The COBRA Double Beta Decay Experiment

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On behalf of the COBRA collaboration

DBD07, Osaka

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Who we are

COBRA collaboration

University of Sussex — University of York
University of Warwick — University of Birmingham
University of Liverpool — Rutherford Appleton Laboratory

University of Dortmund
Material Research Centre Freiburg

Laboratori Nazionali del Gran Sasso

University of Bratislava

Washington University at St. Louis

University of Surrey (UK), University of Hamburg (Germany), Jagellonian University (Poland), University of Prague (Czech Republik), Louisianna State University (USA)

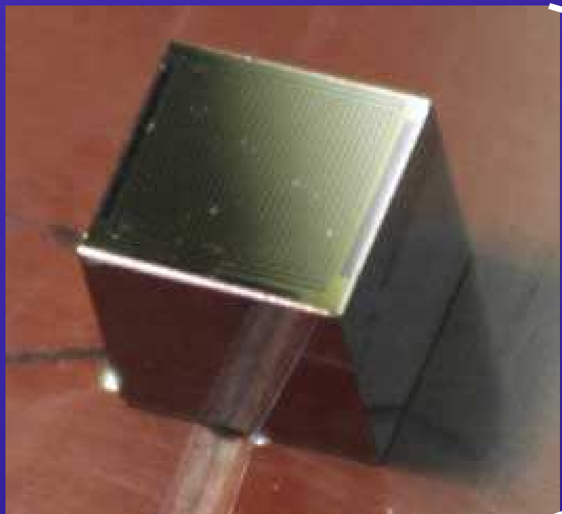
The experimental concept

The COBRA Concept

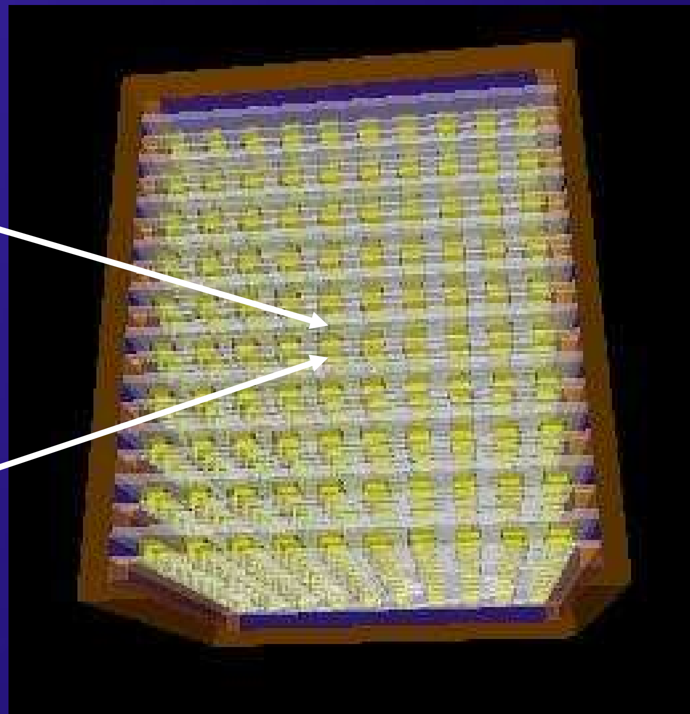
K. Zuber, Phys. Lett. B 519,1 (2001)

CZT 0-neutrino Beta-decay Research Apparatus

Build up a large array of CdZnTe semiconductor detectors
(9 double beta decay isotopes)



1 cm^3 CPG Detector



Isotopes

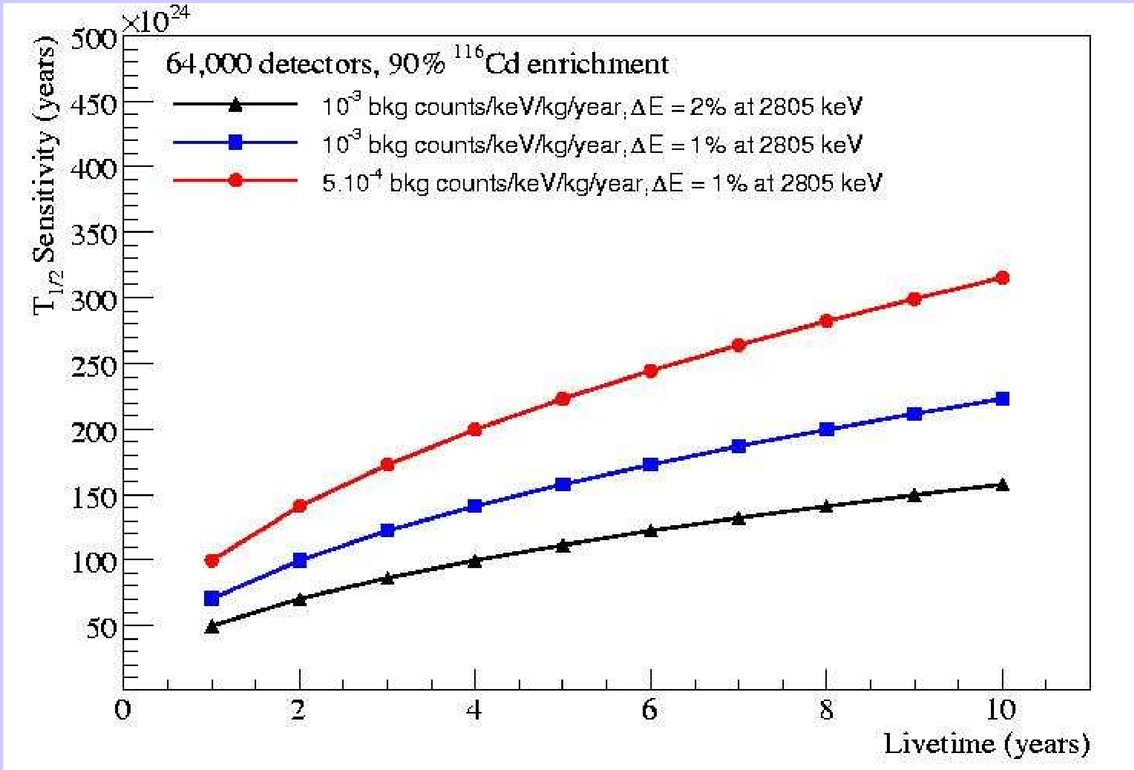
	nat. ab. (%)	Q (keV)	Decay mode
Zn70	0.62	1001	ß-ß-
Cd114	28.7	534	ß-ß-
Cd116	7.5	2809	ß-ß-
Te128	31.7	868	ß-ß-
Te130	33.8	2529	ß-ß-
Zn64	48.6	1096	ß+/EC
Cd106	1.21	2771	ß+ß+
Cd108	0.9	231	EC/EC
Te120	0.1	1722	ß+/EC

Advantages

- Source = detector
- Semiconductor (Good energy resolution ~1%)
- Room temperature
- Modular design (Coincidences)
- Several isotopes and decay modes at once
- Industrial development of CdTe detectors
- ^{116}Cd above 2.614 MeV
- Tracking (Solid state TPC)

Experimental Requirements

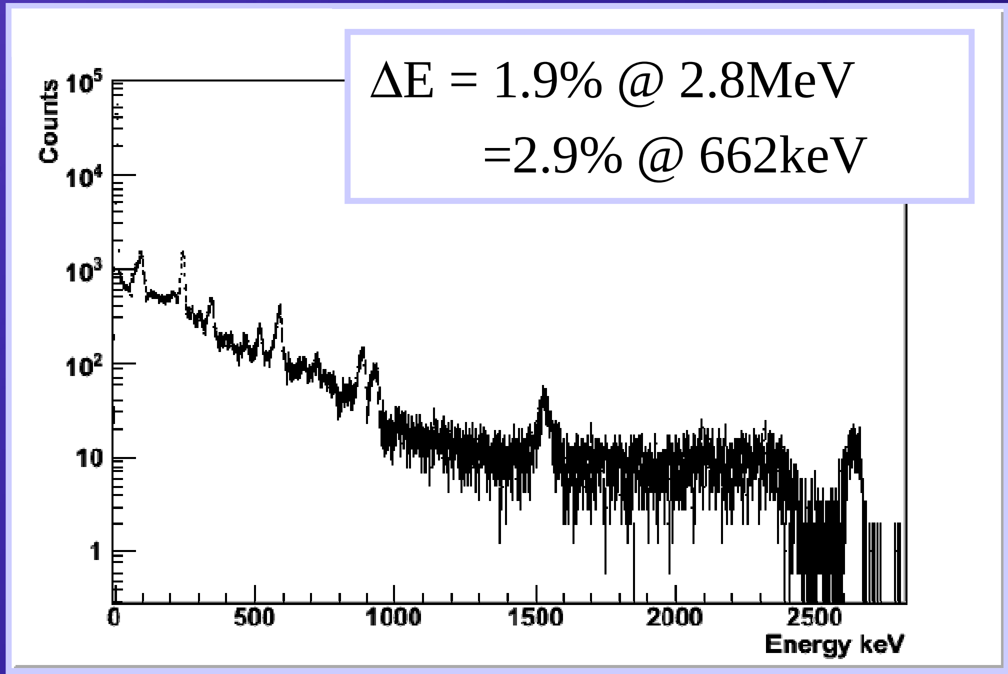
$$T_{1/2}^{0\nu} \propto a\varepsilon\sqrt{\frac{Mt}{\Delta EB}}$$



- 64,000 1cm^3 crystals = 418 kg
- 90% enriched in ^{116}**Cd**
- Backgrounds < 0.001 count keV^{-1}kg^{-1}year^{-1}
- Energy Resolution < 2%

