11th Pisa meeting on advanced detectors

Scintillating bolometers for Double Beta Decay search

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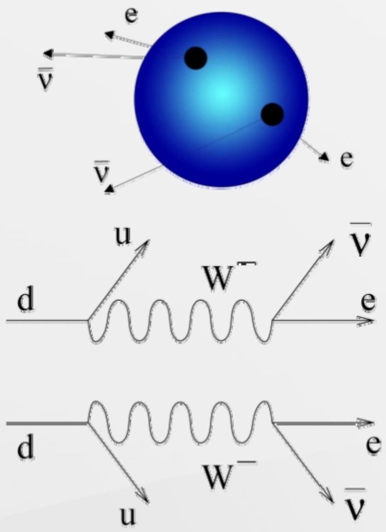
BOLUX collaboration

La Biodola, Isola d'Elba, Italy – 24-30 May 2009

0νDBD – Neutrinoless Double Beta Decay

2νDBD

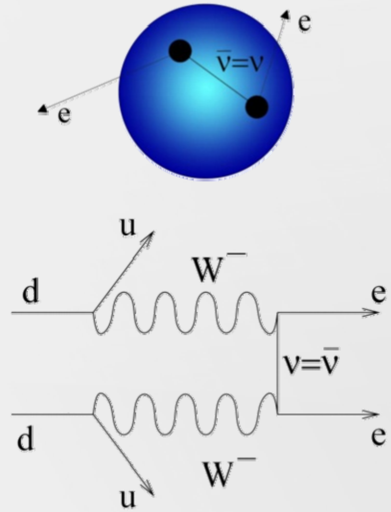
$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\overline{\nu}$$



Isotope	$Q_{\beta\beta}$ (keV)	Natural Abundance
^{76}Ge	2039	7.4 %
^{130}Te	2528	34 %
^{116}Cd	2902	7.5 %
^{82}Se	2996	8.7 %
^{100}Mo	3034	9.6 %

0νDBD

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



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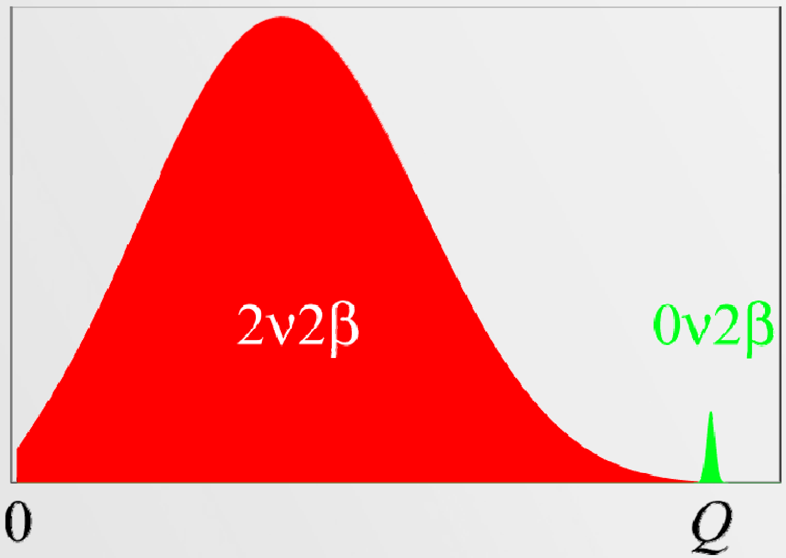
Neutrino:
Majorana particle
Massive particle



0νDBD – Neutrinoless Double Beta Decay

Sensitivity

half life corresponding to the minimal number of detectable events above background, for a given C.L.

S : Sensitivity
A : atomic mass
ε : efficiency
a : isotopic abundance

$$S \approx \frac{a \cdot \varepsilon}{A} \sqrt{\frac{M \cdot t}{b \cdot \Gamma}}$$

M : detector mass [kg]
t : live time [y]
b : background [c/keV/kg/y]
Γ : energy resolution [keV]

Present Sensitivity

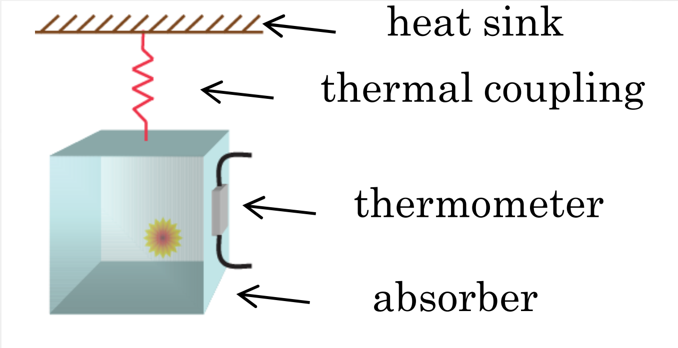
CUORICINO (Bolometric technique) $\langle m_\nu \rangle < 200 - 680\ meV$

Heidelberg – Moscow (Germanium diodes) $\langle m_\nu \rangle = 320 \pm 30\ meV\ (99.97\%\ C.L.)$

Bolometric Technique

is a powerful method to study rare events with some interesting features:

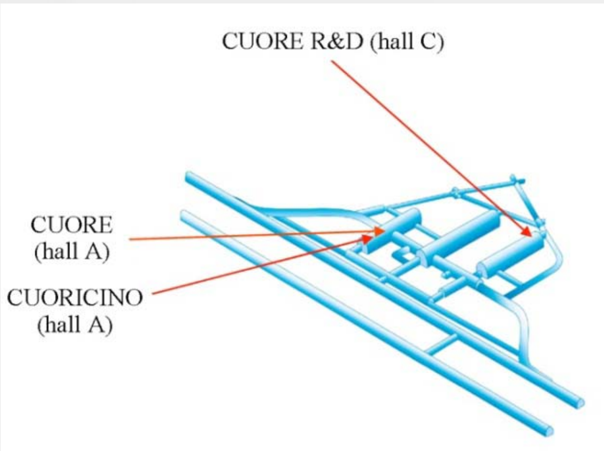
- Possibility to choose different 0νDBD candidate
- Very good energy resolution (0.2 – 0.5 % at 2.5 MeV)
- Source = Detector



Background: The best way to improve sensitivity

There are several main sources of background :

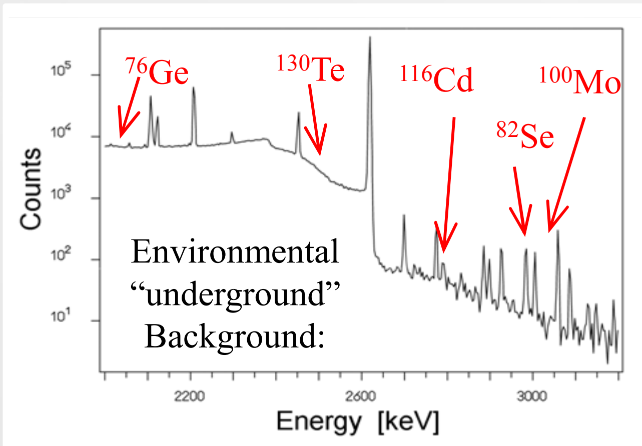
- Internal contaminations (α, β, γ)
- μ and μ-induced particles (n)
- External contaminations (γ)
- **Surface contamination**
- neutrons

