Scintillating Bolometers for next generation Double Beta Decay

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- *Background Limitation for Simple bolometers*
- *Principles of operation*
- *Cd-Mo-Ca based crystals*
- *ZnSe crystals*
- *Conclusions*

Some History

The first measurement of light and heat in a bolometer was performed in 1992 by the Milano group

But this technique, using a silicon PD at low temperatures showed several difficulties

- Radioactivity induced by the PD itself
- Cold stage charge preamplifier inside the cryostat
- Relatively small surface area of the PD

For these reasons the technique was abandoned

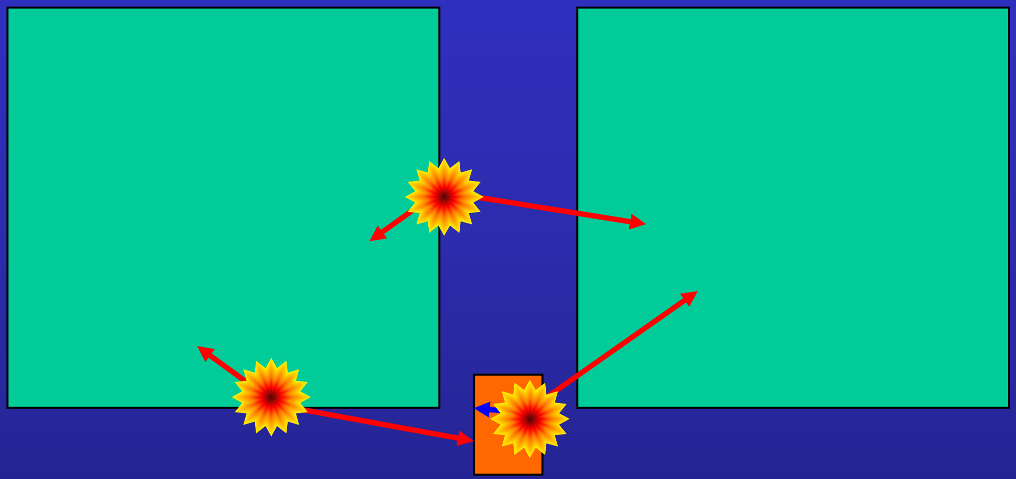
In 2004 we started to develop bolometer as LD (as CRESST and Rosebud Experiments)

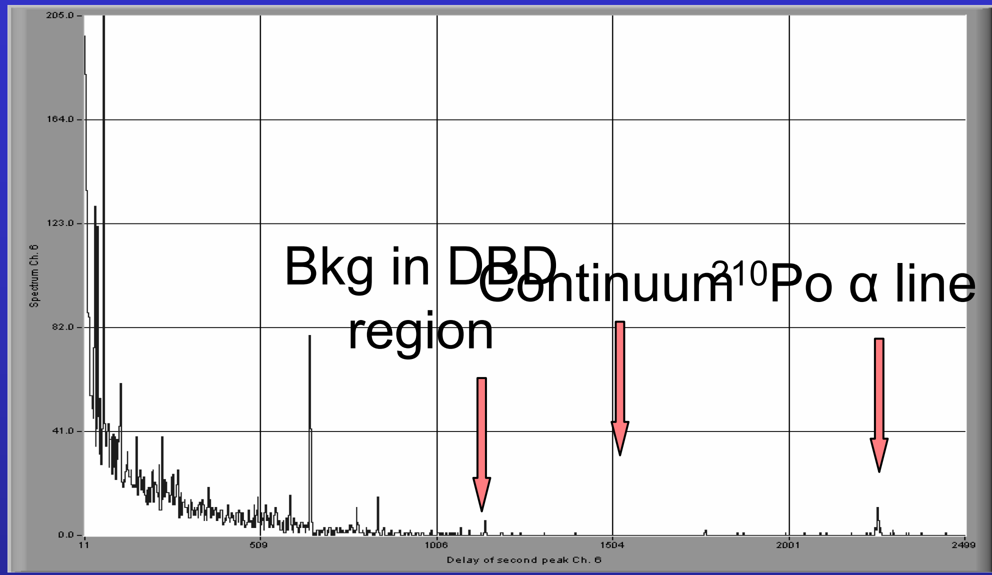
The activity was then funded by INFN through the BoLux (R&D) Experiment* 2007-2009 and by EC

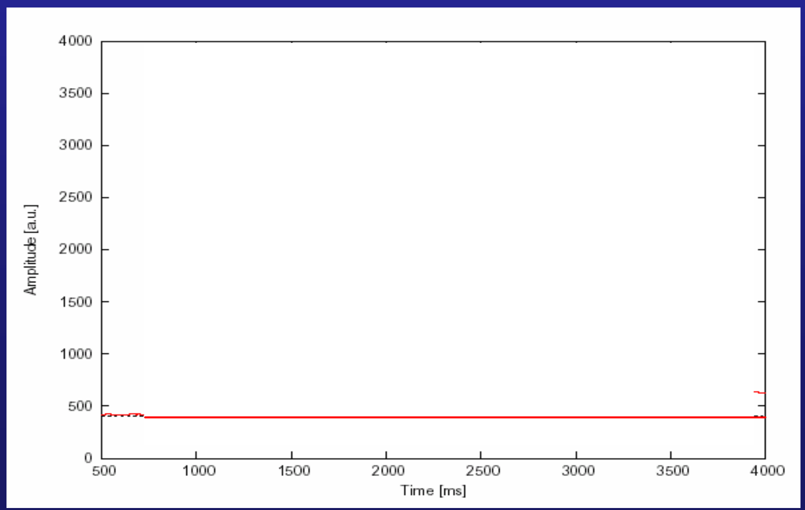
Presently we proposed the CUPIDO R&D* project (INFN) that should demonstrate, on a few kg scale, the potentiality of this technique