Energy Resolution

Resolution of σ=0.8% at 2.8 MeV

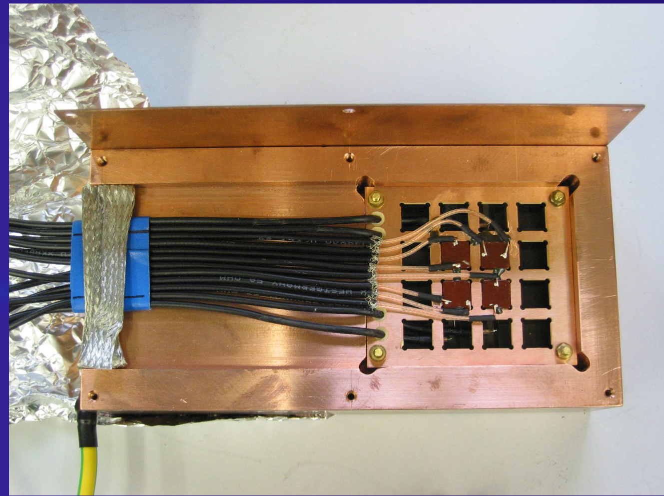


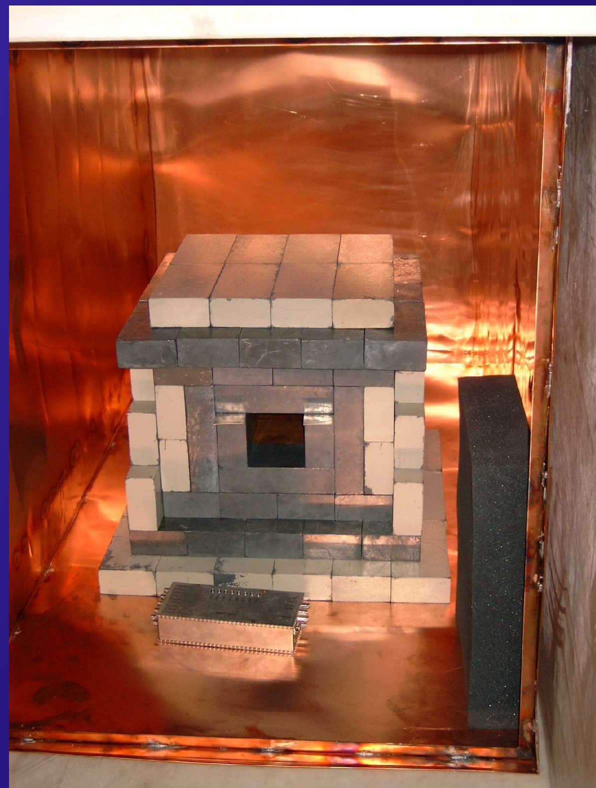
- Only electron signal read out (CPG technology)
- Possible improvements: cooling, new grids
- Better detectors are available

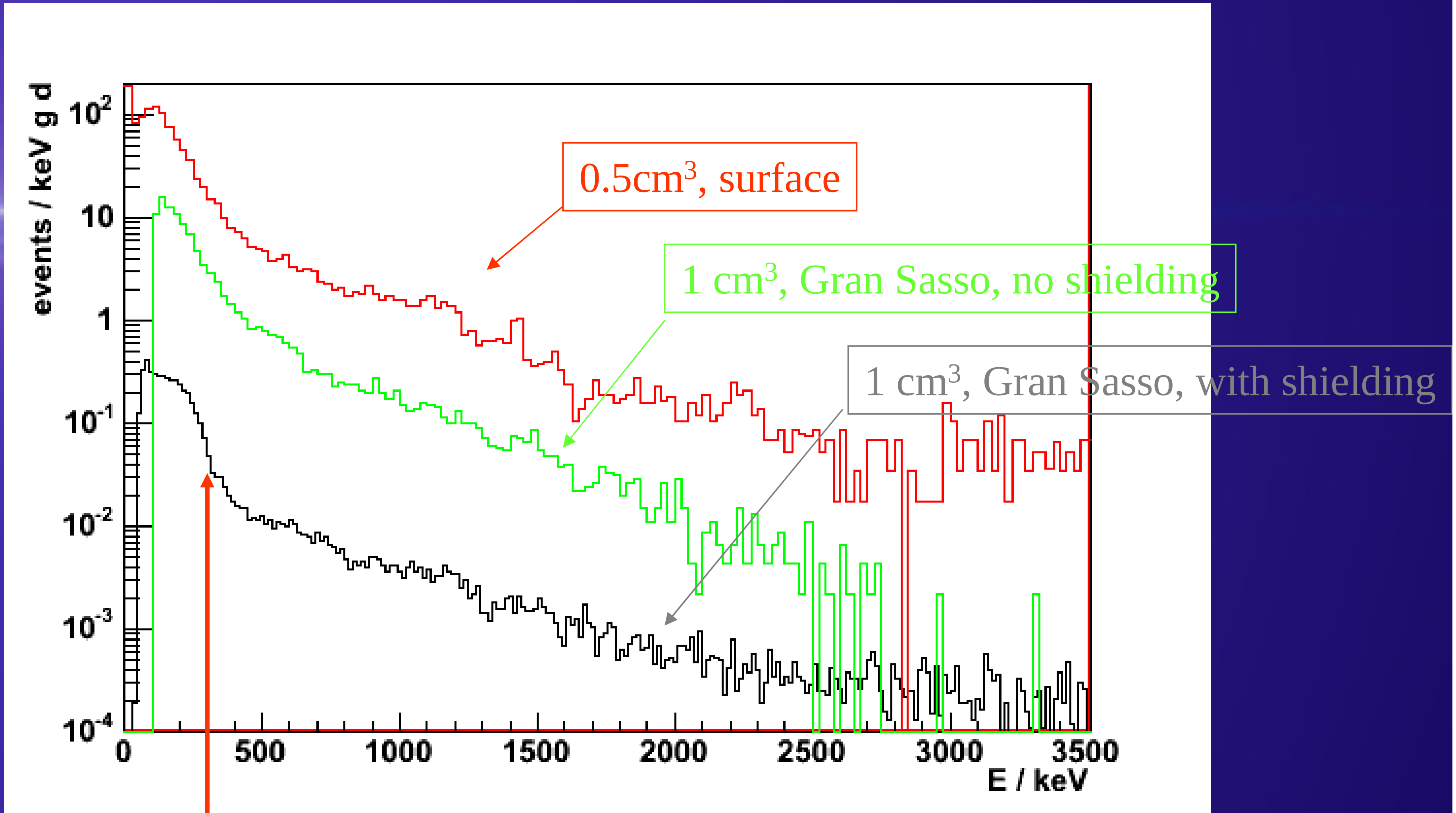
What has been achieved so far?

Proof of concept Stage (2004-2006)

4 detector set up in Gran Sasso







Cd113 half-life (4-fold forbidden decay)
C. Goessling et al.
Phys. Rev C, 72, 064328 (2005)

First COBRA
Double beta results

T. Bloxham et al.
Phys. Rev C, in press

World best limits on ^{64}Zn and ^{120}Te

Isotope	Decay	$T_{1/2}$ limit (years)	
		This work	World Best
$\beta^-\beta^-$ decays			
^{116}Cd	to g.s	3.14×10^{19}	1.7×10^{23} [13]
^{130}Te	to g.s	9.92×10^{19}	1.8×10^{24} [14]
^{130}Te	to 536 keV	3.73×10^{19}	9.7×10^{22} [15]
^{116}Cd	to 1294 keV	4.92×10^{18}	2.9×10^{22} [13]
^{116}Cd	to 1757 keV	9.13×10^{18}	1.4×10^{22} [13]
^{70}Zn	to g.s	2.24×10^{17}	9.0×10^{17} [16]
^{128}Te	to g.s	5.38×10^{19}	1.1×10^{23} [17]
^{116}Cd	to 2112 keV	1.08×10^{19}	6.0×10^{21} [13]
^{116}Cd	to 2225 keV	9.46×10^{18}	$1.0\times10^{20\dagger}$ [18]
$\beta^+\beta^+$ decays			
^{64}Zn	$0\nu\beta^+$EC to g.s.	2.78×10^{17}	2.4×10^{18} [16]
^{64}Zn	0νECEC to g.s.	$\mathbf{1.19\times10^{17}}$	7.0×10^{16} [16]
^{120}Te	$0\nu\beta^+$EC to g.s.	$\mathbf{1.21\times10^{17}}$	2.2×10^{16} [19]
^{120}Te	0νECEC to g.s.	$\mathbf{2.68\times10^{15}}$	-
^{120}Te	0νECEC to 1171keV	$\mathbf{0.72\times10^{15}}$	-
^{106}Cd	$0\nu\beta^+\beta^+$ to g.s.	4.50×10^{17}	2.4×10^{20} [20]
^{106}Cd	$0\nu\beta^+$EC to g.s.	7.31×10^{18}	3.7×10^{20} [20]
^{106}Cd	0νECEC to g.s.	5.70×10^{16}	1.5×10^{17} [21]
^{106}Cd	$0\nu\beta^+\beta^+$ to 512keV	1.81×10^{17}	1.6×10^{20} [20]
^{106}Cd	$0\nu\beta^+$EC to 512keV	9.86×10^{17}	2.6×10^{20} [20]

TABLE II: 90% confidence limits obtained for all decays analysed in this work with conservative systematic uncertainties applied, compared to the world best limits. New world best values from this work are shown in bold. †Quoted limit is 68% not 90%.