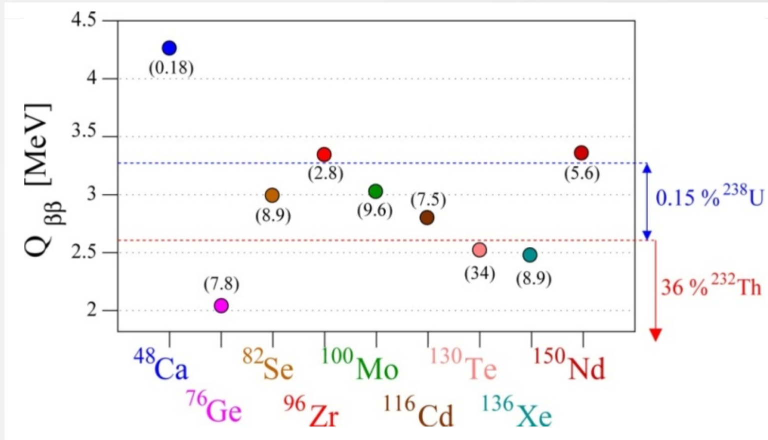


Neutron shield

Selection of material, ‘delayed’ coincidences

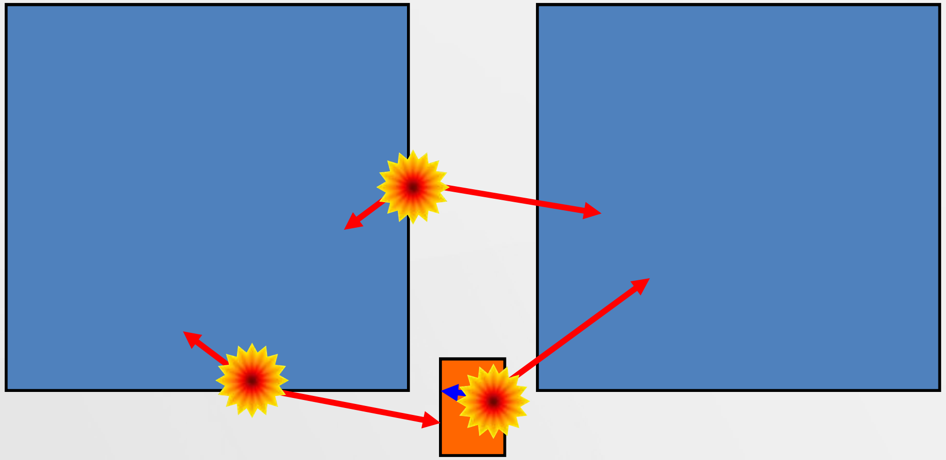
Lead shield, isotope ($Q_{\beta\beta}$ >2615 keV)

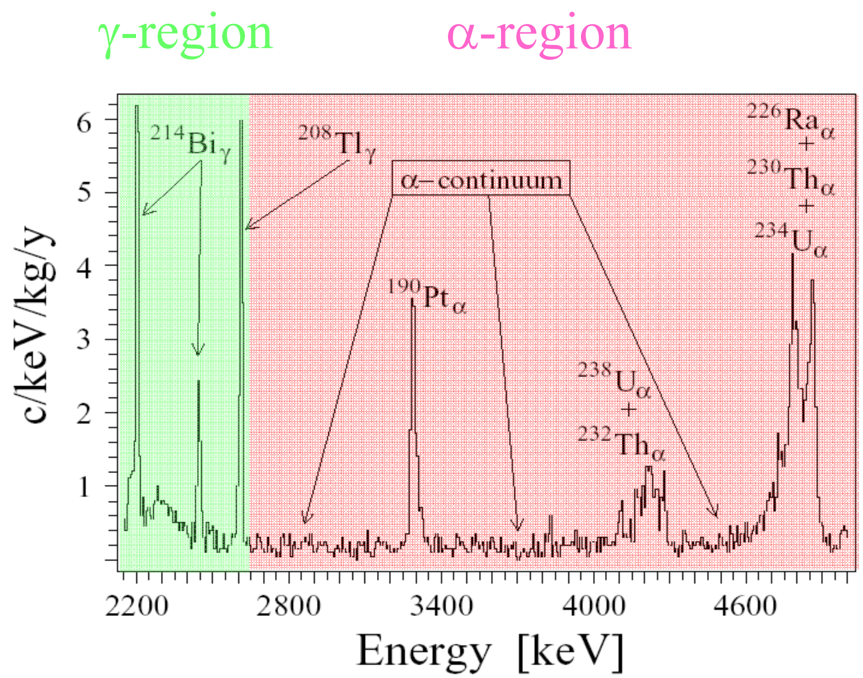




Background: Surface Contamination

Surface contaminations represents the main source of background for bolometric detectors such as CUORICINO.





CUORICINO Background

A lot of work in improving background rejection through coincidences and surface cleaning

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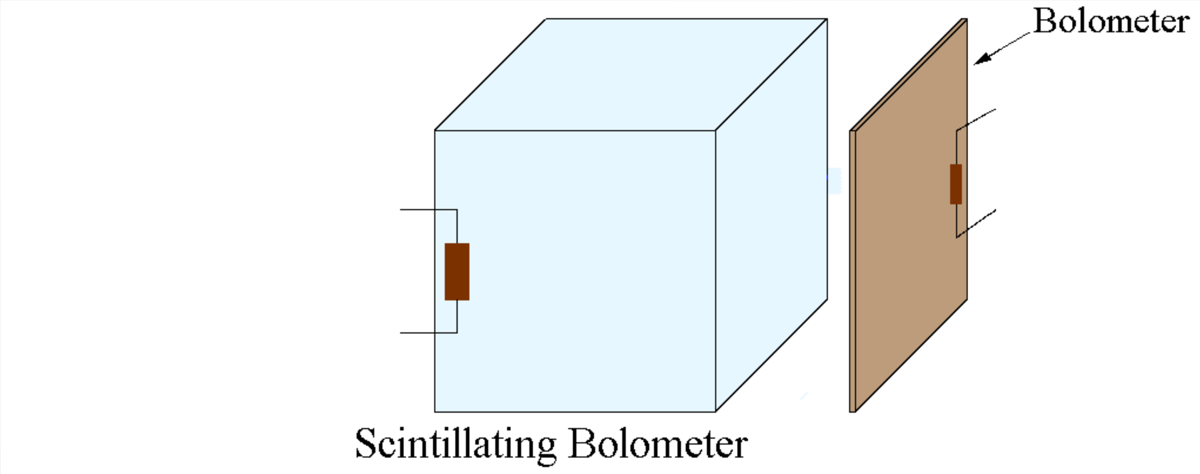
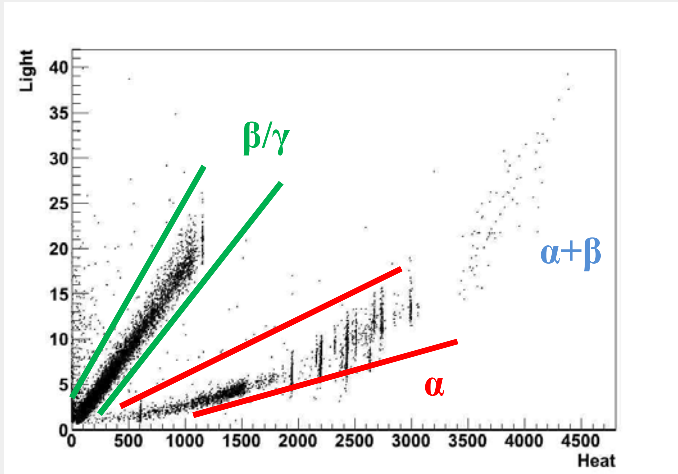
Active Method: Scintillating Bolometers

Scintillating Bolometers Operating Principles

A powerful tool in order to discriminate α particles is the scintillation light.
The idea is to use a scintillating crystal as bolometer and to measure both (heat + light) channels.

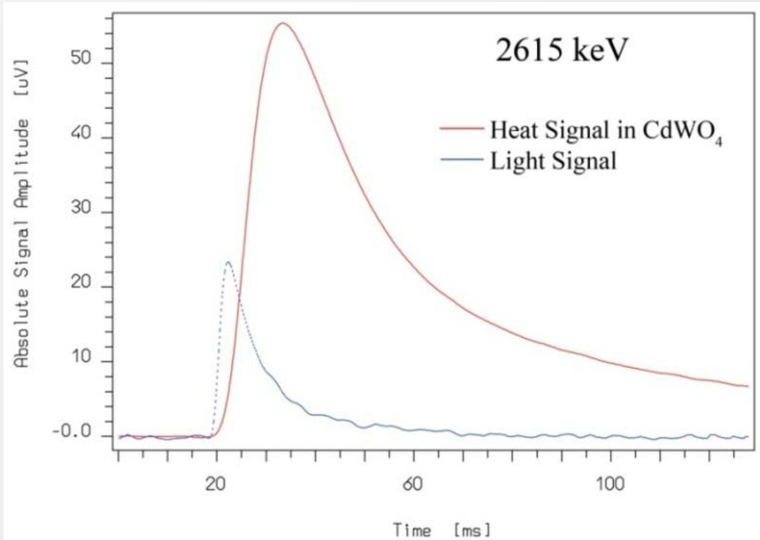




$$\Delta T = \frac{\Delta E}{C} \qquad \tau = \frac{C}{G}$$

C = heat capacity
G = thermal conductance

$$\Delta T(t) = \frac{\Delta E}{C} e^{-\frac{t}{\tau}}$$



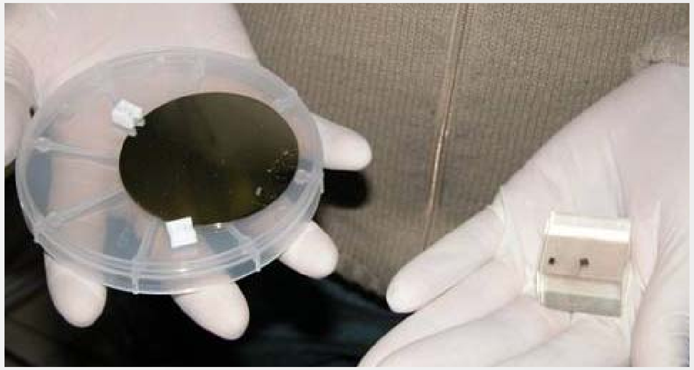
Tested different scintillating crystals (**$CdWO_4$**, CaF_2, **$CaMoO_4$**, $SrMoO_4$, $PbMoO_4$, **ZnSe**, ...).