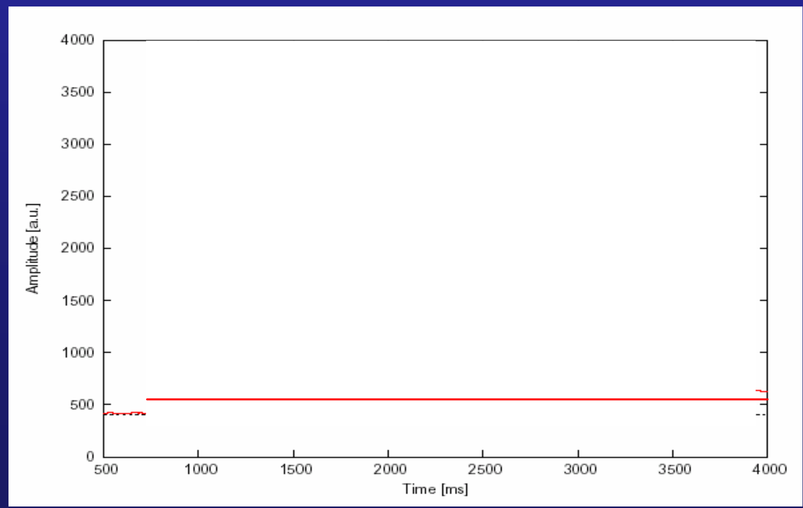
* Spokesman: Stefano Pirro

A serious problem : Surface contaminations



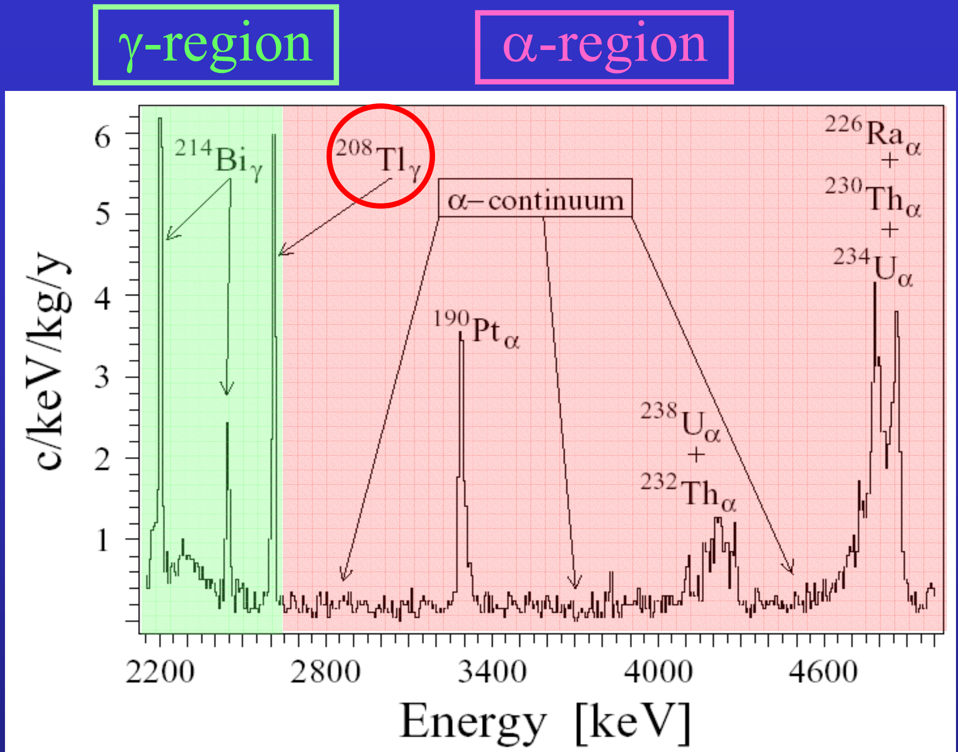




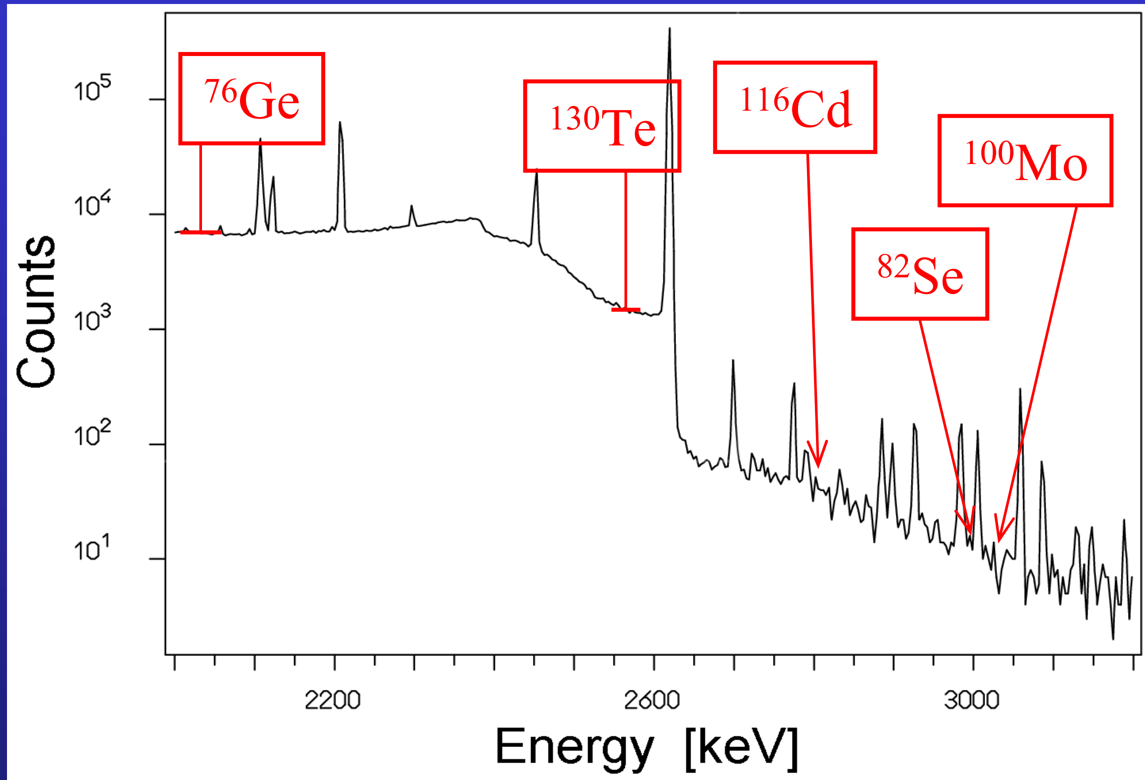


Sum energy: 2527 keV

Surface and Bulk contaminations



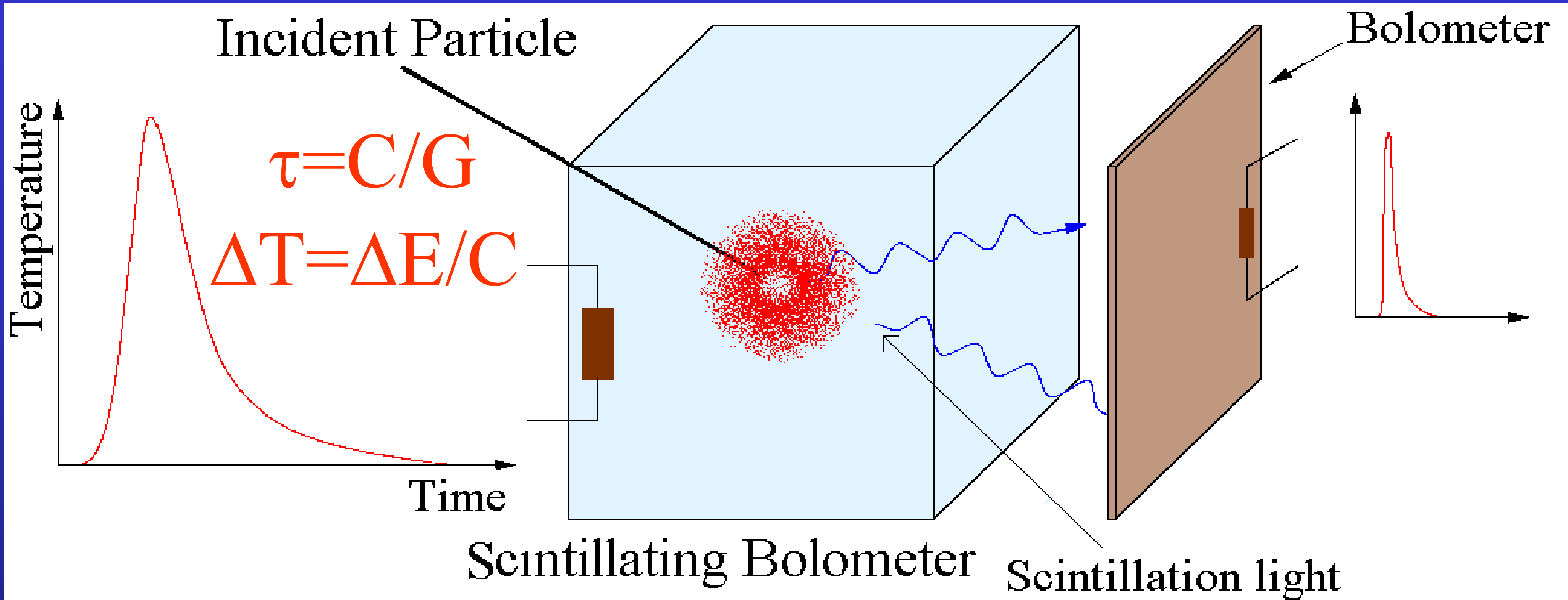
CUORICINO α Background



Environmental "underground" Background: ^{238}U and ^{232}Th trace contaminations

Furthermore a not negligible part of the background can arise from high energy neutrons from μ-spallation

Principles of operation



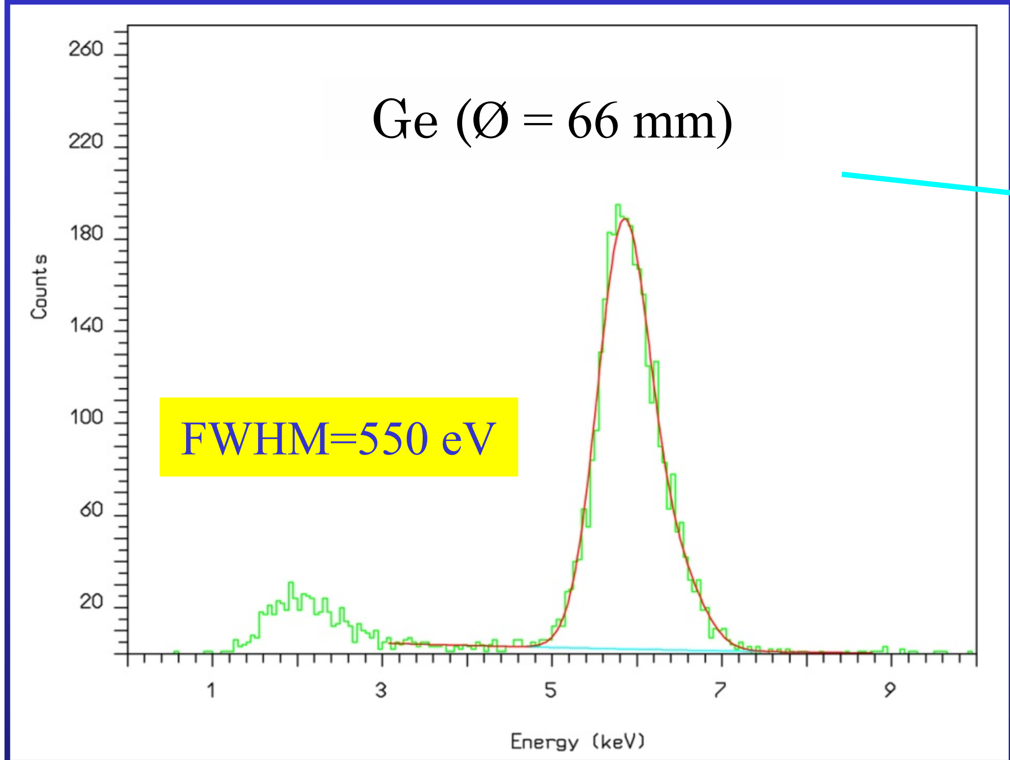
A Bolometric Light Detector is fully active a particle detector

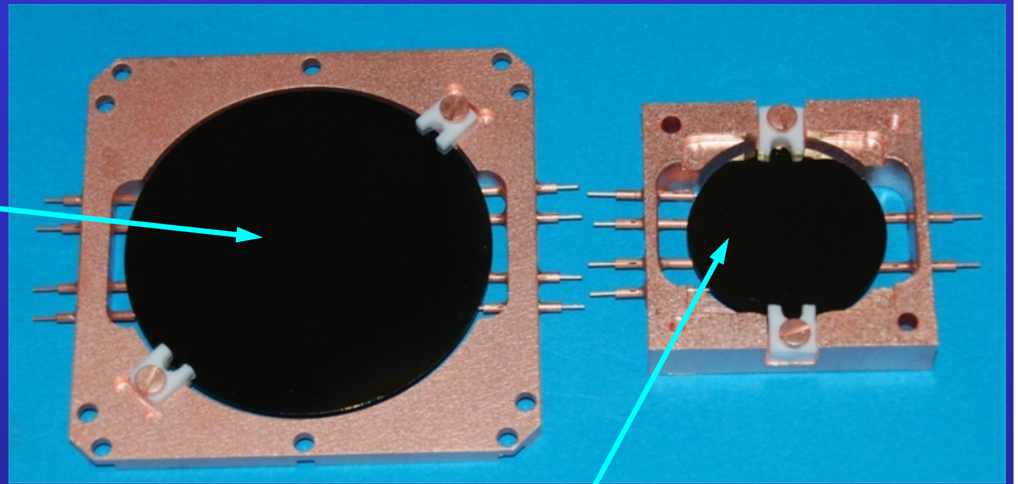
The time response of a BLD is the same of a standard bolometer O (ms)