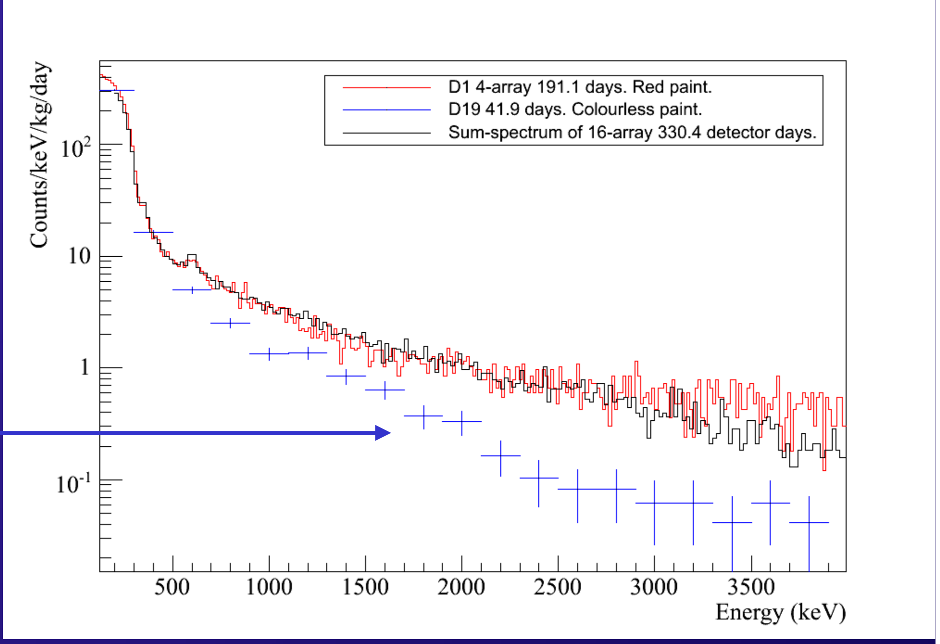
Samples measured at LNGS
Activities (mBq/kg)

isotope	detectors	pertinax (base plate)	pertinax (grid)	paint (passivation)	copper
^{228}Ra	<47	29	18	1100	<2.1
^{228}Th	<60	32	15	730	< 2.3
^{226}Ra	<51	170	66	2100	< 2.5
^{234}Th	<210	250	<92	1100	< 100
^{234m}Pa	< 1200	480	< 180	1600	< 47
^{235}U	<5	12	2	170	< 1.4
^{40}K	<260	330	340	6900	< 11
^{60}Co	<19	<4	<2	< 20	< 0.6
^{137}Cs	40	650	19	15	< 0.9

Main problem is passivation paint used on detectors

New Passivation Paint

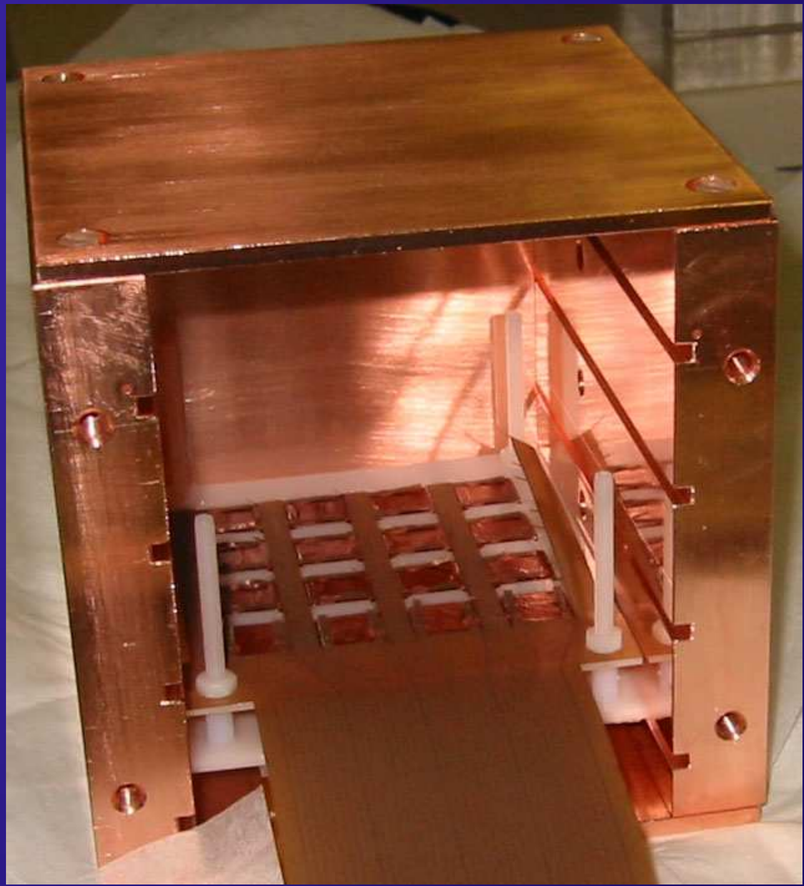
Decrease x10
Had expected x10^3
Next level of background (Rn?)



Test Stage (2006-present)