$CdWO_4$

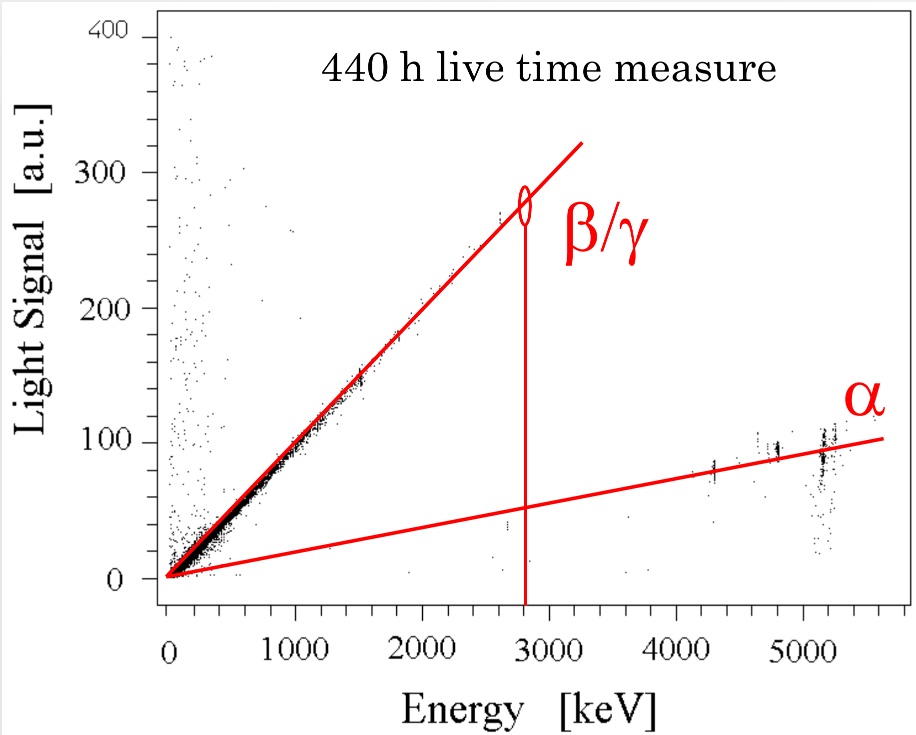
April 2005

background measurement with 3x3x2 cm^3,140 g, $CdWO_4$ crystal. Light Detector: Ge, Ø=63mm, h=1mm.

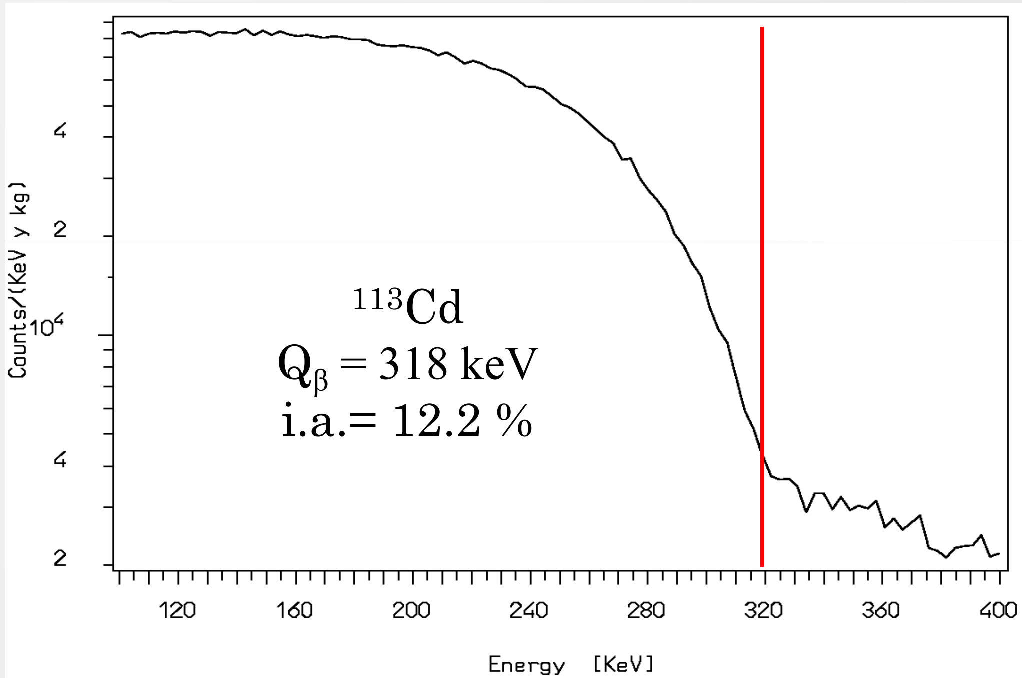
$Q_{\beta\beta}(^{116}Cd)$=2805 keV
i.a. = 7.5 %



The α-continuum is completely ruled out.



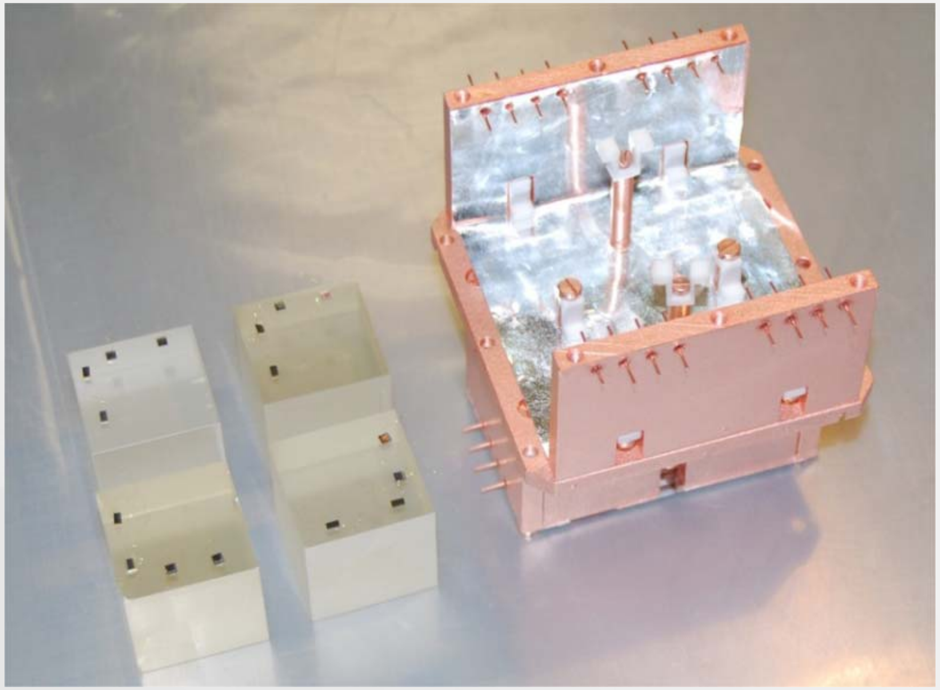
The large number of events in the 0–300 keV region is due to the natural decay of ^{113}Cd.