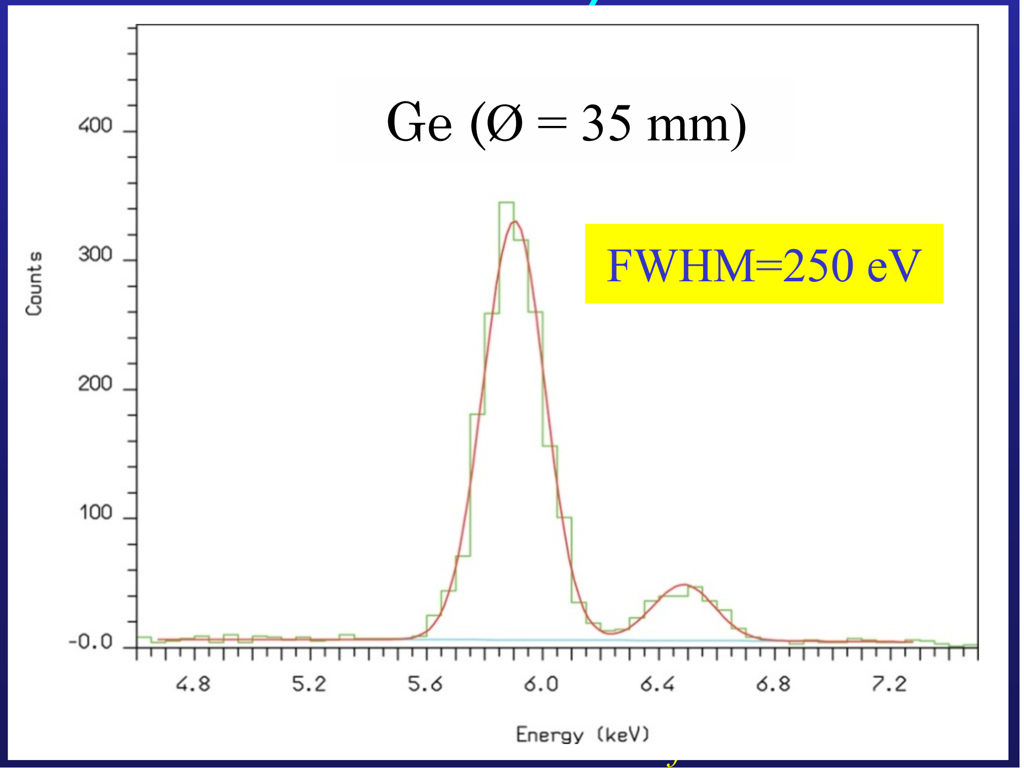
The QE of a BLD is, probably, comparable with that one of PD's but it is not easy to measure it

Light Detectors - Performances

Our Light detectors are generally Pure Germanium disks (thickness 0.3-1 mm) . The Performances of a LD are normally evaluated through the Energy resolution on the ^{55}Fe doublet (5.9 & 6.5 keV X-Ray)







Summary of (almost) all the measured crystals

Good Scintillation light

- $PbMoO_4$
- ZnSe
- $CdMoO_4$
- $SrMoO_4$
- $CdWO_4$
- CaF_2
- $CaMoO_4$
- $ZnMoO_4$

Poor Scintillation light

- ZrO_2
- Li_2MoO_4

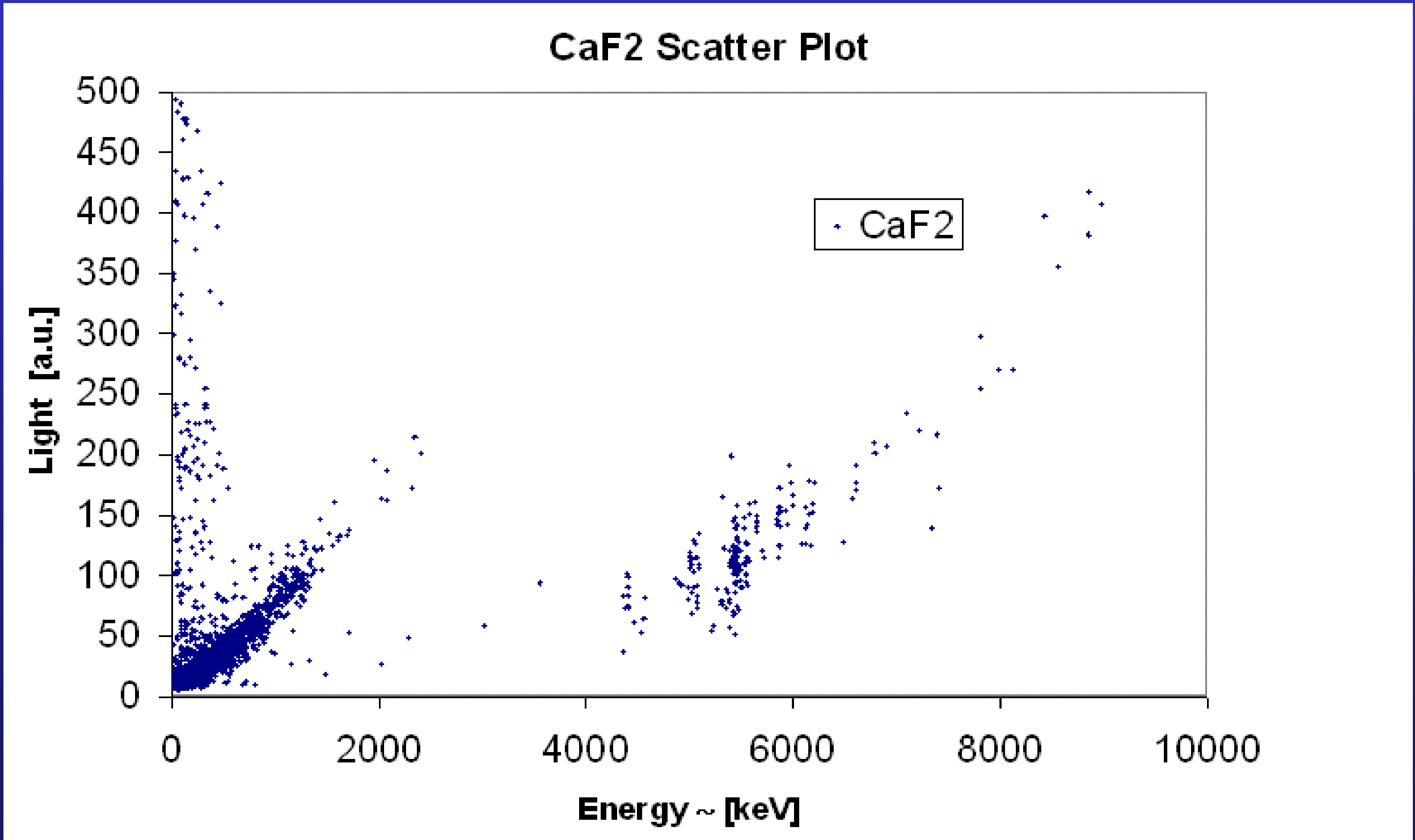
No Scintillation light

- $MgMoO_4$
- TeO_2

Undoped CaF_2

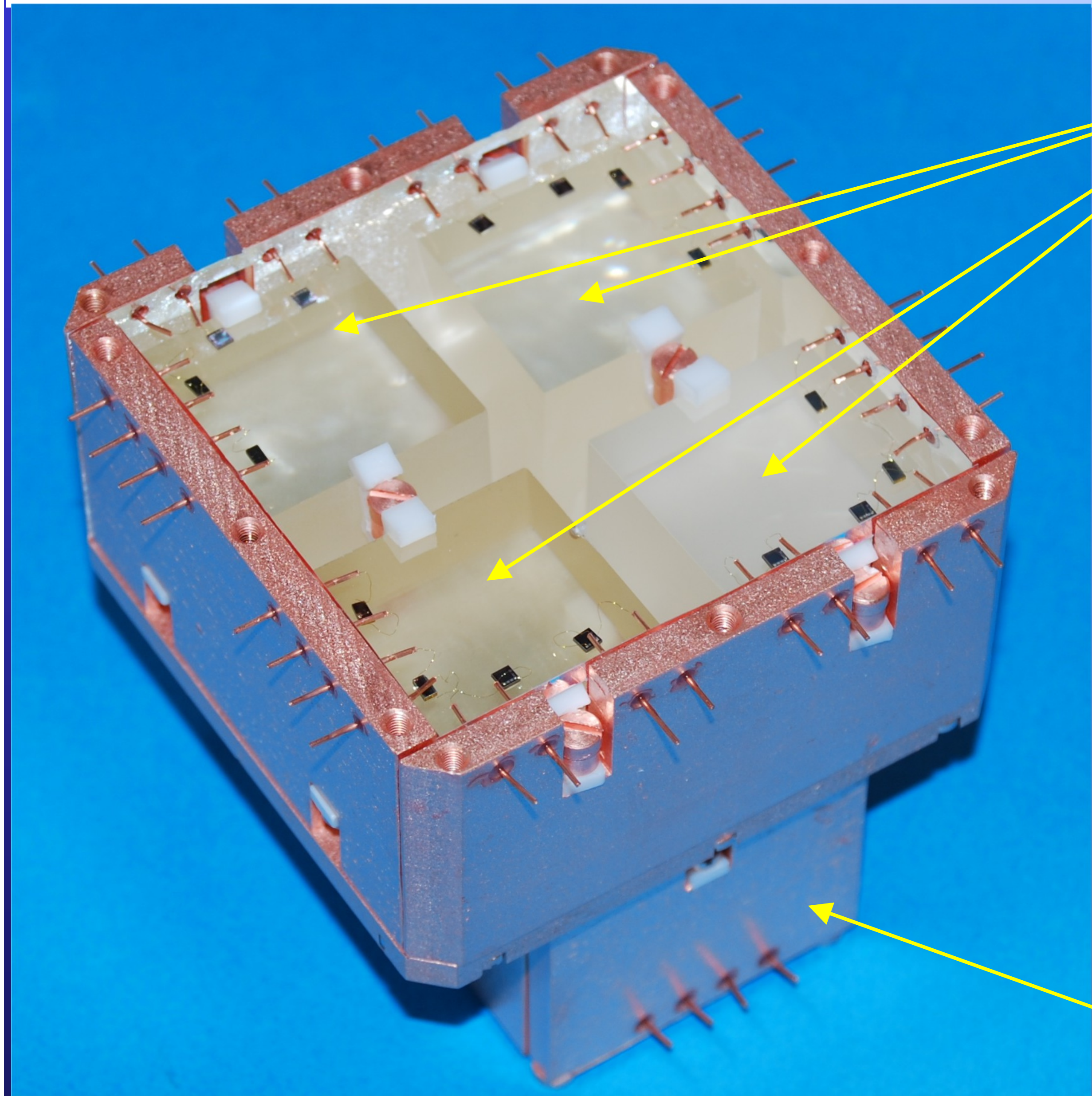
In 2007 we tested a CaF_2 crystal. The light output was "rather poor" but definitively enough to discriminate alpha's