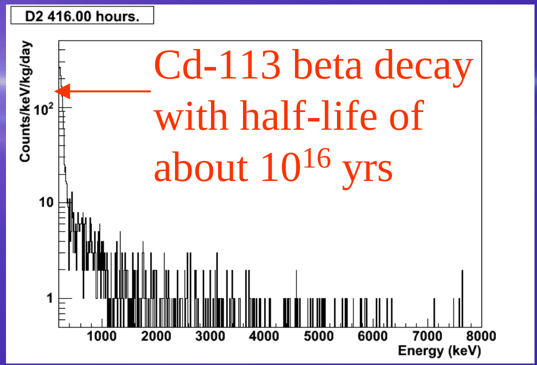
64 detector set up in Gran Sasso

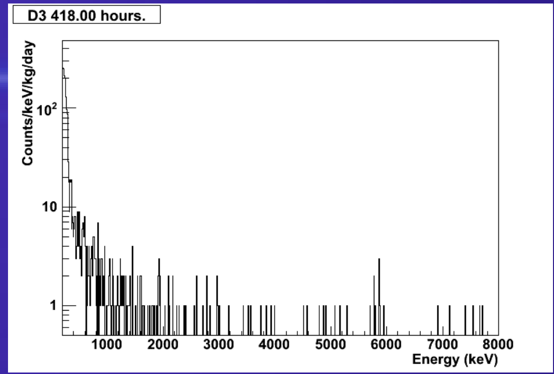
The first layer

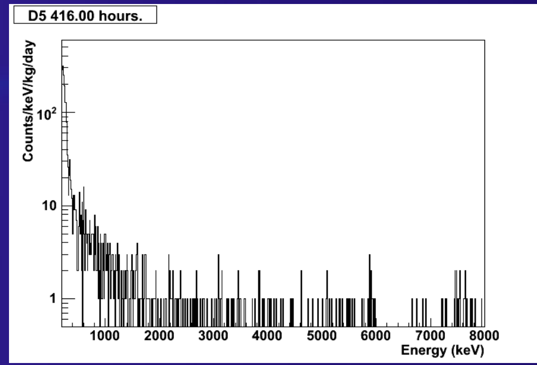


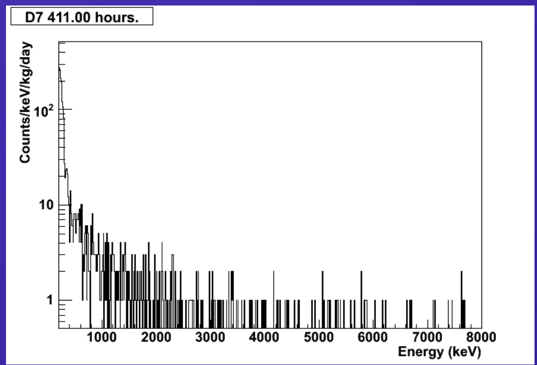
Installed at LNGS in summer 2006

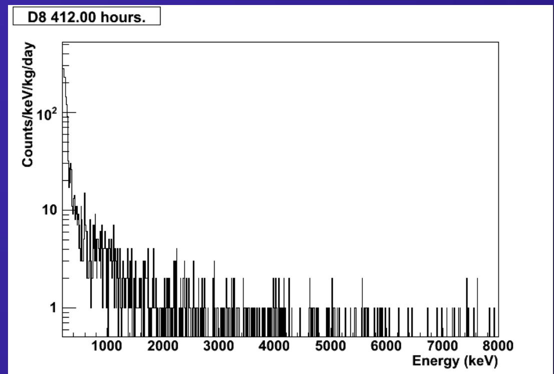
The first layer - some spectra

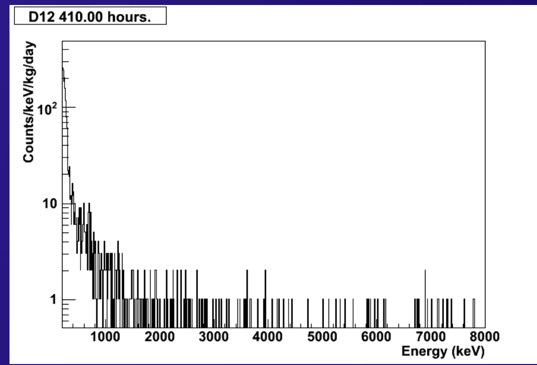


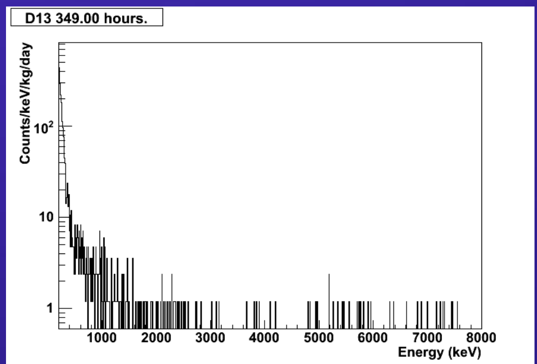


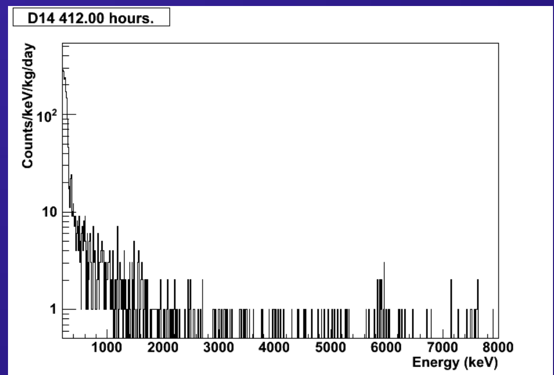


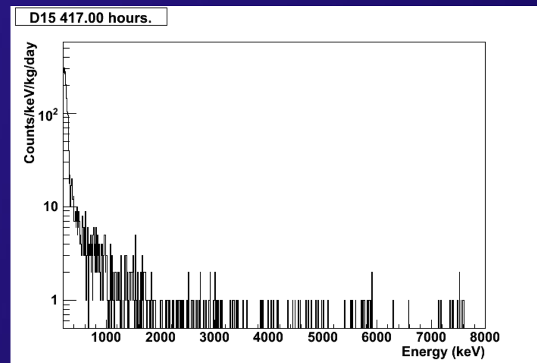






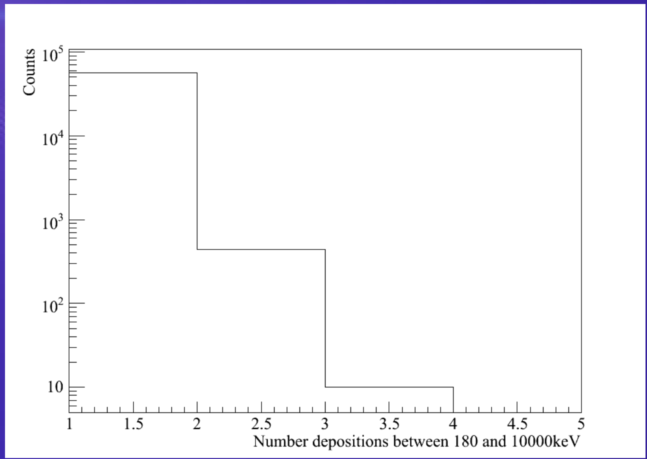


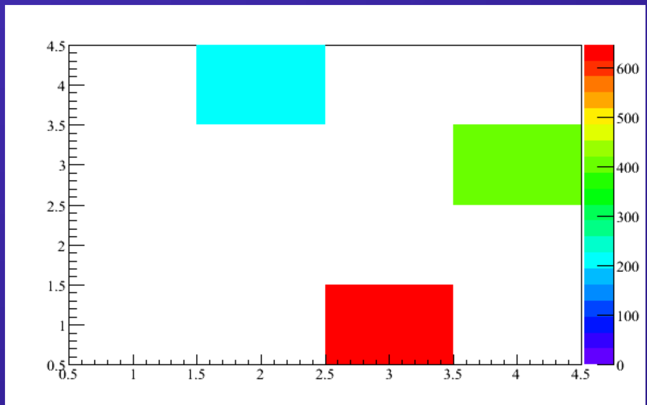




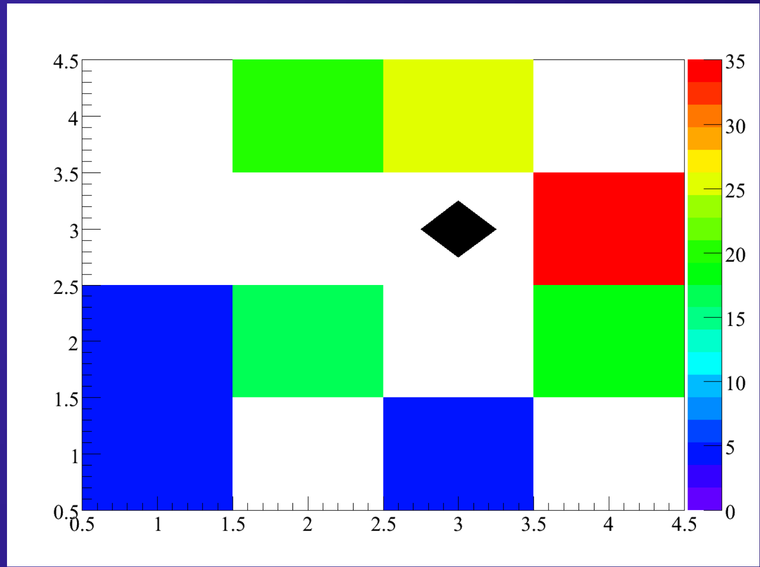
The first layer - Coincidences

Coincidences





Coincidences around Det 9

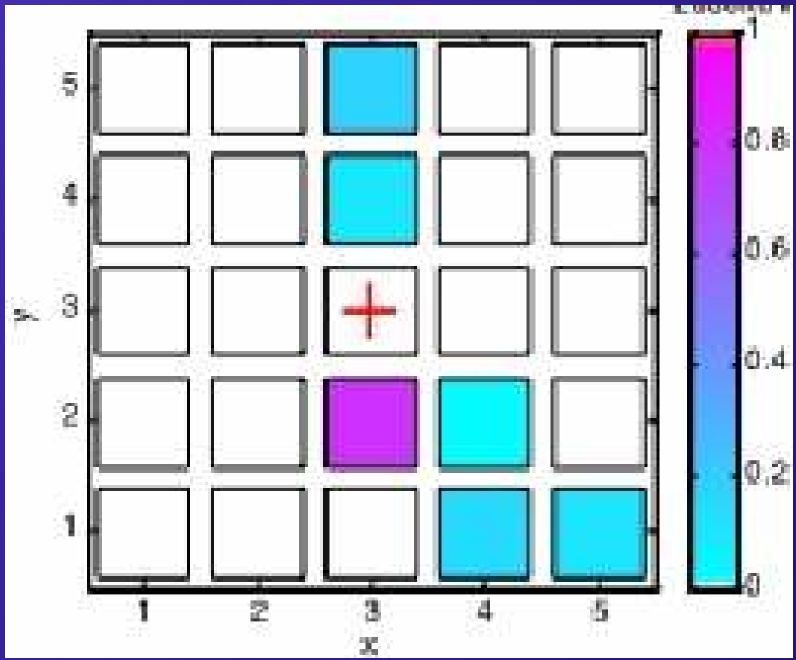


Example:
3-coincidence

Powerful tool!!!

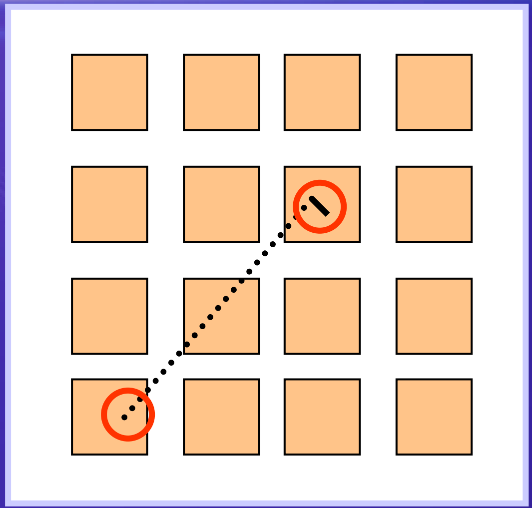
Just starting to analyse/understand the power of this

Simulation of energy deposition in a 5 x 5 detector array for a 2614 keV gamma starting from in central detector



Spatial Coincidences

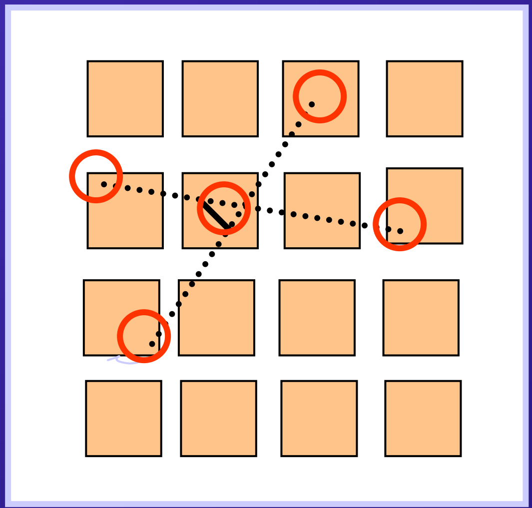
^{116}Cd 0νββ is single crystal event ~64% of the time



β – γ from natural background

Beta and gamma generally
in different crystals

Reduce ^{232}Th chain events from crystals by >50%



^{106}Cd $\beta^+ \beta^+$ decay

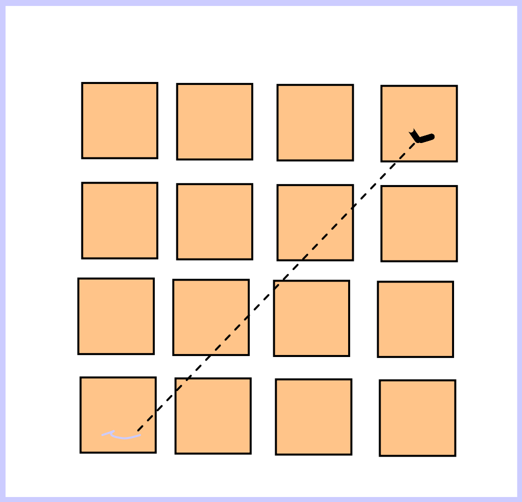
Four 511keV gammas plus beta

Completely clean signal

Spatial Coincidences

Can also identify decays to excited states
(may give handle on physics mechanism)

$^{116}Cd \rightarrow ^{116}Sn$ (2^+, 1294keV)



1511keV β^- pair

1294keV de-excitation γ

Timing Coincidences

The major contribution to ^{238}U spectrum at 2–3MeV is the fast β–α decay:

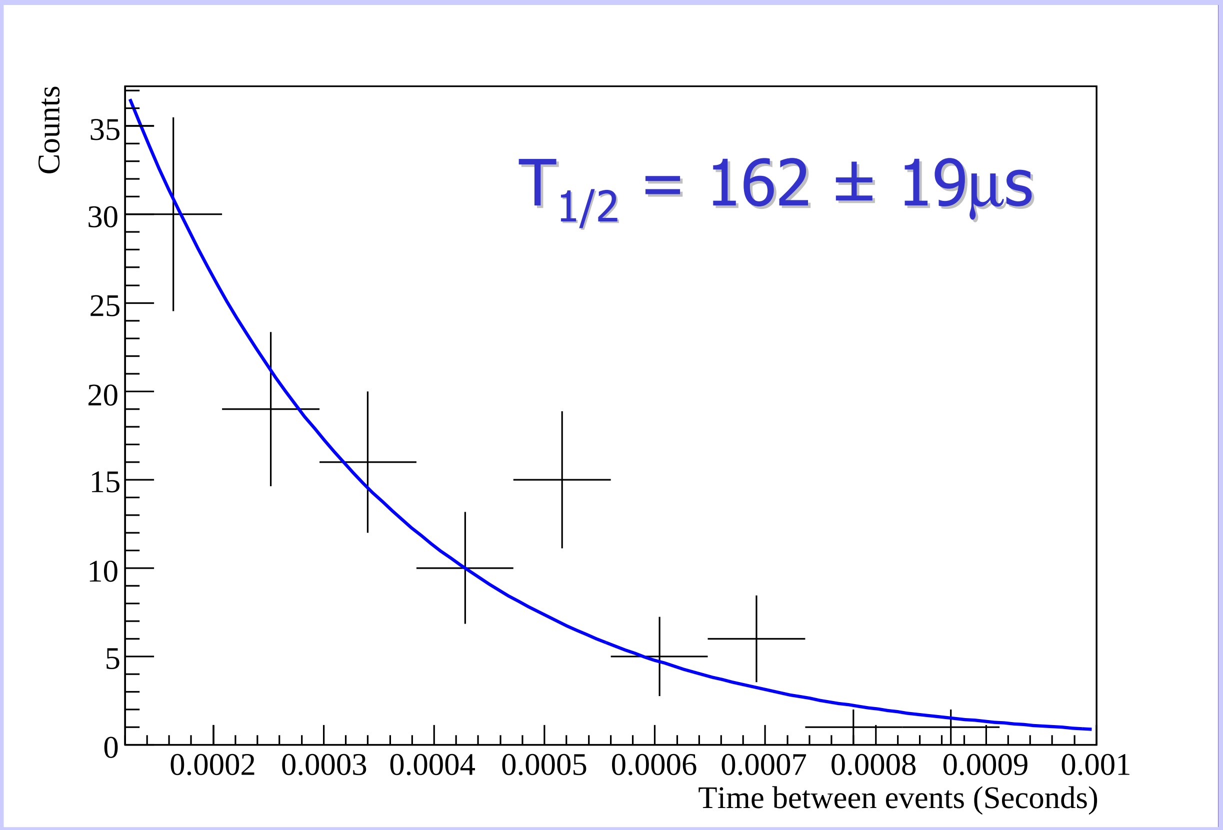
$$^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Pb$$

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

7.7MeV alpha
half-life = 164.3μs

>40% efficiency for tagging ^{214}Bi events originating inside the crystals

Observation of ^{214}Bi events

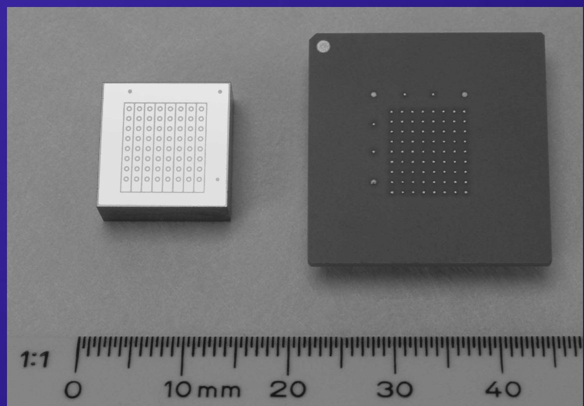


The next steps

Two main approached to double beta decay

Energy resolution

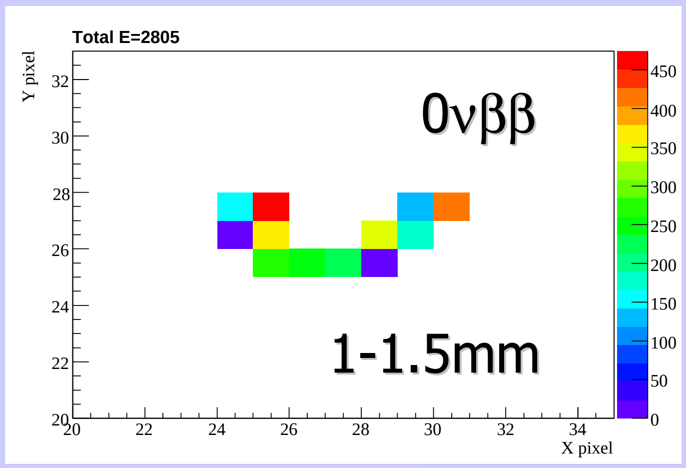
Tracking

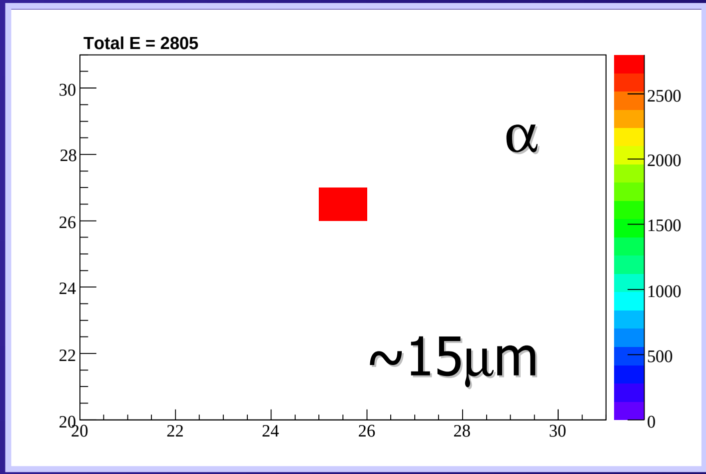


Pixellated CdZnTe detectors

Pixel CZT- A solid state TPC

Massive BG reduction by particle ID , 200μm pixels (example simulations):





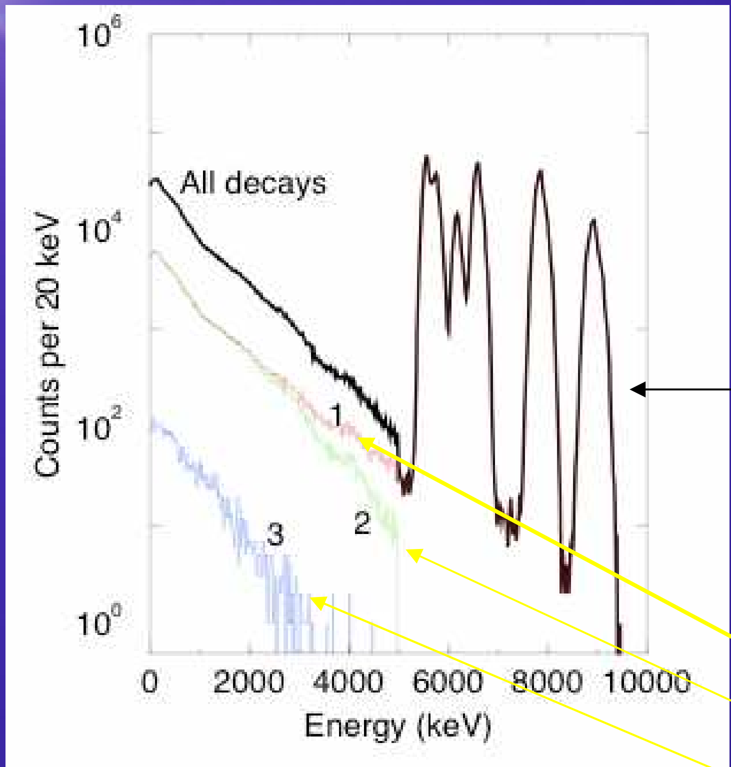
α= 1 pixel, β and ββ= several connected pixel, γ= some disconnected p. (or different detector)

eg. Could achieve nearly 100% identification of ^{214}Bi events (^{214}Bi → ^{214}Po → ^{210}Pb)