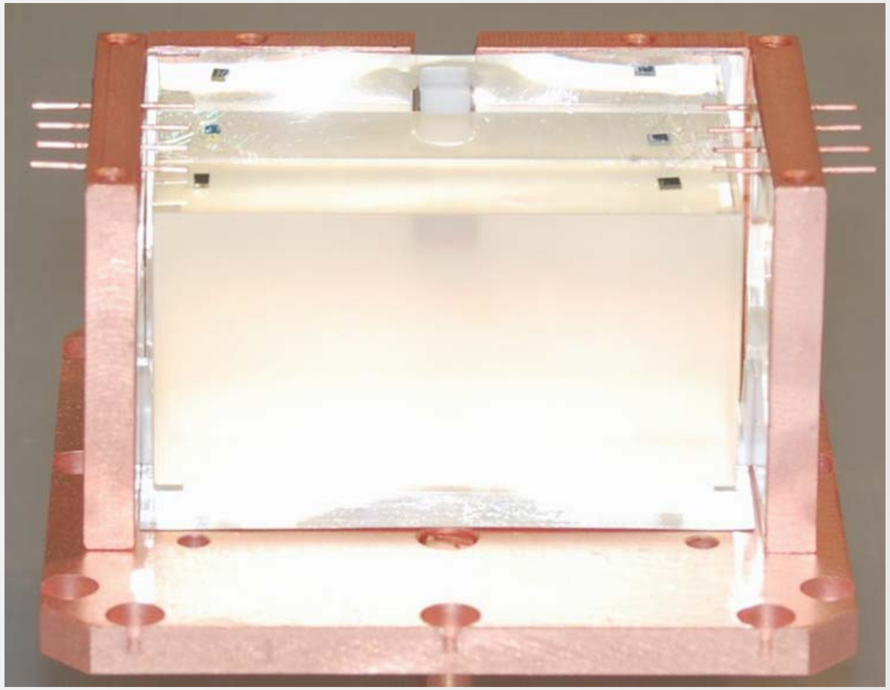


$CdWO_4$

April 2008

array of 5 $CdWO_4$ crystals (4 3x3x3 cm^3 crystals and a 3x3x6 cm^3 crystal). The 4 detectors are coupled to the same light detector.





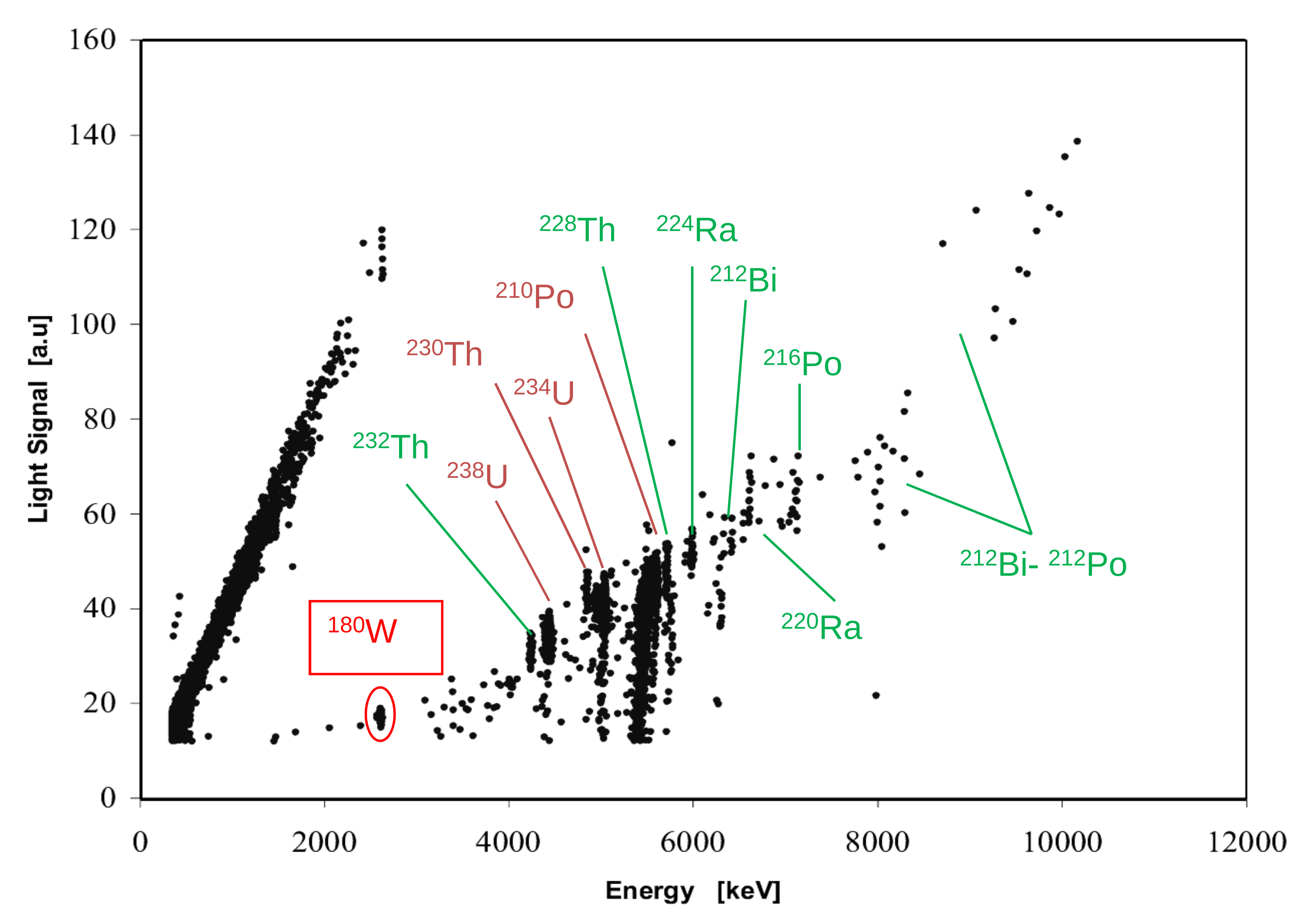
The aim of this test are:

- Demonstrate the technical feasibility of this technique through an array of detectors.
- Perform a long background measurement in the best conditions in order to prove the achievable background in the 0ν-DBD, "projecting" (through simulations) the background obtained in the low energy region.

$CdWO_4$

Background $CdWO_4$ 3x3x6 (426 g) – Scatter Plot

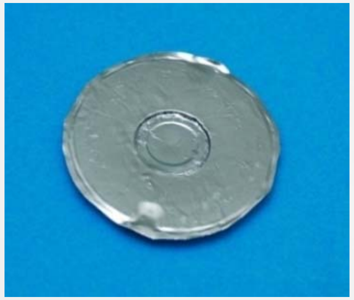
724 hours

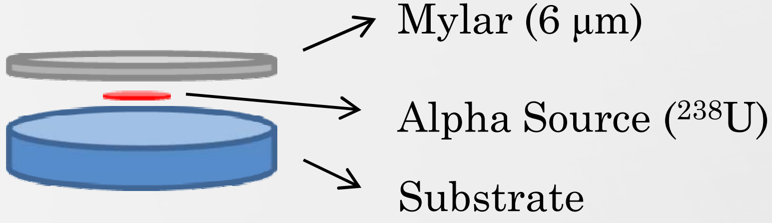


$CdWO_4$

March 2009

Alpha sources (^{238}U) facing crystal covered with ~ 6μm of Mylar in order to have high number of counts due to alpha particles in 2-4 MeV region (degraded alpha).



