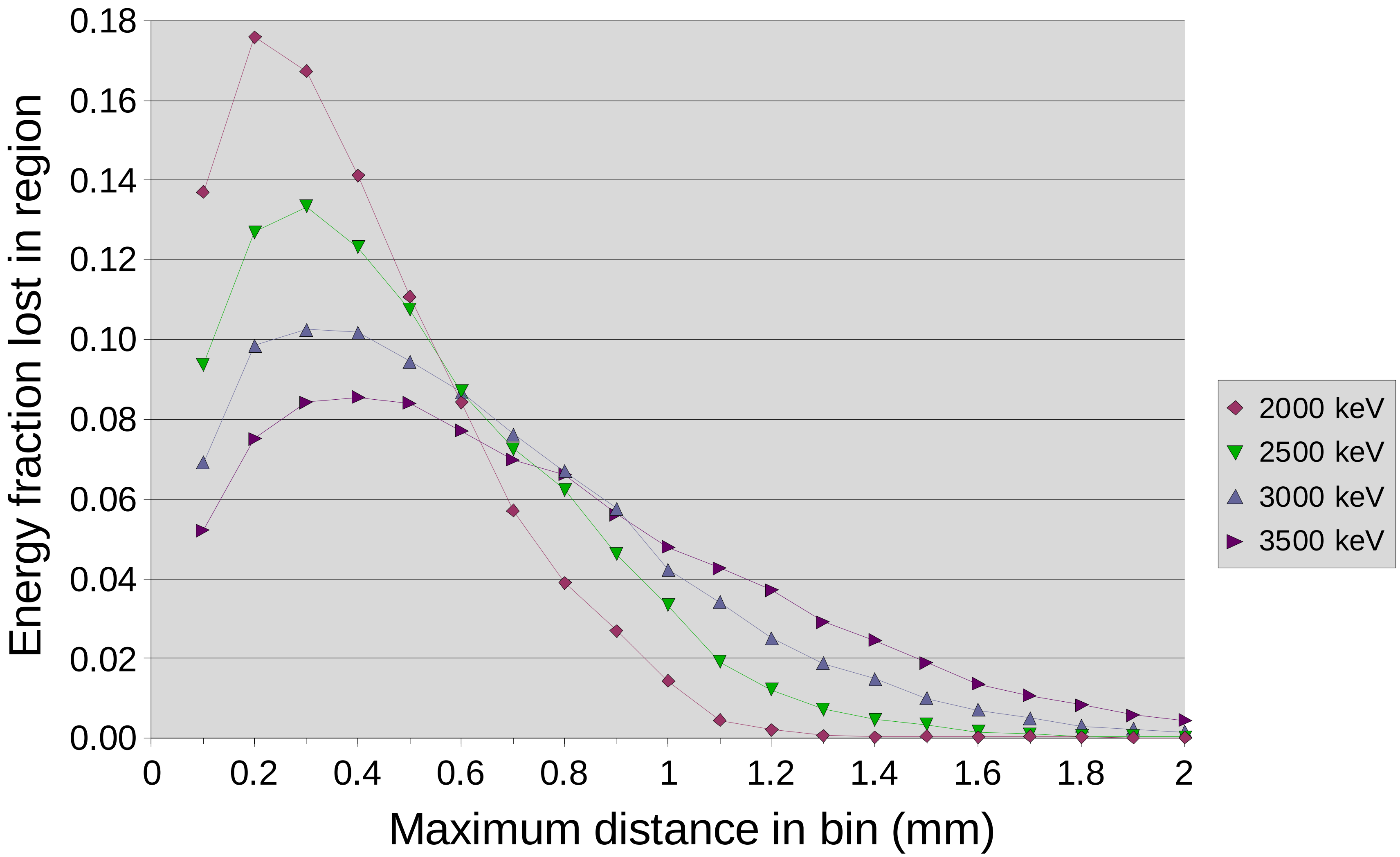
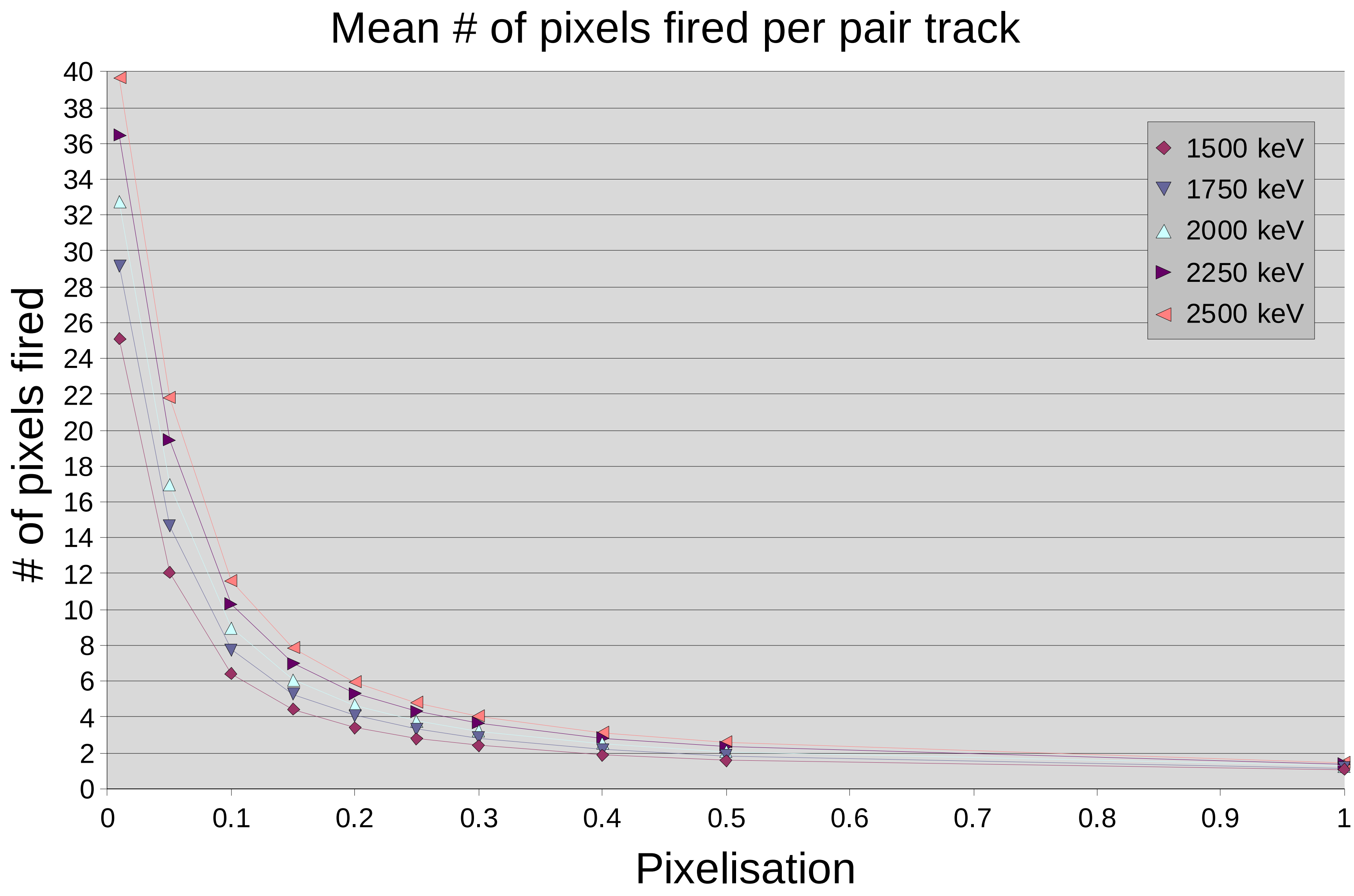
Fraction of energy deposited by pair events





Mean # of pixels fired per pair track
# of pixels fired
Pixelisation
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1500 keV
1750 keV
2000 keV
2250 keV
2500 keV