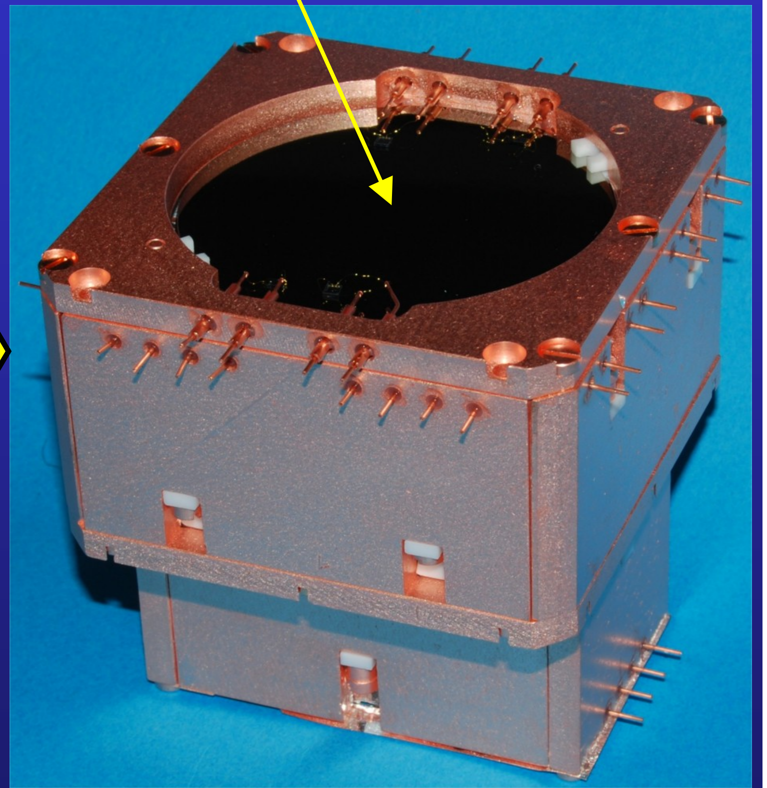
Calibration (^{232}Th) on a 3x3x3 cm^3 PURE CaF_2 crystal



There was a lack of an actual calibration due to the "lightness" of the compound; nevertheless the Signal/noise ratio of the CaF_2 was excellent.

Results on the first array of $CdWO_4$ crystals (1)



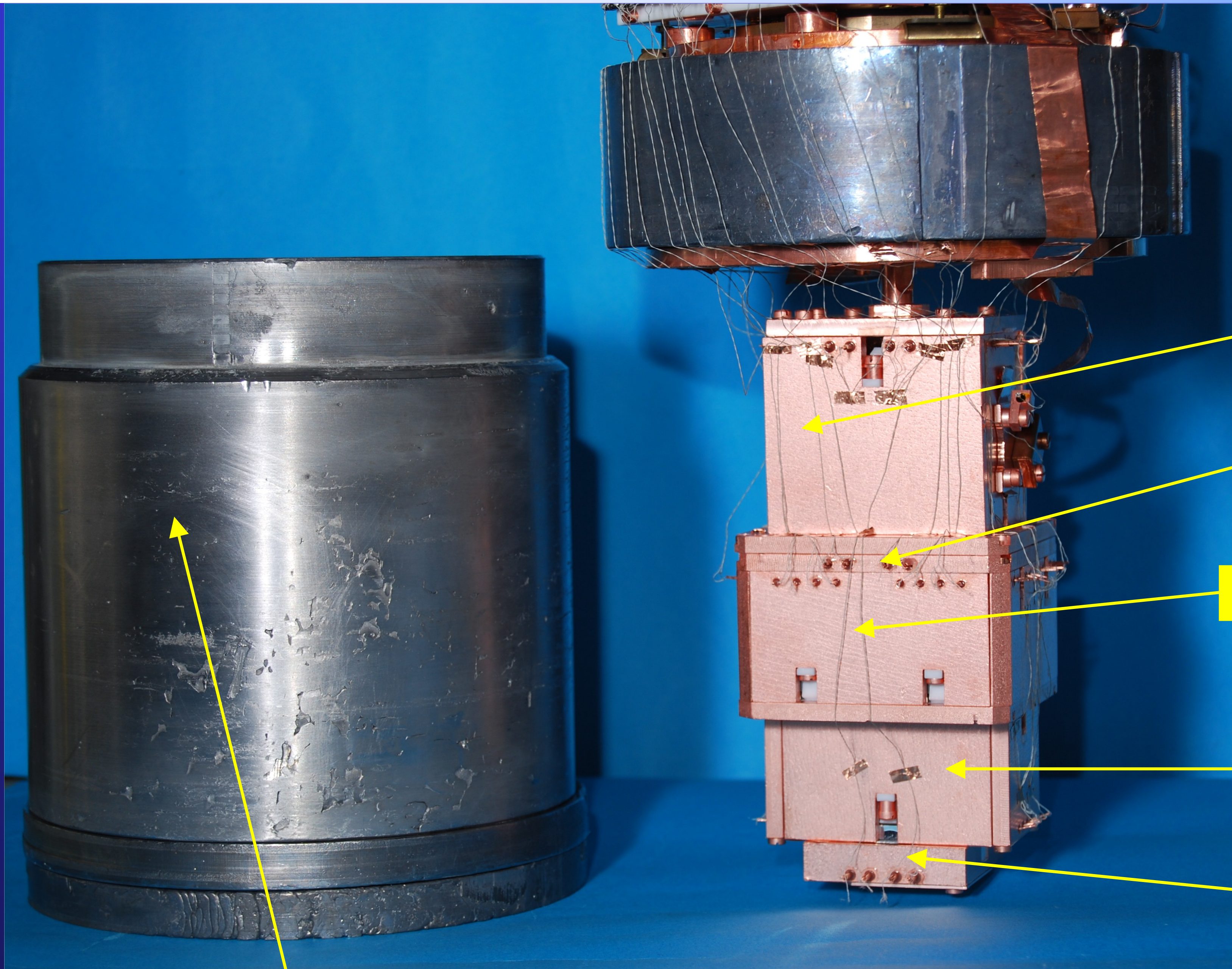


4 3x3x3 cm^3 (215 g each) $CdWO_4$

1 common LD facing the 4 crystals

$CdWO_4$ – 3x3x6

Results on the first array of $CdWO_4$ crystals (2)



CUORE test crystal

Large light detector

4 $CdWO_4$ 3x3x3 cm^3 crystal array

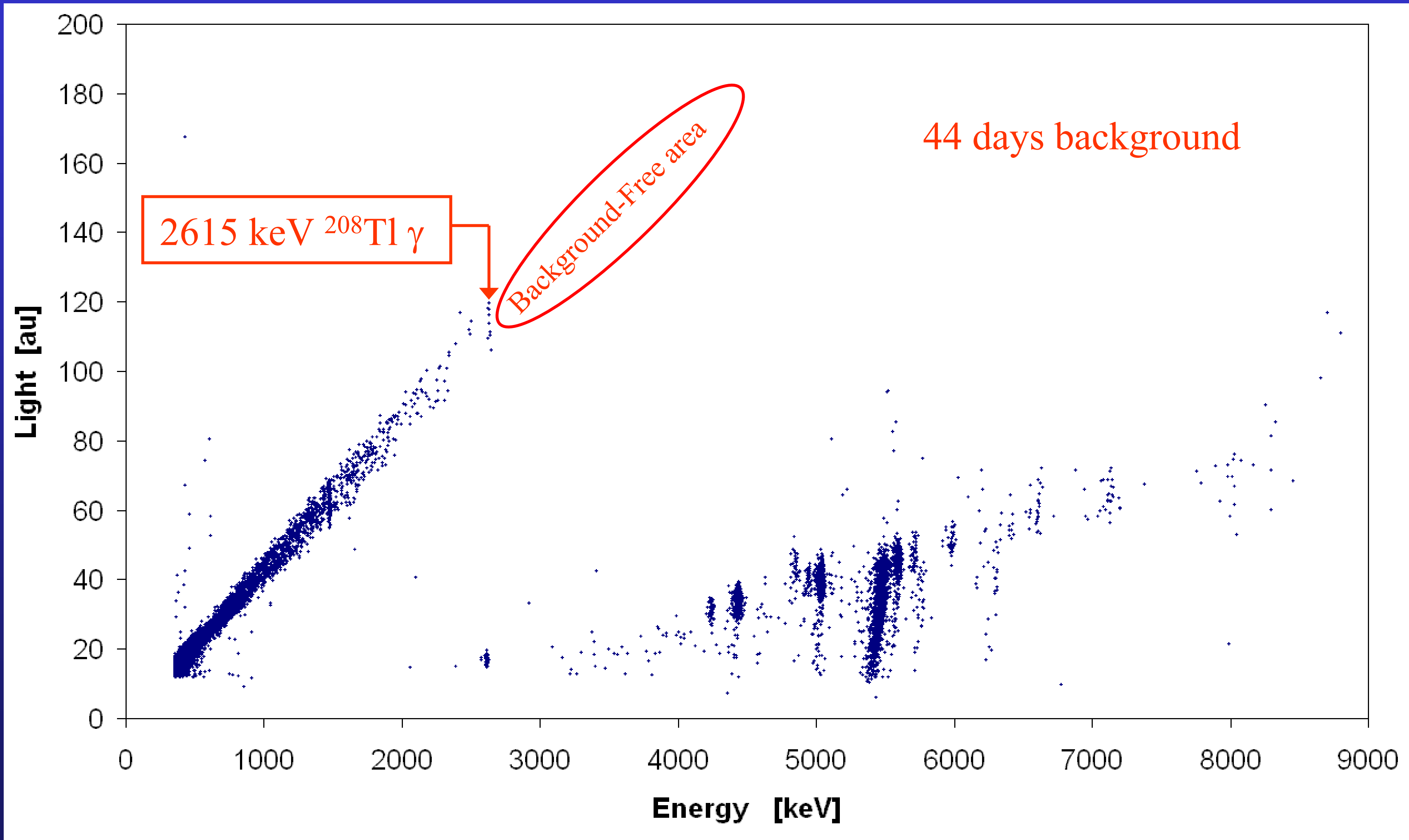
$CdWO_4$ 3x3x6 cm^3

Small light detector

Internal Roman lead shield

Results on the first array of $CdWO_4$ crystals (3)