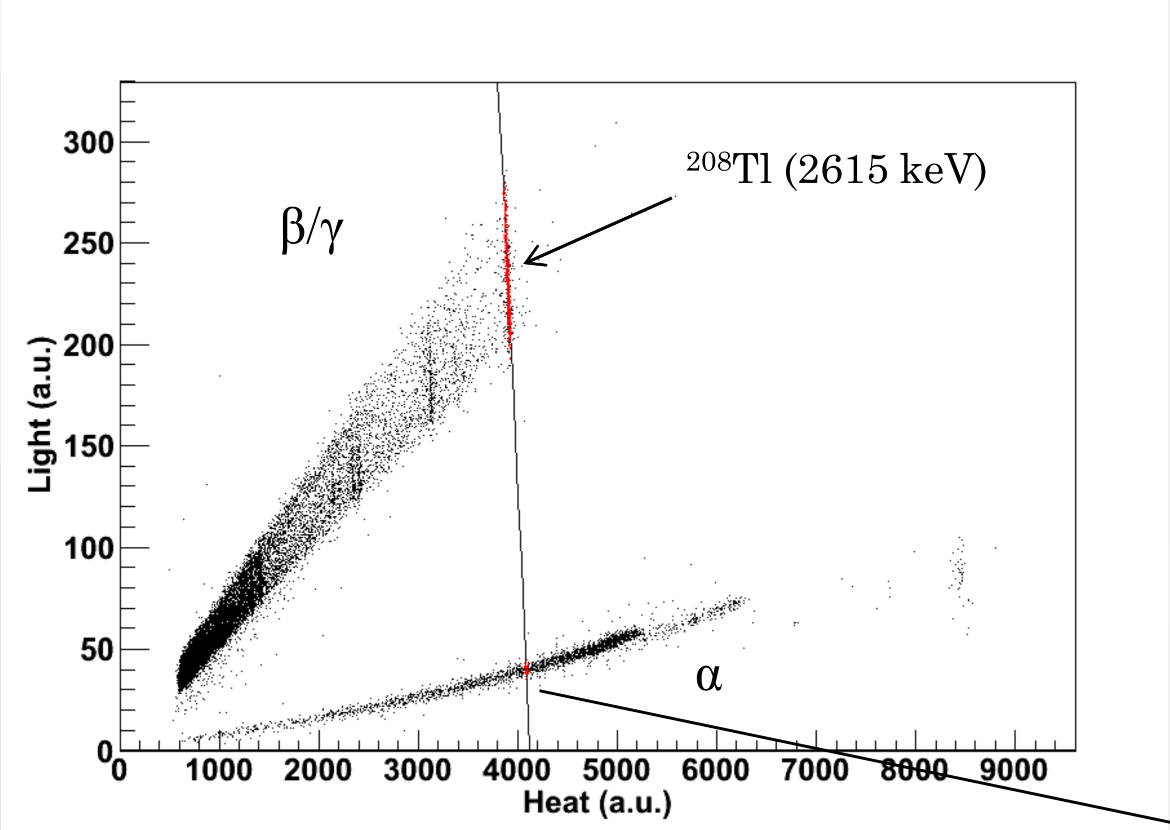


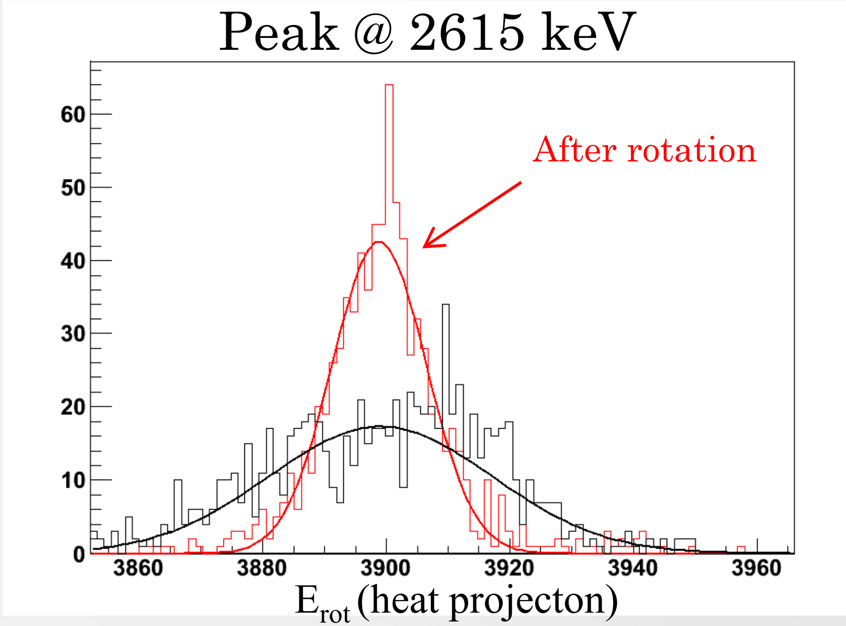
New Crystal

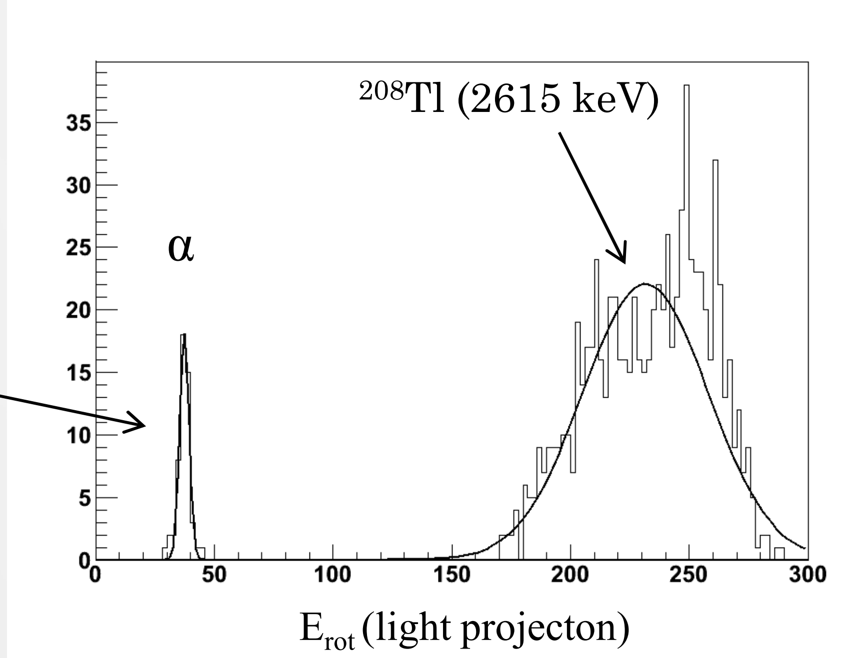
- Is the biggest $CdWO_4$ crystal tested up to now (508 g, cylindrical, Ø=40mm, h=50mm)
- Perfect optical surfaces
- Stand-alone mounting

$CdWO_4$ Alpha source

The resolution of the main bolometer is affected by the fluctuation of the fraction of energy going in the heat and light channels. Since the energies of the two channel are anticorrelated, it is possible reconstruct the intrinsic energy resolution of the bolometer.





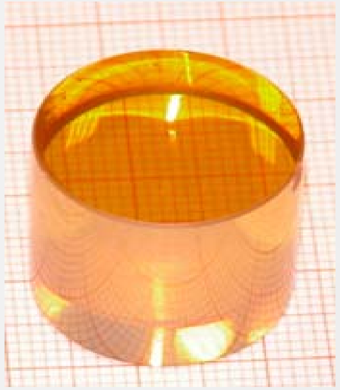


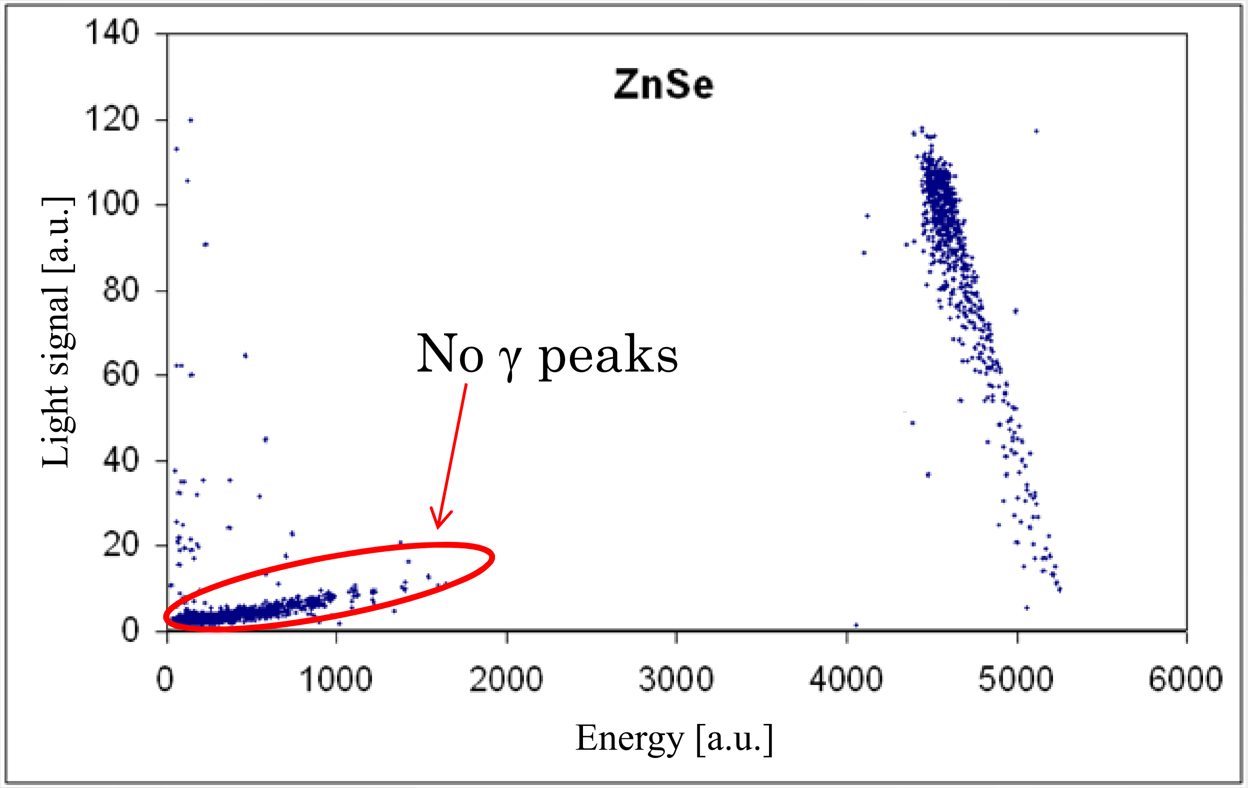
ZnSe

September 2005

background measurement with a small sample of ZnSe (cylindrical, Ø=20mm, h=21mm, 37.5g).