Beta with endpoint 3.3MeV

7.7MeV α with life-time = 164.3μs

Rejection power of pixels



T. Bloxham, M. Freer, Nucl. Inst. Meth. A (2007)

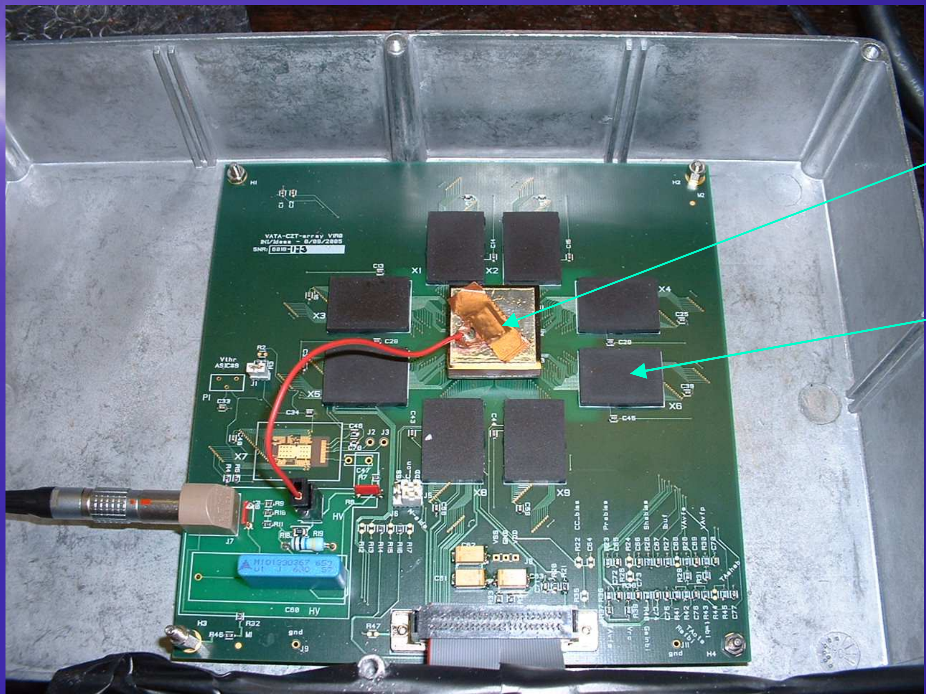
Simulation for 3mm thick detector with 16 x 16 200μm pitch pixels

^{232}Th and ^{238}U chains

1. One/two electrons
2. ….plus alpha rejection
3. ………plus β–α time correlation

Suggests a background reduction of 1000!

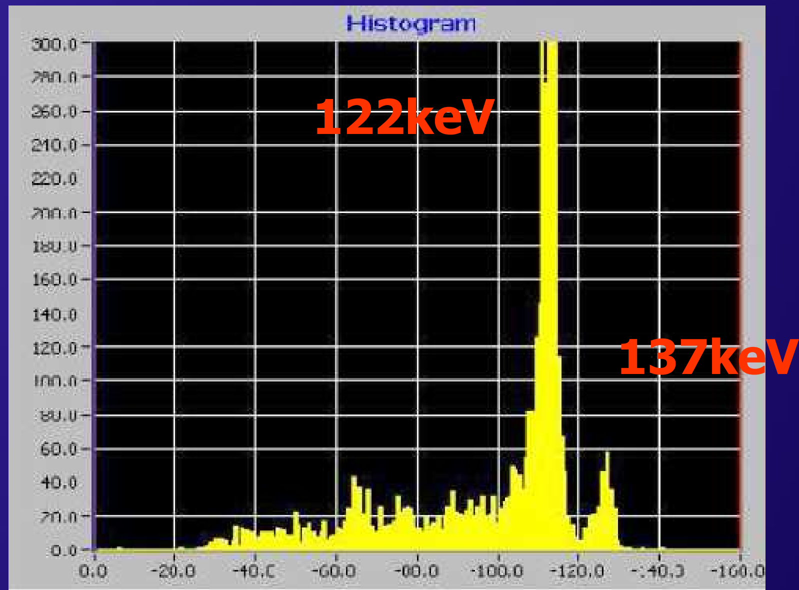
Tests of 16×16 1.6mm pixel detectors



Detector

ASIC Readout

Single Pixel ^{57}Co spectrum



Two detectors with 200μm pixillation being produced

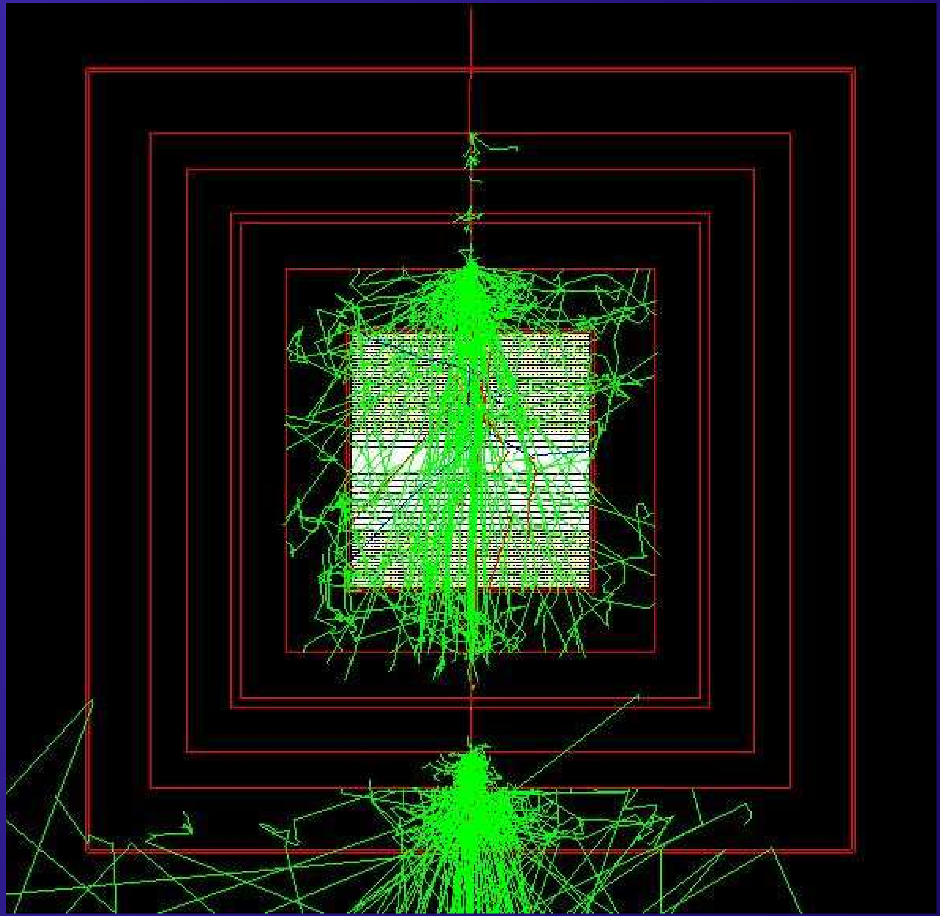
Looking at new generation ASICs for readout of these