The data on the single 420 g 3x3x6 cm^3 crystal is presented here.
The obtained scatter plot is shown it corresponds to 1066 hours of background measurement

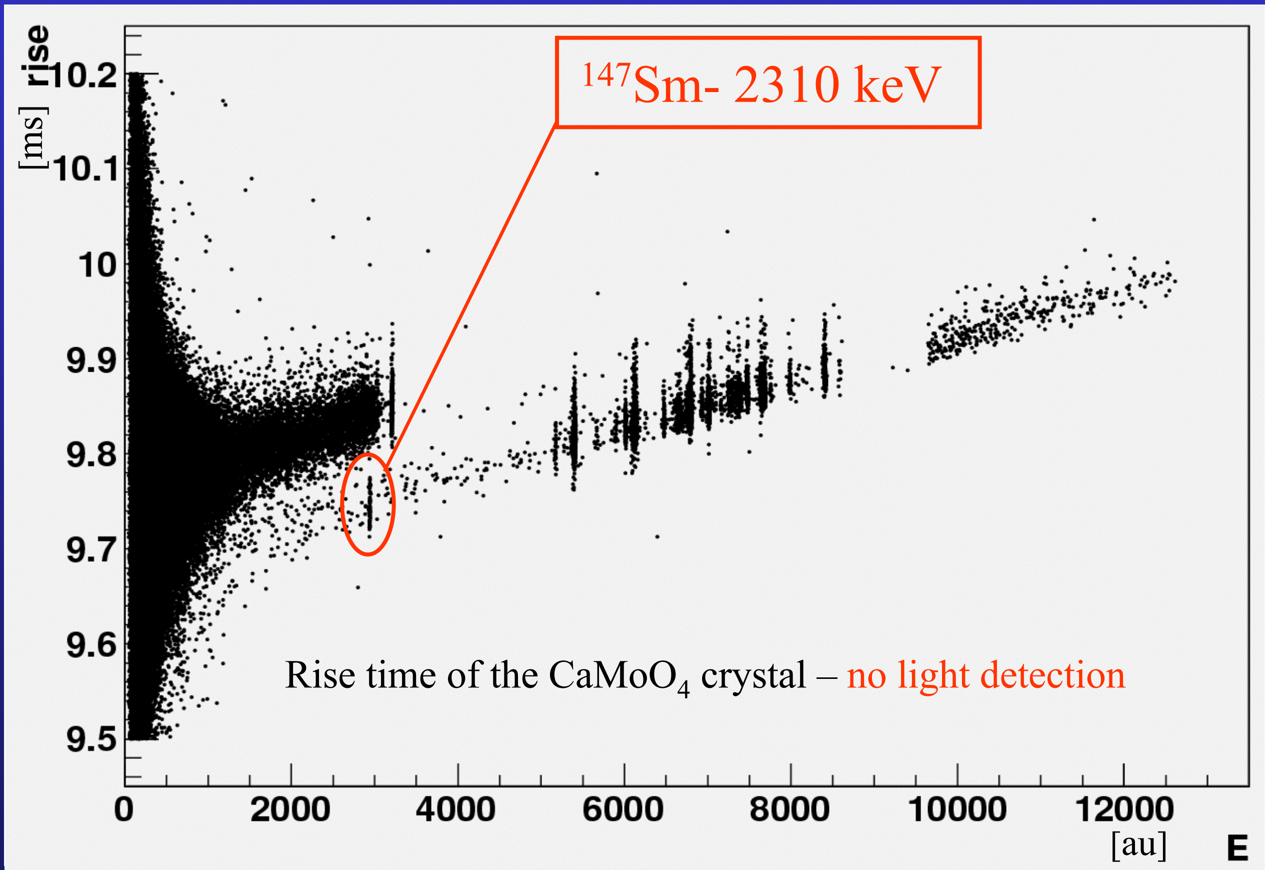


The MC simulation predicts a background level of 10^{-4} c/keV/kg/y in the region of interest

Results on "large" crystals - $CaMoO_4$

$CaMoO_4$ is not a "perfect candidate" for future DBD Experiment since it contains ^{48}Ca

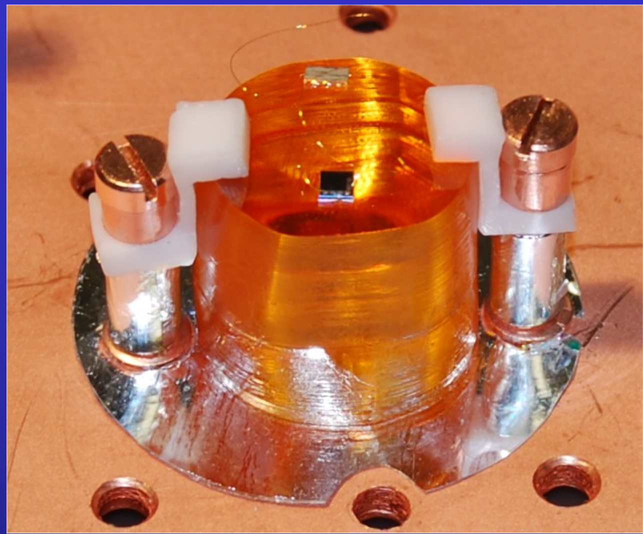
But this compound did show an extreme interesting feature

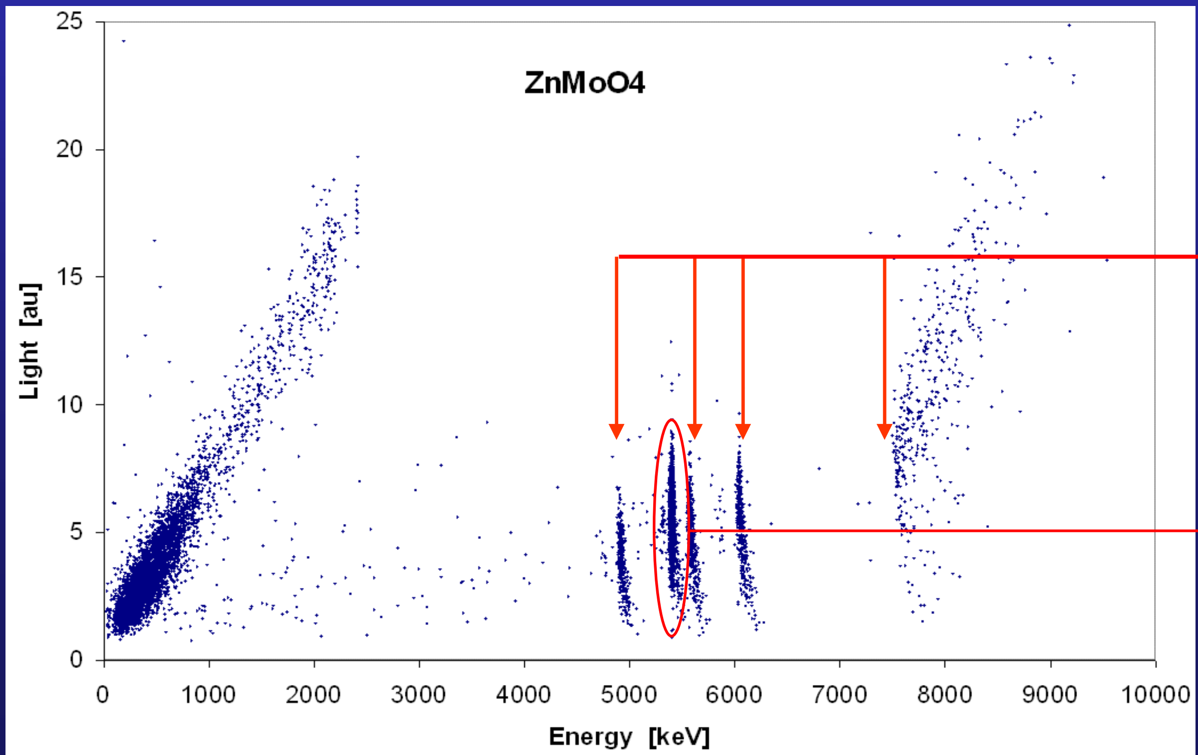


$CaMoO_4$ Bolometers permits alpha discrimination (99,7%) without Light detection !!!!

$ZnMoO_4$ – A promising Molibdate

A 22 g $ZnMoO_4$ crystal was grown by Institute for Scintillation Materials (Kharkov, Ukraine) In collaboration with by Institute for Nuclear Research (Kiev, Ukraine)





^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Bi-^{214}Po

(56 mBq/kg)

^{210}Pb

(360 mBq/kg)