$Q_{\beta\beta}(^{82}Se)$ = 2995 keV
i.a. = 8.9 %

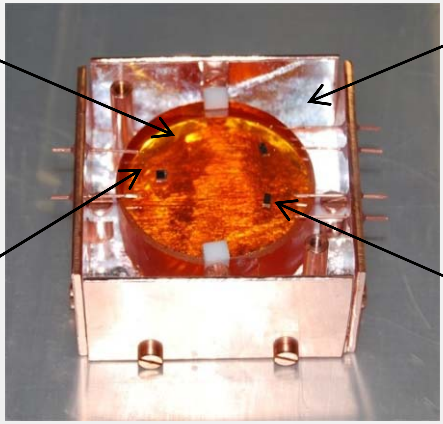


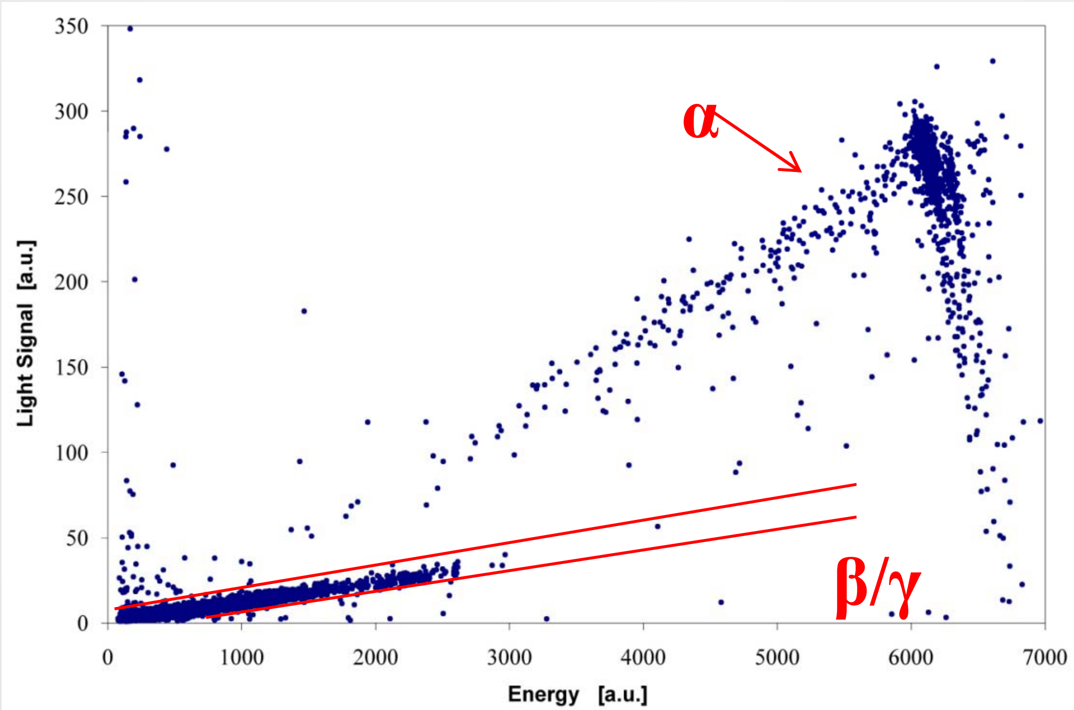


ZnSe

April 2008

measure with a new, bigger, ZnSe crystal (cylindrical, Ø=41mm, h=17mm, 120g, impurity).





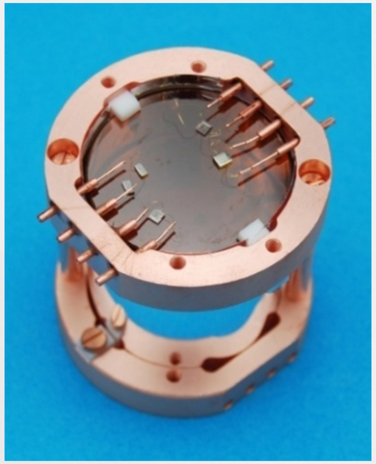
1053 hours

FWHM @ 2615 keV = 18 keV (good @ 25 mK)

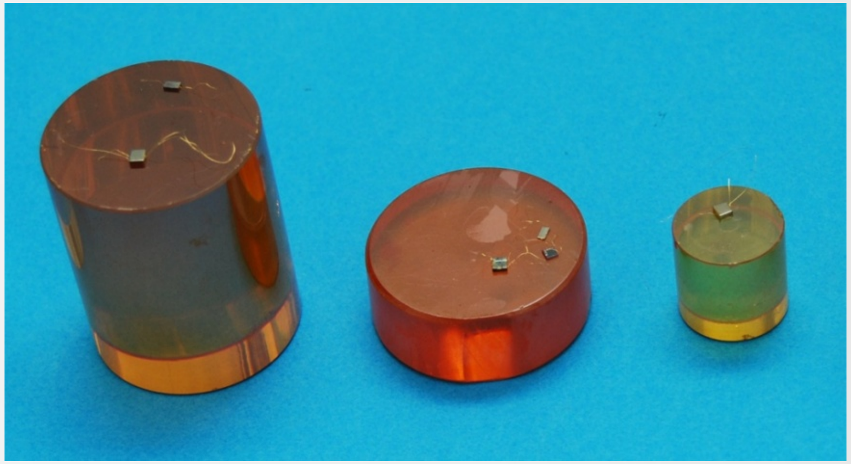
ZnSe

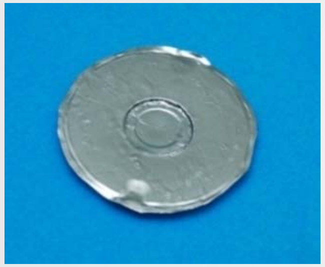
March 2009 (New Crystal)

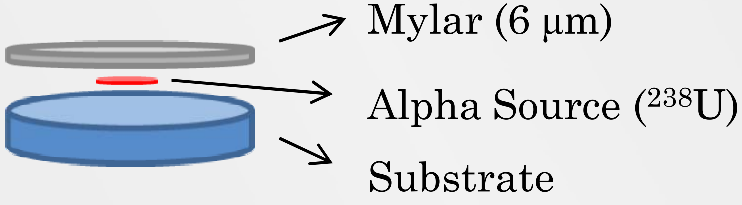
- Is the biggest ZnSe crystal tested up to now (337 g, cylindrical, Ø=40mm, h=50mm)
- Perfect optical surfaces
- Stand-alone mounting
- Alpha source



ZnSe crystals tested (different stoichiometry)





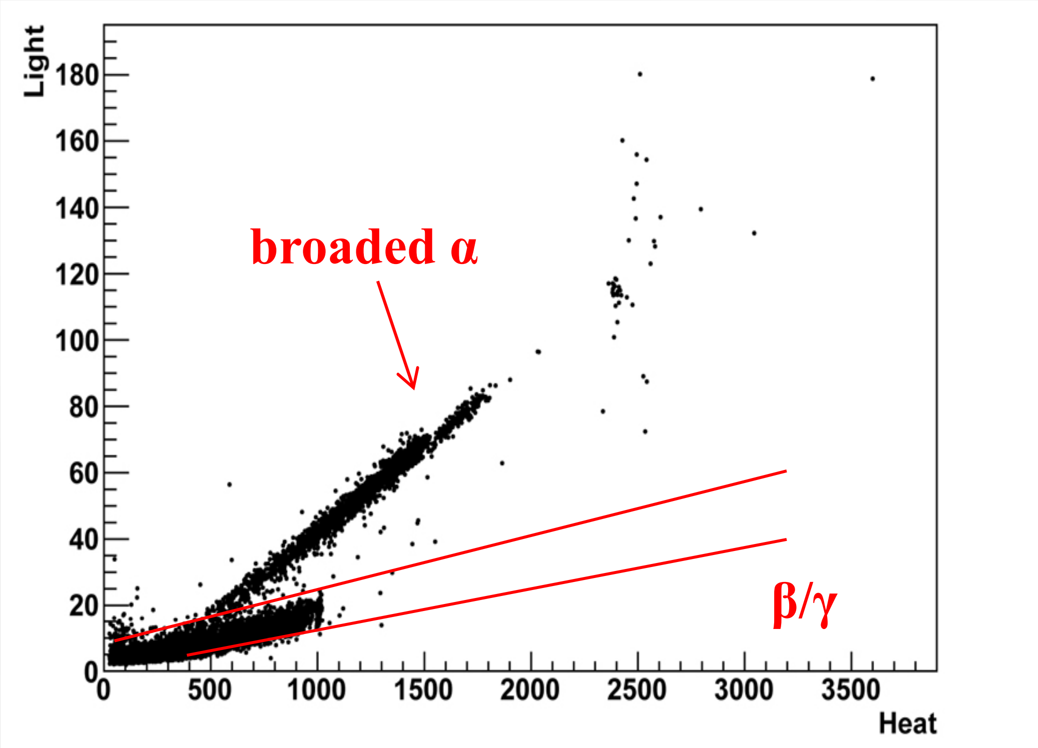


March 2009 (Old Crystal)