Other current activities

Monte Carlo

Sophisticated MC based on GEANT4, written in C++

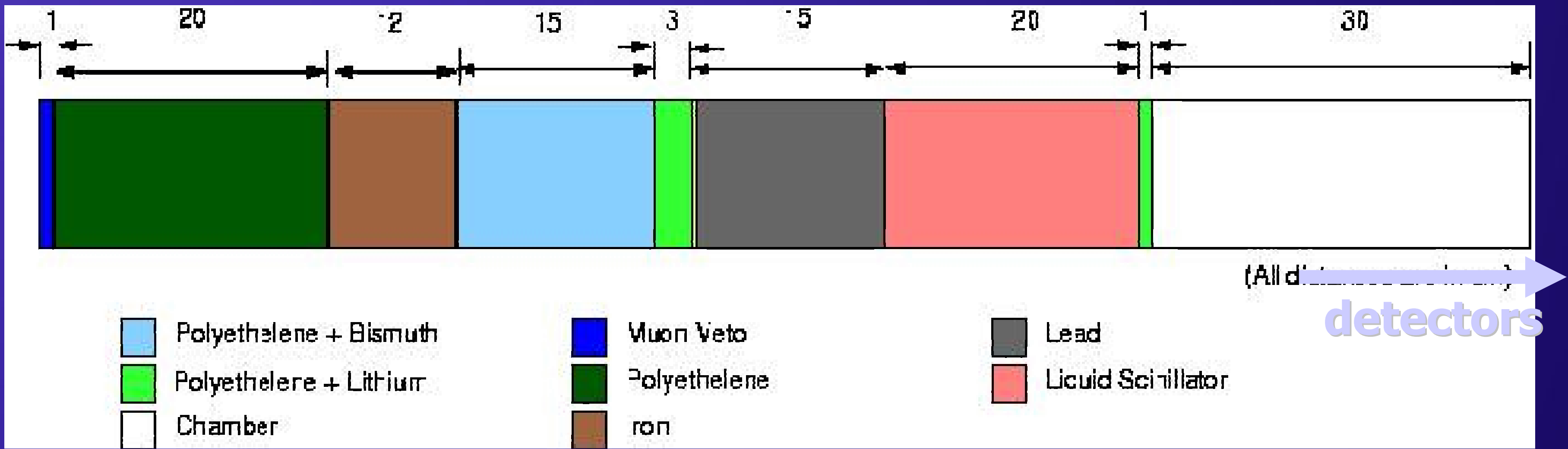
Signal (DECAY0) and background



200 GeV muon

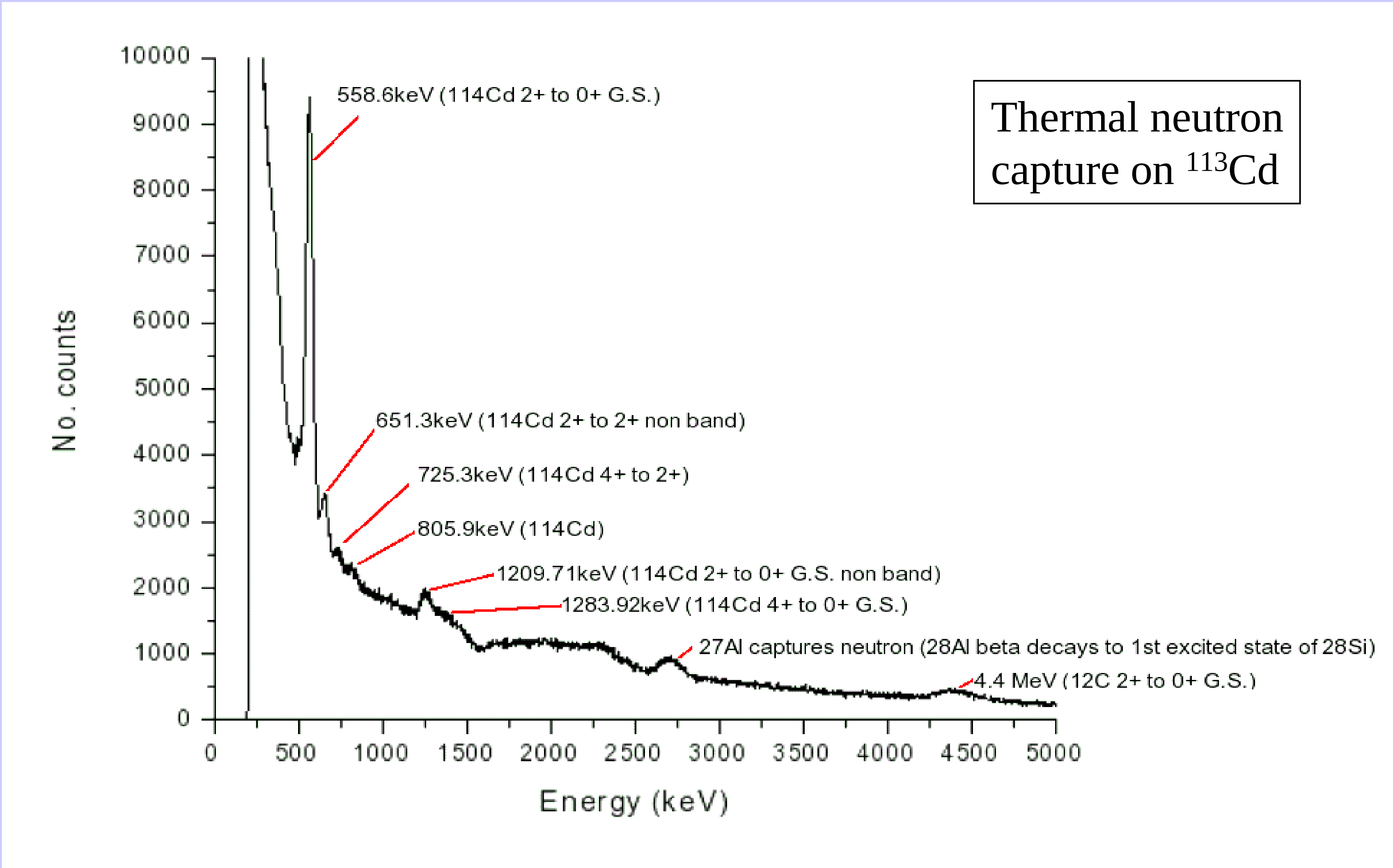
Shielding and Veto

- Simulated LNGS neutron flux
- ~3x10^{-7} counts/year/kg/keV in the crystals.
- **<1 neutron per year!** (in 64000 detectors)



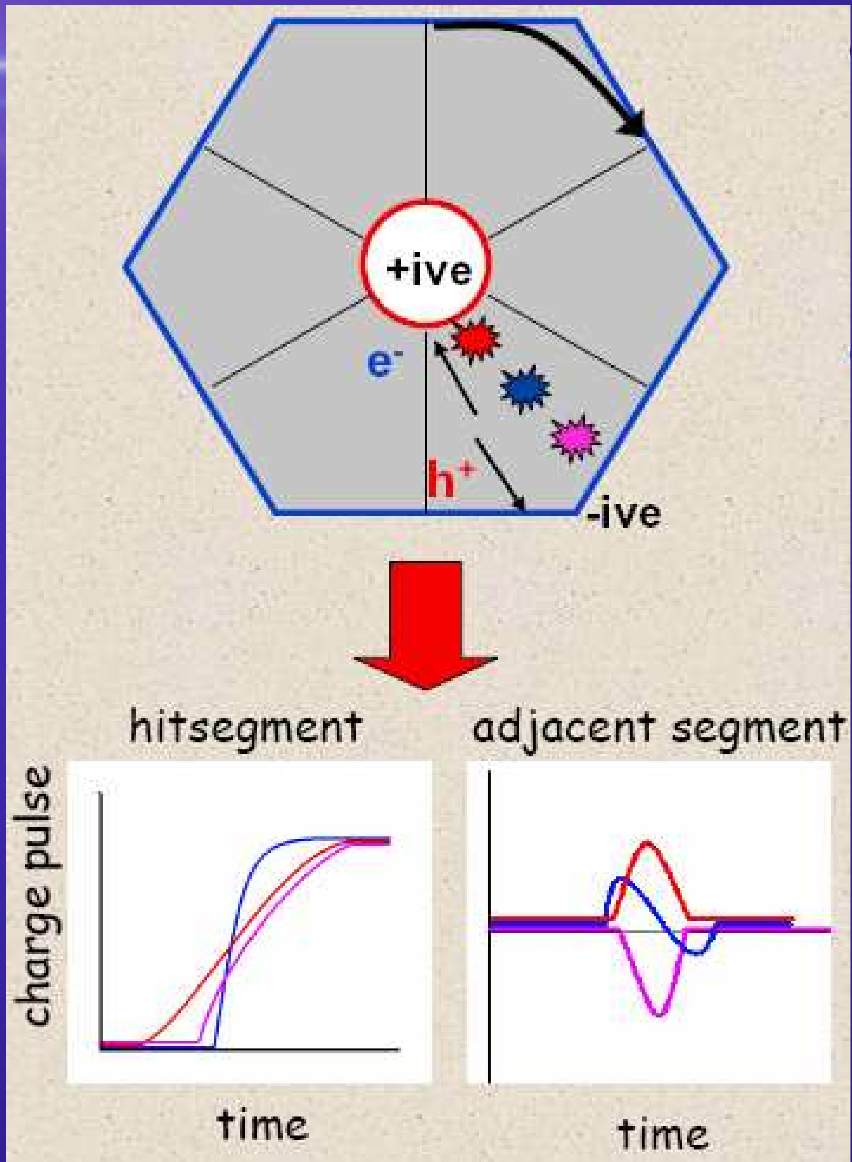
D. Stewart et al., accepted by Nucl. Inst. Meth. A

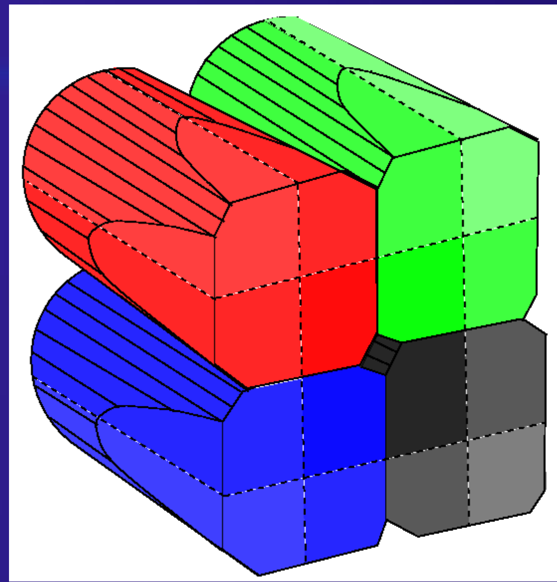
Understand n-capture backgrounds

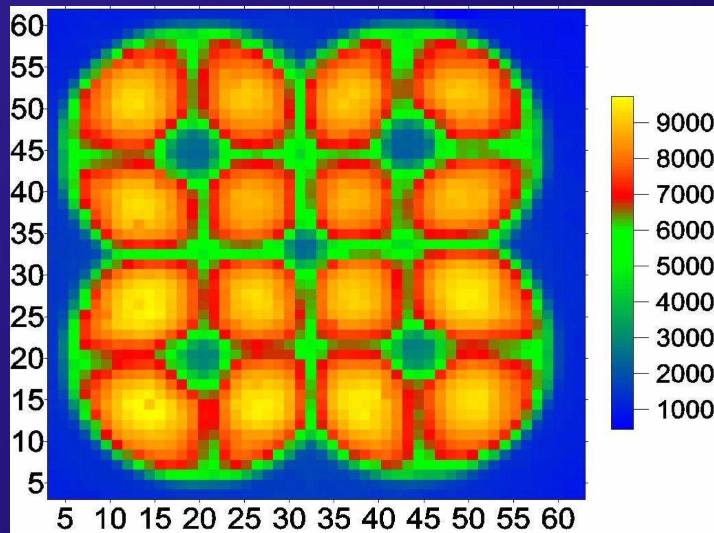


Digital pulse shape readout

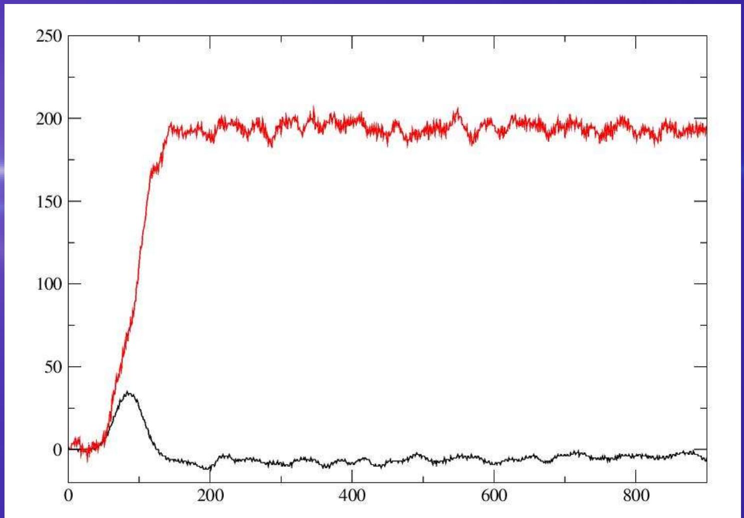
(improved resolution and position from induced signals)