ZnSe – an extremely interesting compound

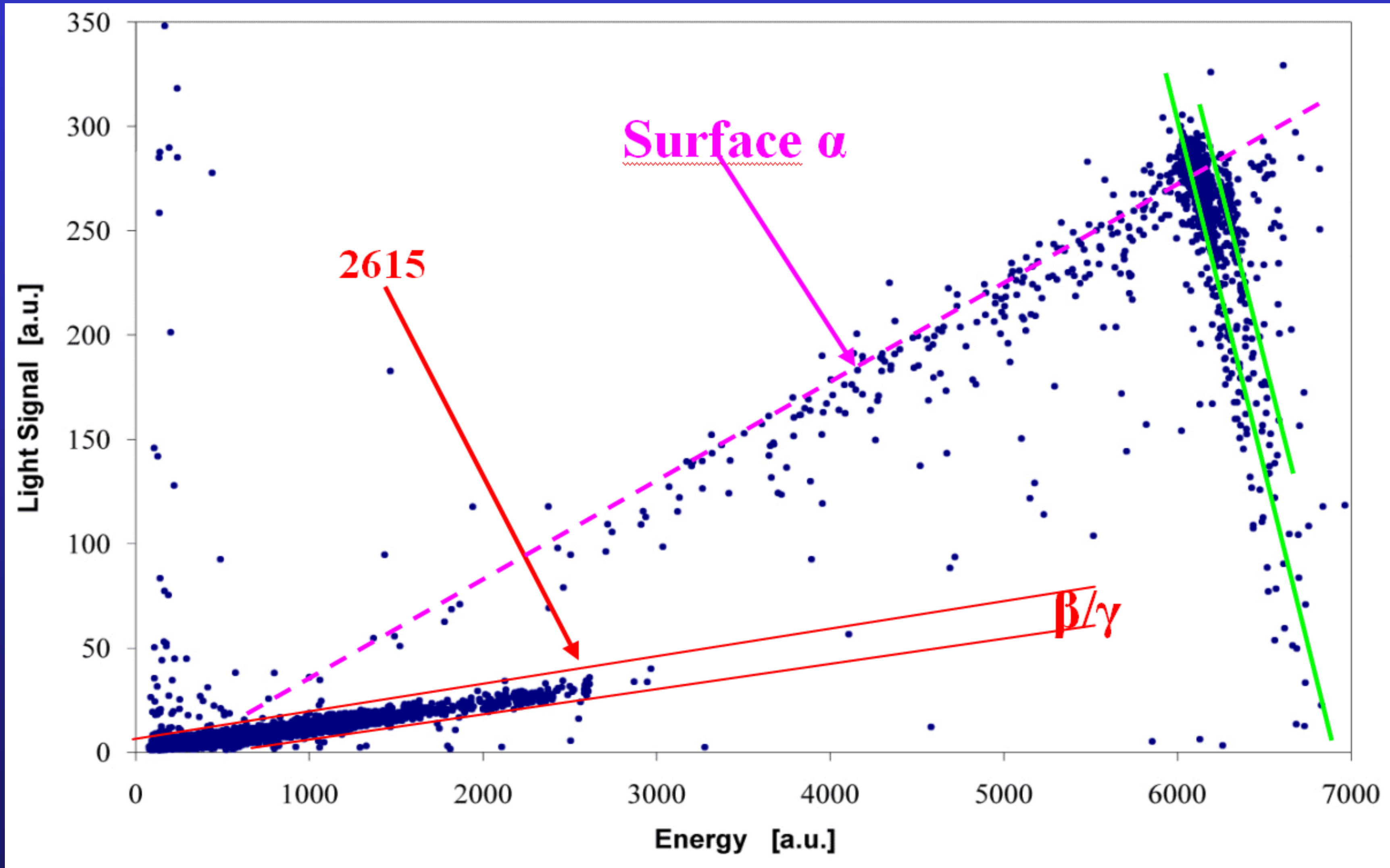
ZnSe crystal was/is an extremely puzzling and interesting material.

ZnSe crystal has a **huge** scintillation output but the emission spectra is close to the absorption spectra ($\lambda \approx 1$ mm)

It normally doped with Te in order to increase the overall light output (we tested UNDOPED crystals)

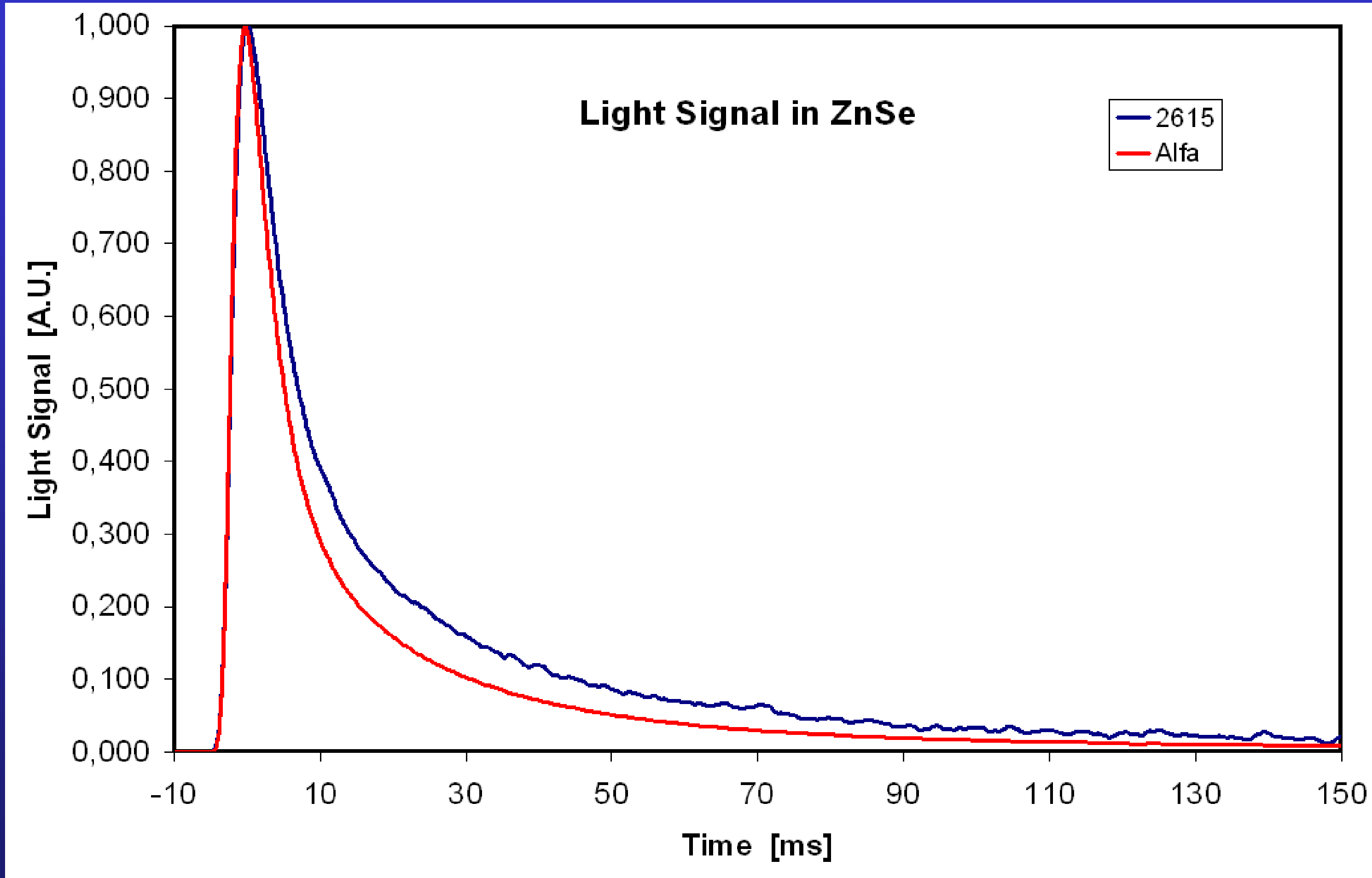
ZnSe – a puzzling scintillation

In the first run (2007) we observed a "very" strange scatter plot



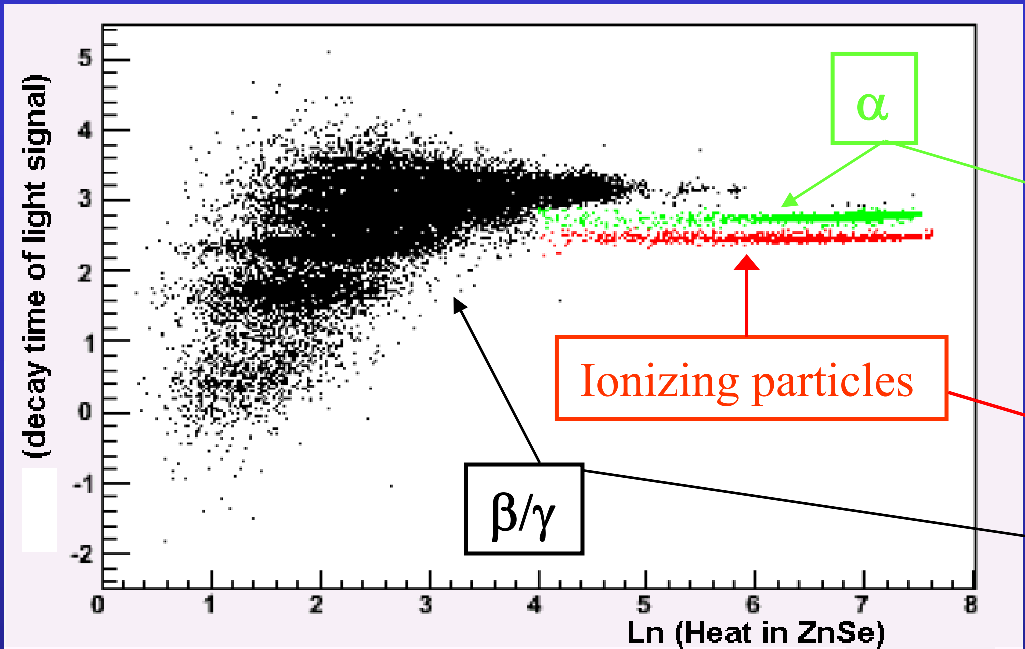
ZnSe - Pulse

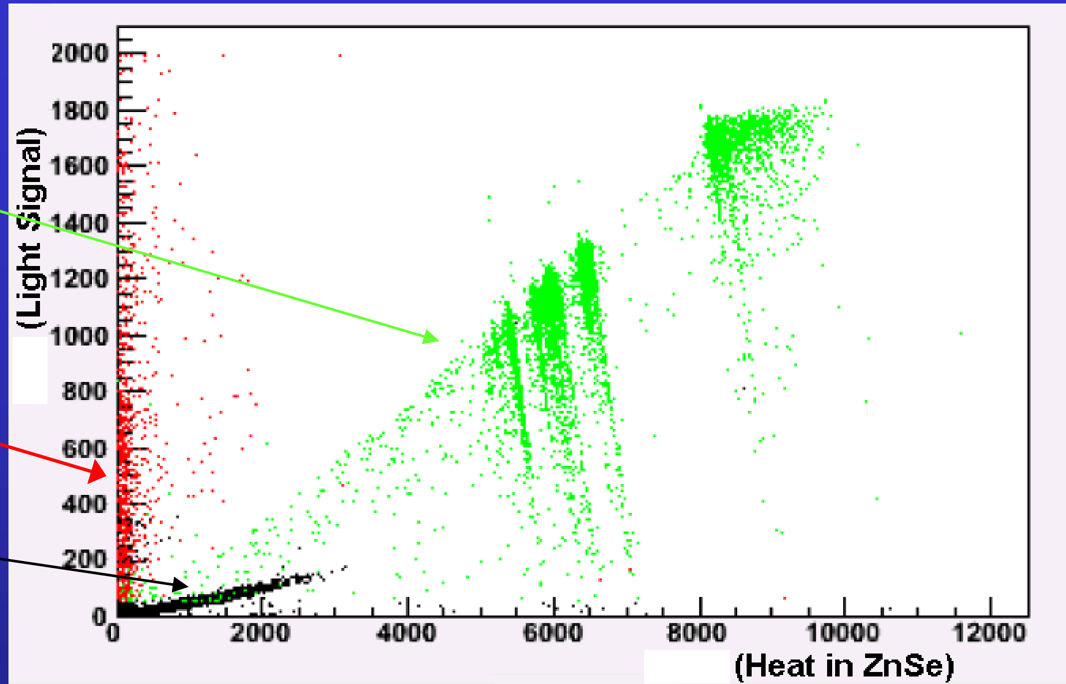
Moreover a "good" surprise arise from the time development of the Scintillation Signal