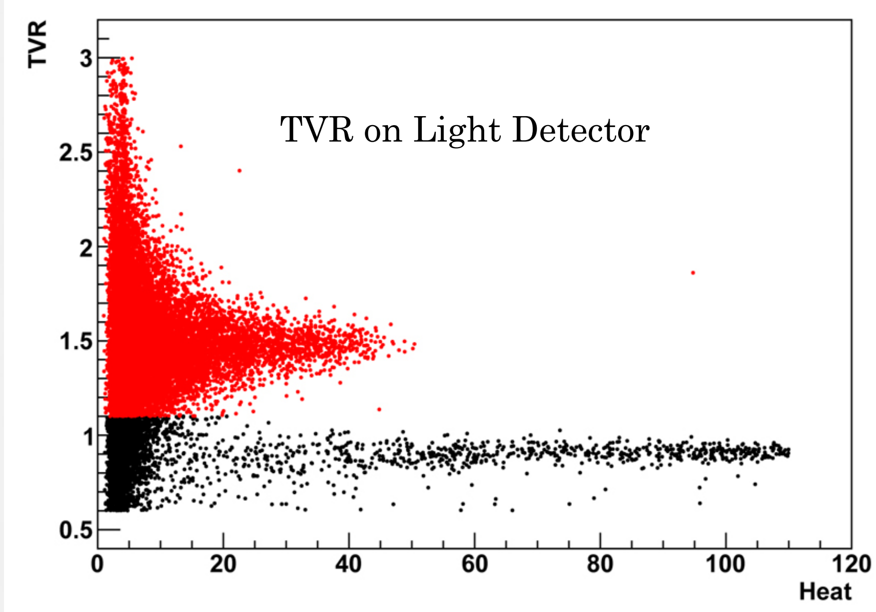
- Alpha source

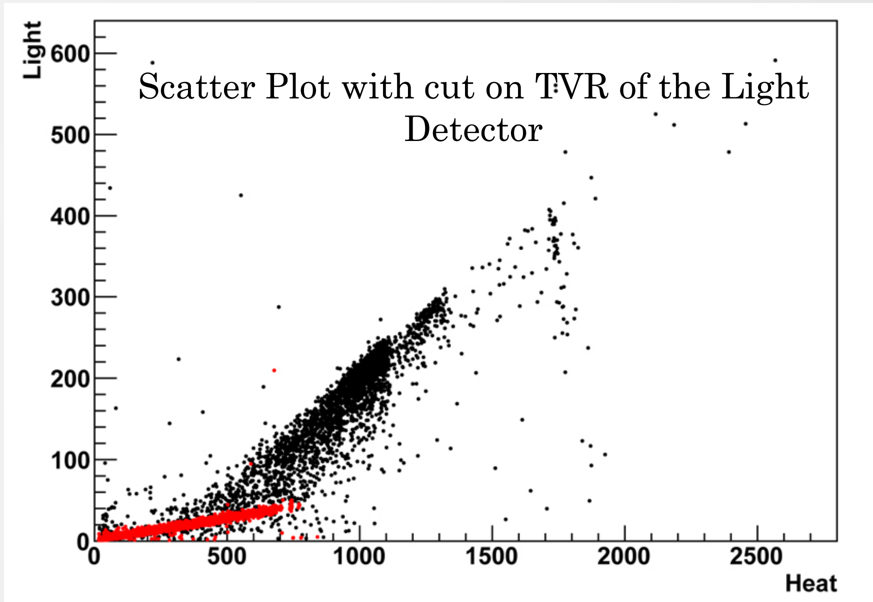
ZnSe Alpha source

New Crystal
Perfect optical surfaces



Old crystal





TVR = Standard deviation between points (right) of the filtered signal and the medium signal

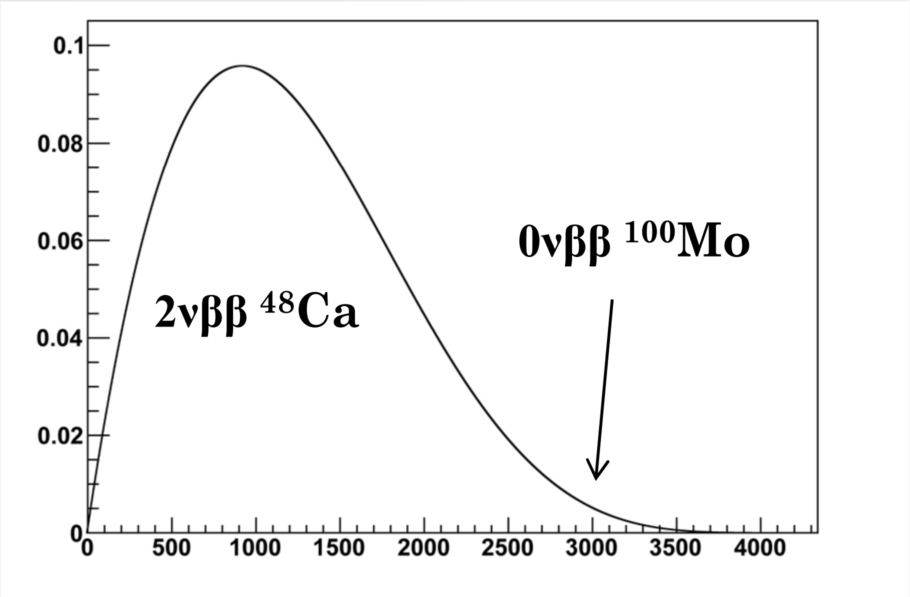
$CaMoO_4$

March 2009

measure with alpha sources (^{238}U) covered with ~ 6μm of Mylar. Measure with a $CaMoO_4$ crystal (cylindrical, Ø=35mm, h=40mm, 158g)