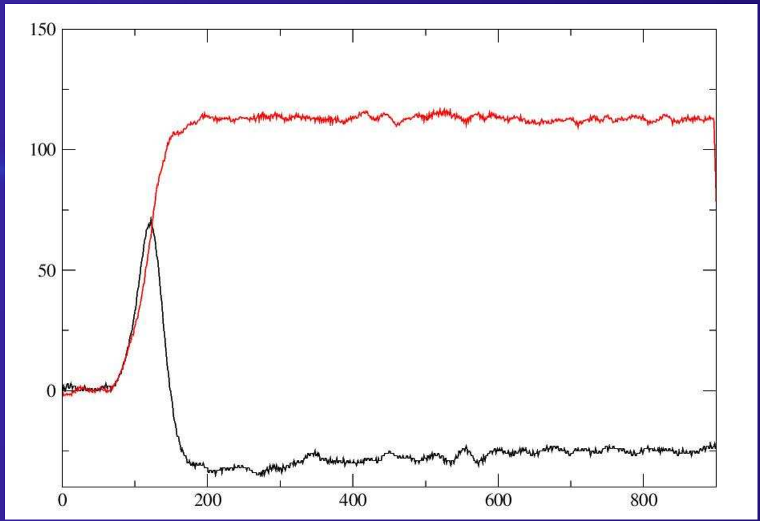




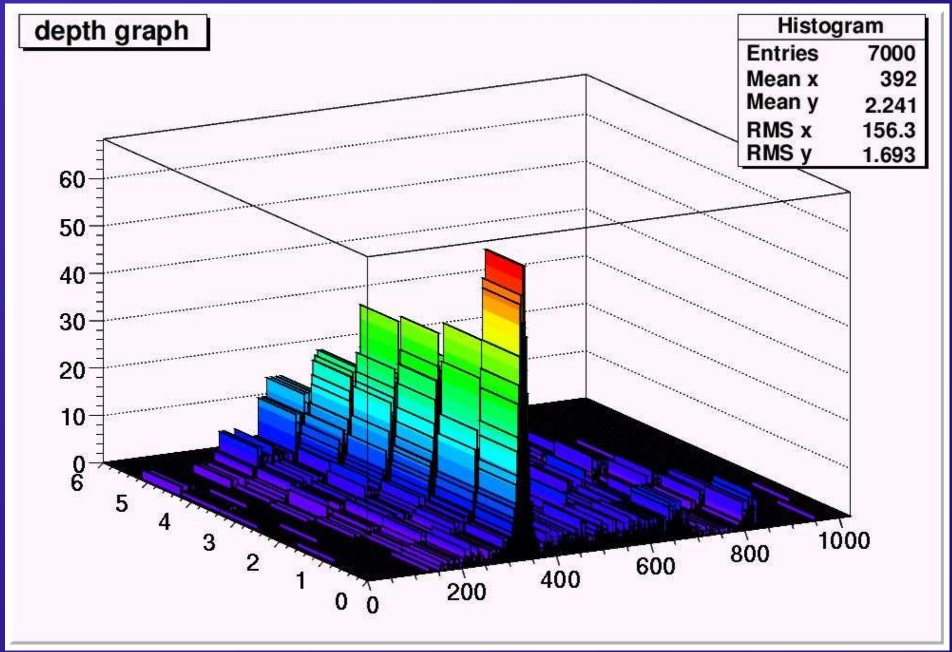
First results from CZT detectors



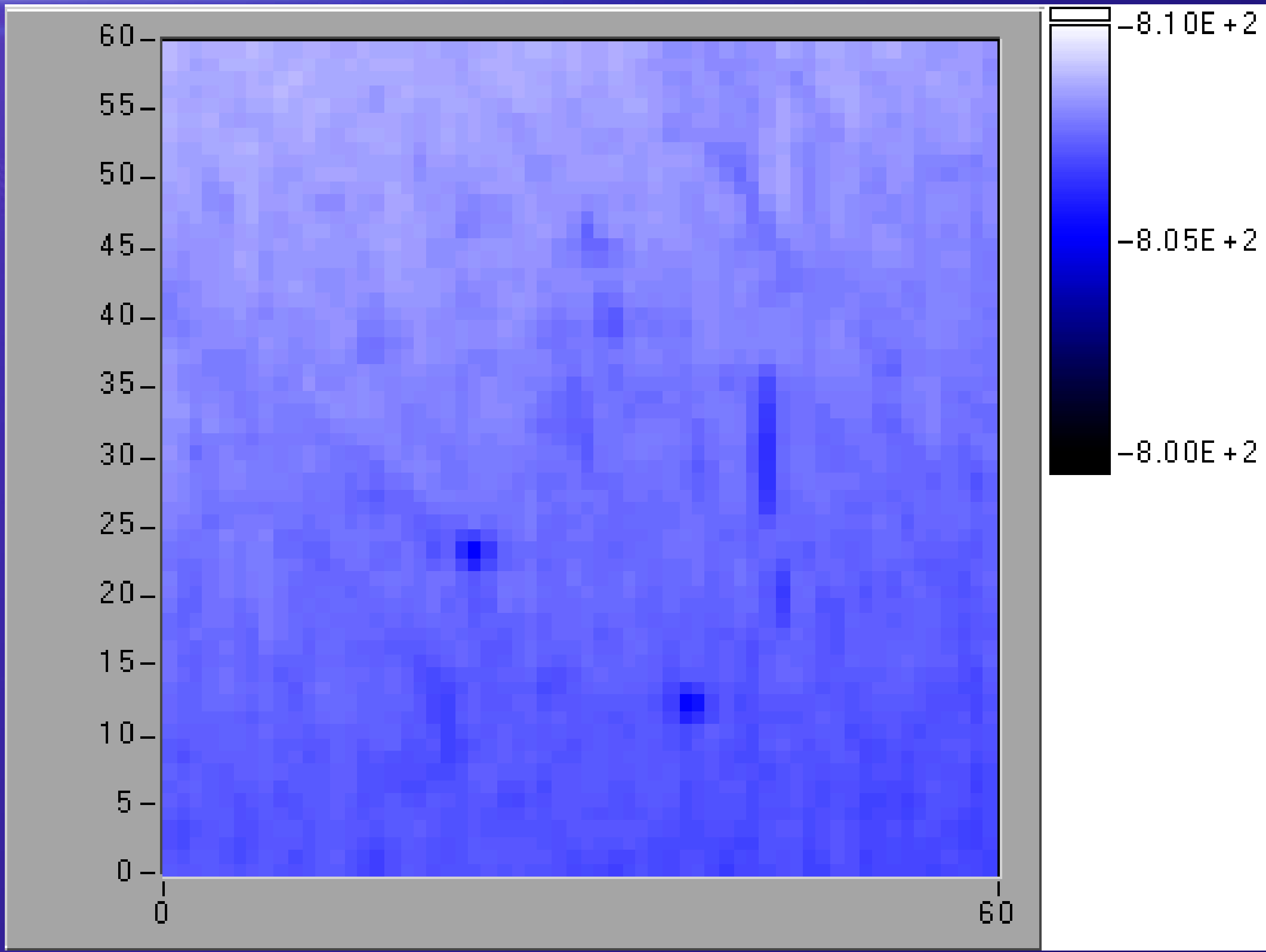
Event near anode



Event near cathode



Materials studies to improve detectors



SUMMARY

- We have established a potential approach for neutrinoless double beta decay offering some advantages
- We have a test setup at Gran Sasso which will allow us to improve backgrounds and explore the advantage of concidences
- Starting a major programme to develop pixillated CZT detectors which would provide a tracking capability to give an enormous background reduction

Eventual goal would be a 64,000 detector experiment

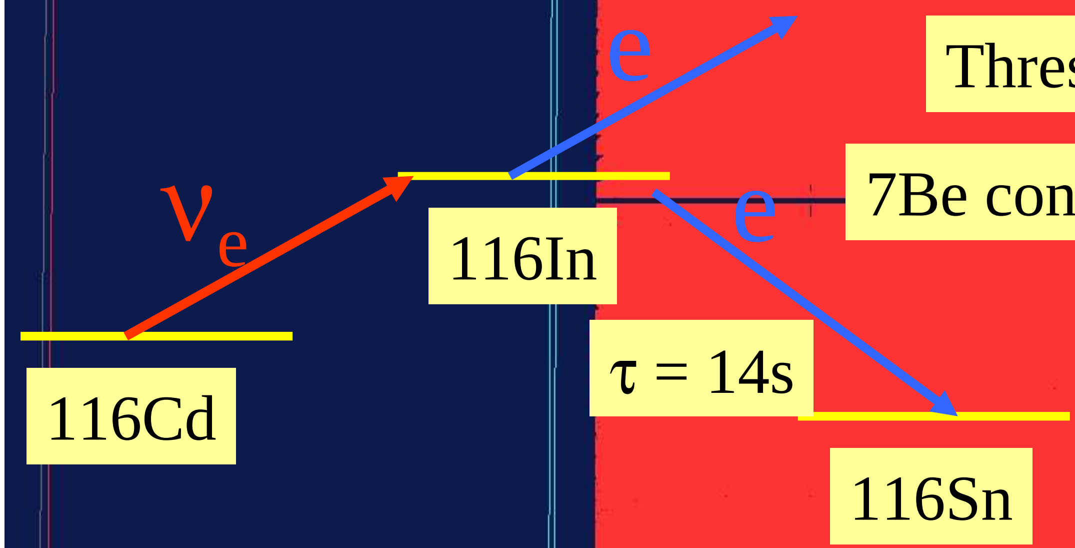
And we have dreams…..

Solar neutrinos with COBRA - KING COBRA

A real time low-energy solar neutrino experiment?

Threshold energy: 464 keV

7Be contribution g.s. alone: 227 SNU



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

Signal: Coincidence between two electrons in a single detector