The scintillation signal has a difference in the O(10ms) range. This effect is absolutely unexpected, even at very low temperatures

ZnSe - an extremely interesting compound (4)





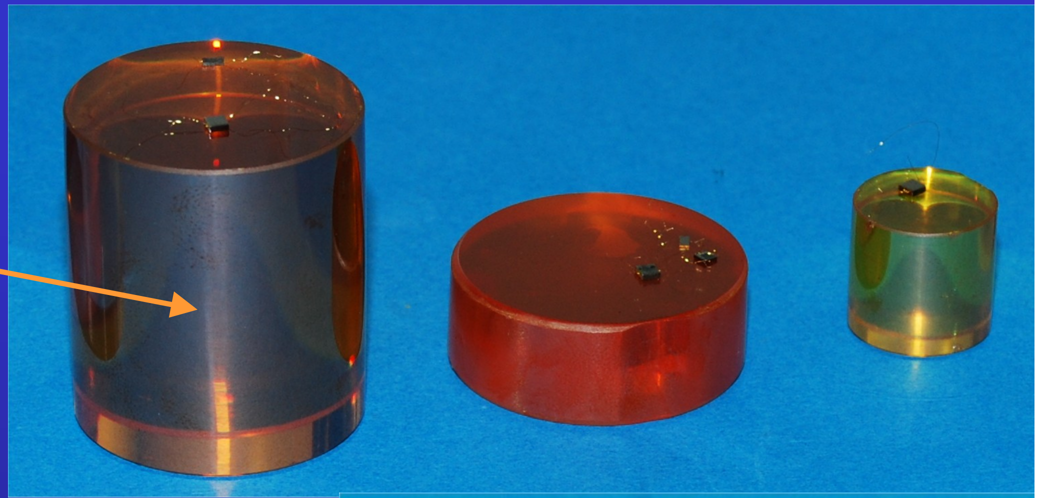
Looking at the coincidences between Heat in ZnSe and “Light” in the light detector, three population appears

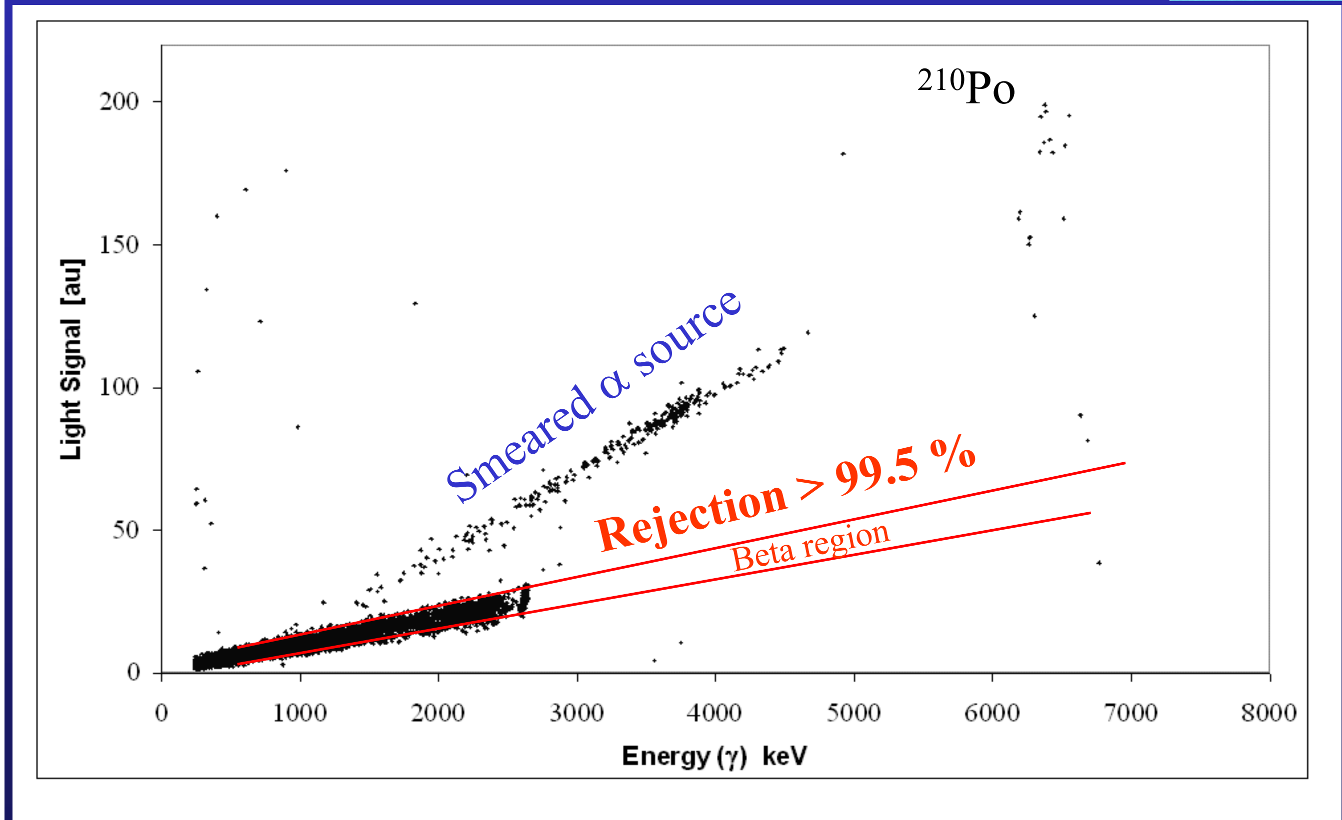
In this way > 99.8 % of the alpha’s are recognized

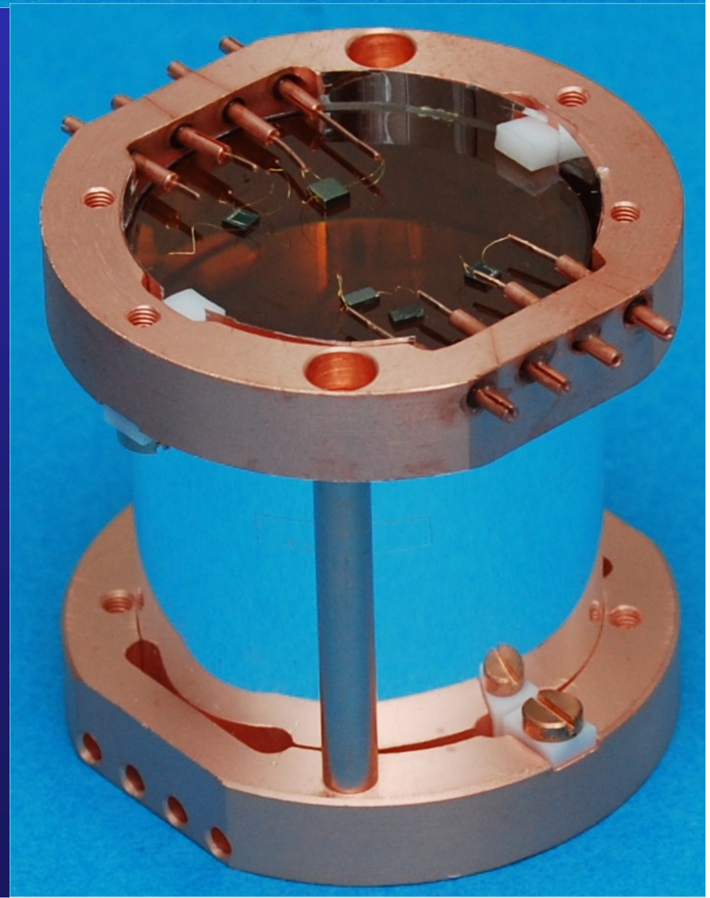
ZnSe – an extremely promising compound (5)