$Q_{\beta\beta}(^{100}Mo)$ = 3030 keV
i.a. = 9.6 %

$Q_{\beta\beta}(^{48}Ca)$ = 4270 keV
i.a. = 0.187 %

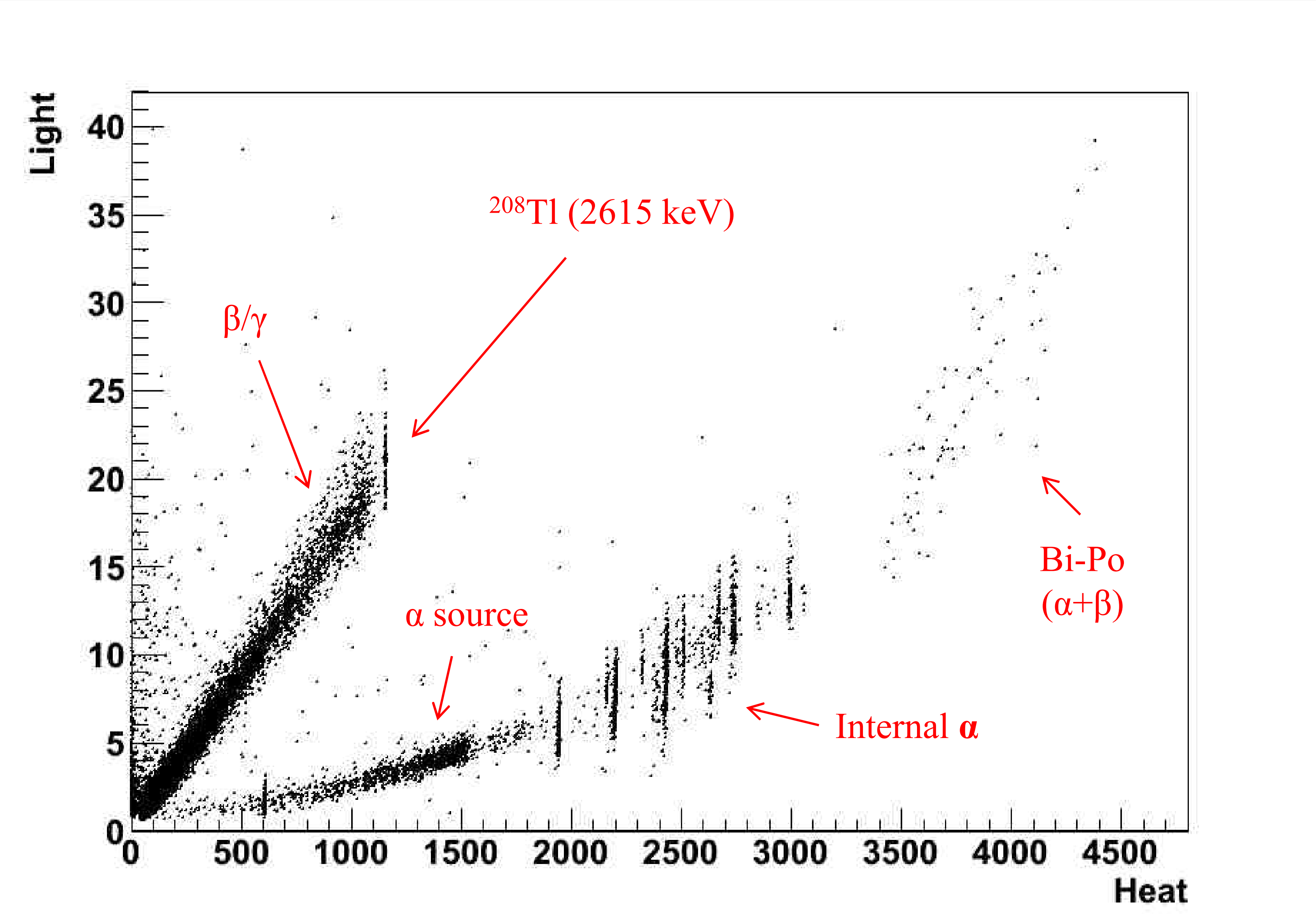


$\tau_{2\nu\beta\beta}(^{48}Ca) = 4.2 \cdot 10^{19}$ years

Number of counts between 3025 keV and 3035 keV
(FWHM = 10 keV)

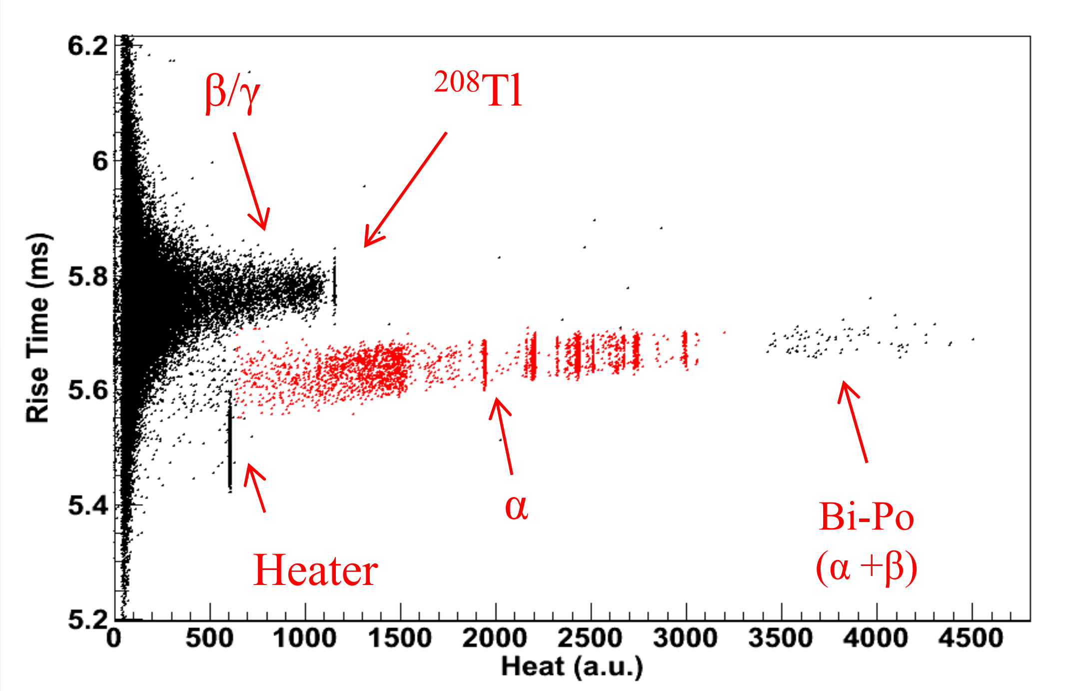
$3.44 \cdot 10^{-3}$ counts/keV/kg/y

$CaMoO_4$ Alpha source



$CaMoO_4$ Alpha source

Rise Time on $CaMoO_4$ crystal



Efficiency of alpha rejection:

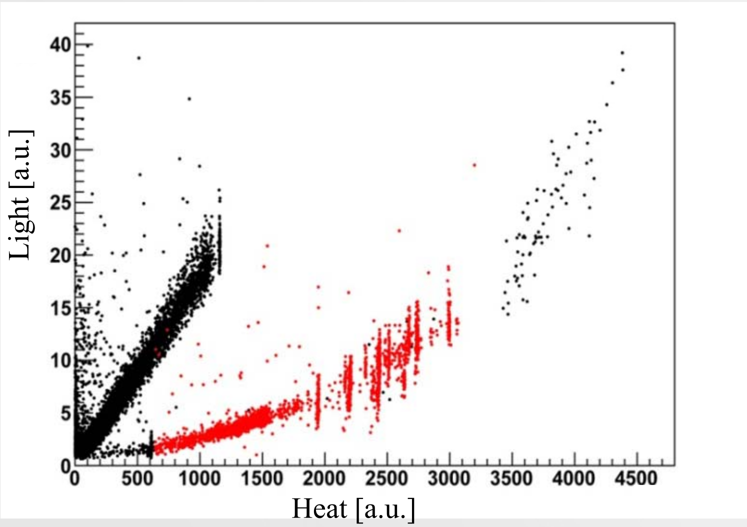
99,7 %

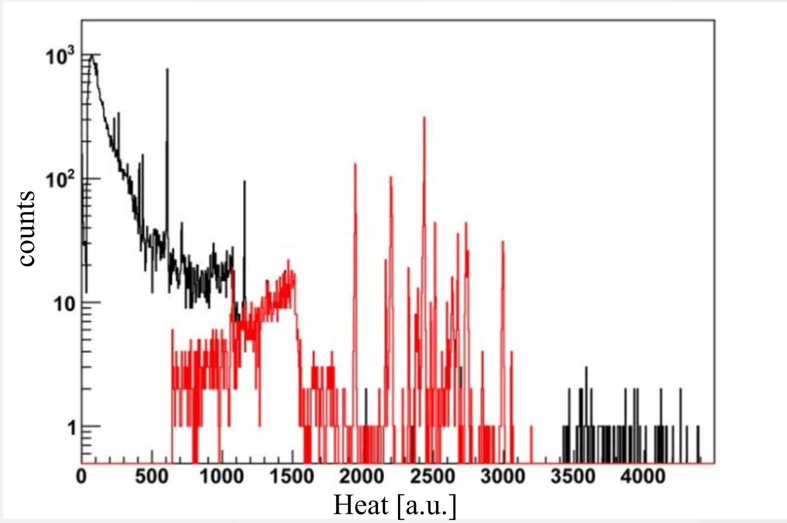
(preliminary)

Alpha discrimination on the Rise Time:

NO LIGHT DETECTOR
(easier to build)

NO REFLECTING SHEET
(analysis surface contaminations)





In red: events selected in the scatter plot of the Rise Time

Summary

Scintillating Bolometer

Surface contaminations represents the main source of background for bolometric detectors. Scintillating bolometers are a powerful tool in order to discriminate α particles and reduce this kind of background.

$CdWO_4$

All the crystals tested in different run work very well and show that its possible to reject all the counts in background due to alfa particle.
The run performed in 2008 also show the possibility to use this technique through an array of detectors.

ZnSe

ZnSe crystals are very clean and very promising crystals to the 0v Double Beta Decay searches.
Further study are necessary to understand the sensitivity reachable with this crystal.

$CaMoO_4$

The sensitivity of this crystal is limited by $2\nu\beta\beta$ decay of ^{48}Ca. Nevertheless for the first time this crystal has shown the possibility to discriminate alpha particle with pulse shape analysis.