First Results on a 4 cm ∅ 5 cm height 337 g ZnSe Crystal

337 g "new" ZnSe Crystal





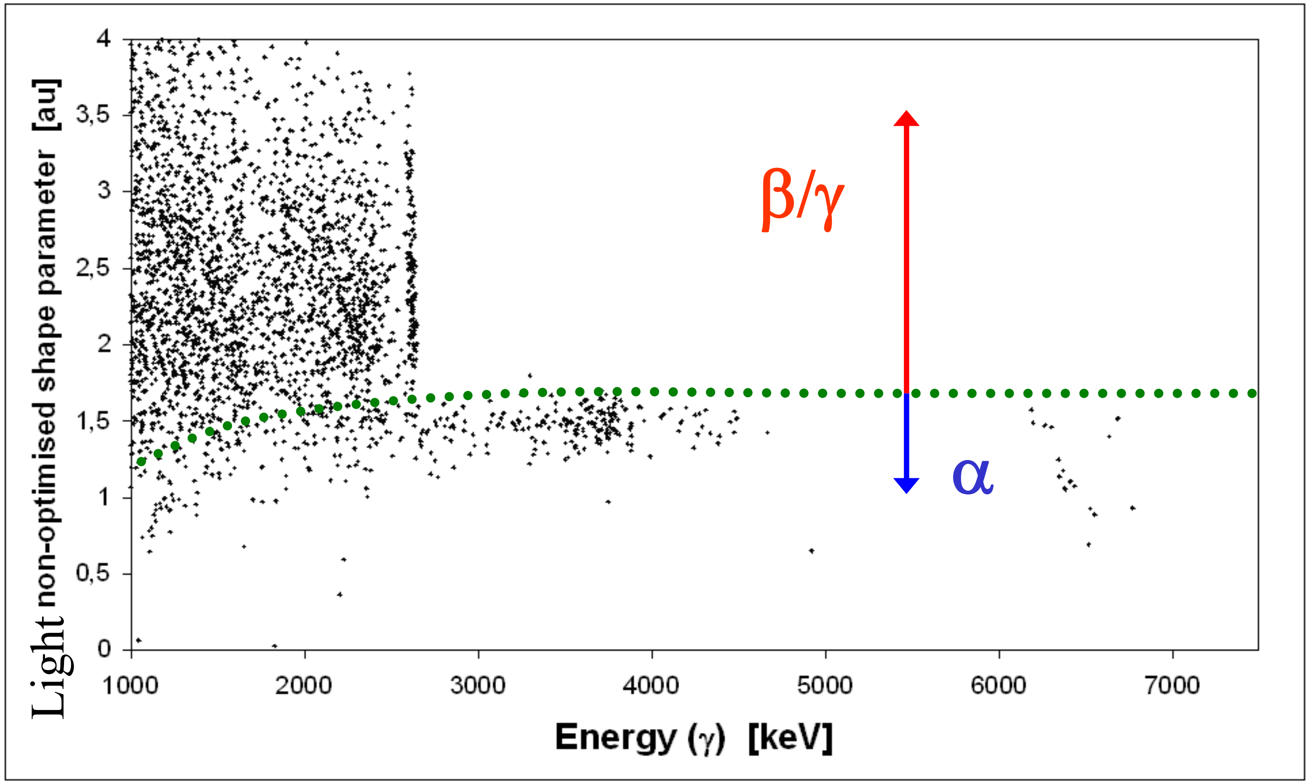


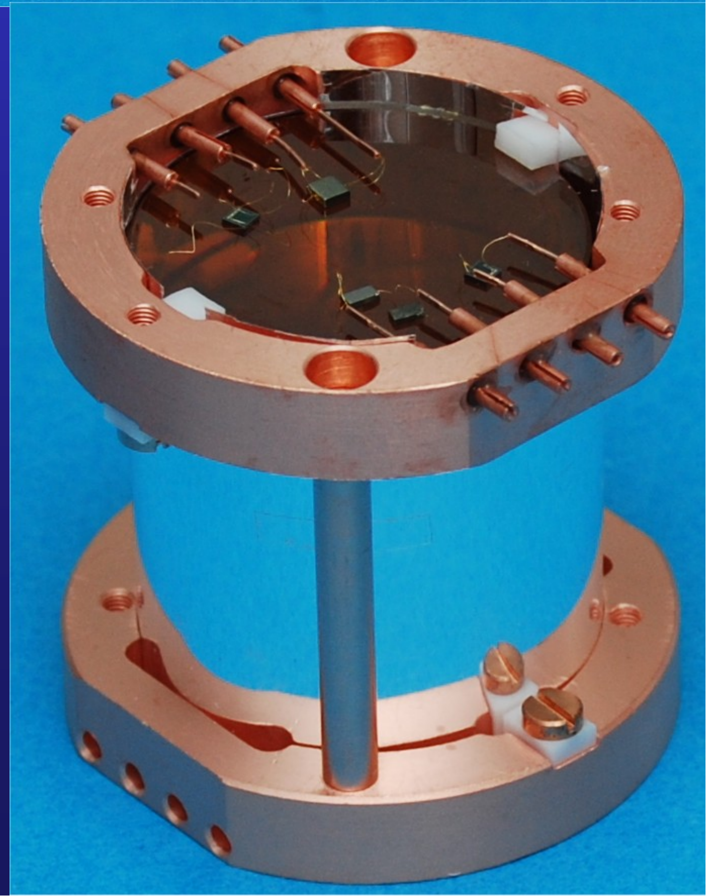
Calibration with ^{232}Th and a smeared α source

ZnSe – an extremely promising compound (5)

First Results on a 4 cm ∅ 5 cm height 337 g ZnSe Crystal

337 g "new" ZnSe Crystal

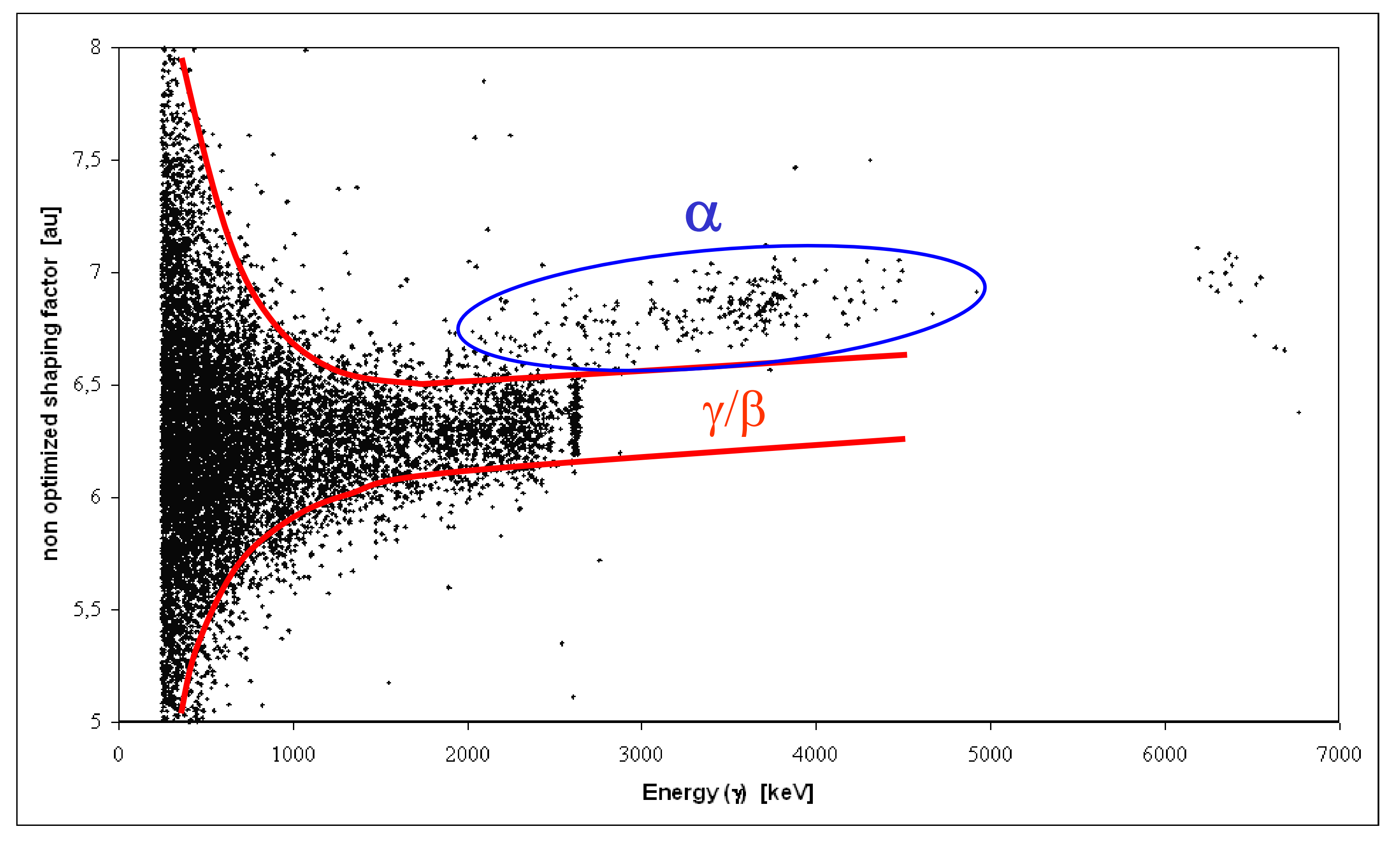




Calibration with ^{232}Th and a smeared α source

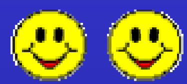
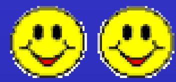
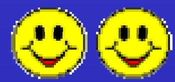
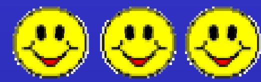
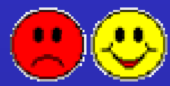
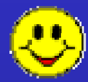
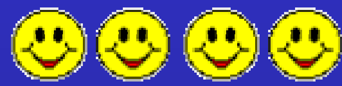
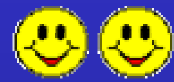
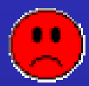
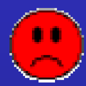
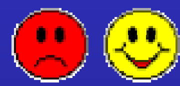
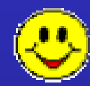
ZnSe – an extremely promising compound (6)

This compound shows another <u>very interesting</u> feature: α's show different thermal pulse development



α rejection > 97 % <u>without</u> light detection

Summary

	Reproducibility	Availability	Radiopurity	α/n rejection
$^{116}Cd \rightarrow CdWO_4$				
$^{82}Se \rightarrow ZnSe$				
$^{100}Mo \rightarrow$ …. $ZnMoO_4$				

Conclusions

✓ We tested several types of scintillating crystals with interesting ββ emitters (^{100}Mo, ^{116}Cd, ^{82}Se, ^{48}Ca)

✓ Within them $CdWO_4$ is "ready to use"

✓ The "outsider" ZnSe is now, probably, the best candidate , even if some more tests are needed

✓ Molibdates needs more R&D both for radioactivity and scintillation light

✓ This technique is the only one that can be used for several interesting DBD emitters with excellent energy resolution (0.3 ÷ 1 % FWHM)

✓ Simulations show that a background level of 10^{-4} 10^{-5} c/keV/kg/y can be "easily" reached without too much "restrictions" on internal radioactivity.

✓ Within next year we plan to test 2 small arrays of $CdWO_4$ and ZnSe crystals (O(kg)) in order to completely test the technique

➢ Even if theoretically, this is presently the *only technique* that fulfills all the requirements needed to proceed down to the direct hierarchy region.