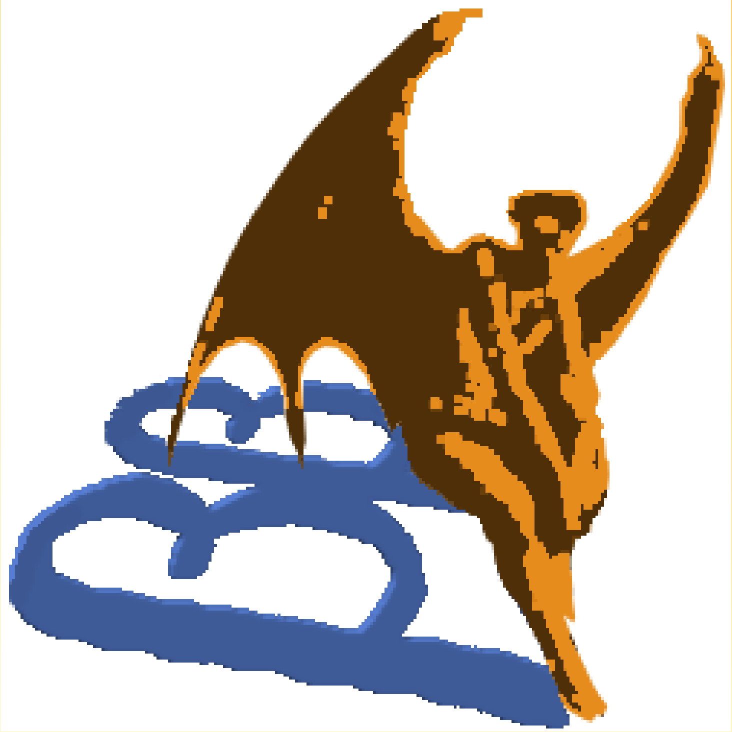
Current status and future perspectives for the LUCIFER experiment



Stefano Pirro - INFN

US-Italy Physics Program at Laboratori Nazionali del Gran Sasso, *Princeton, October 15 2013*

Lucifer

Is a DBD demonstrator/experiment funded mainly (3.3➔ 2.7 M€) by ERC, in the form of an advanced GRANT (03/2010➔03/2015) assigned to F. Ferroni

The experiment will be based on the **scintillating bolometer technique**, early developed within CUORE

It is therefore (probably not so…) clear that the people wowrking in Lucifer also join CUORE. Also the test set-up is the same used for the CUORE R&D, as well as the final location of the experiment (CUORE-0)

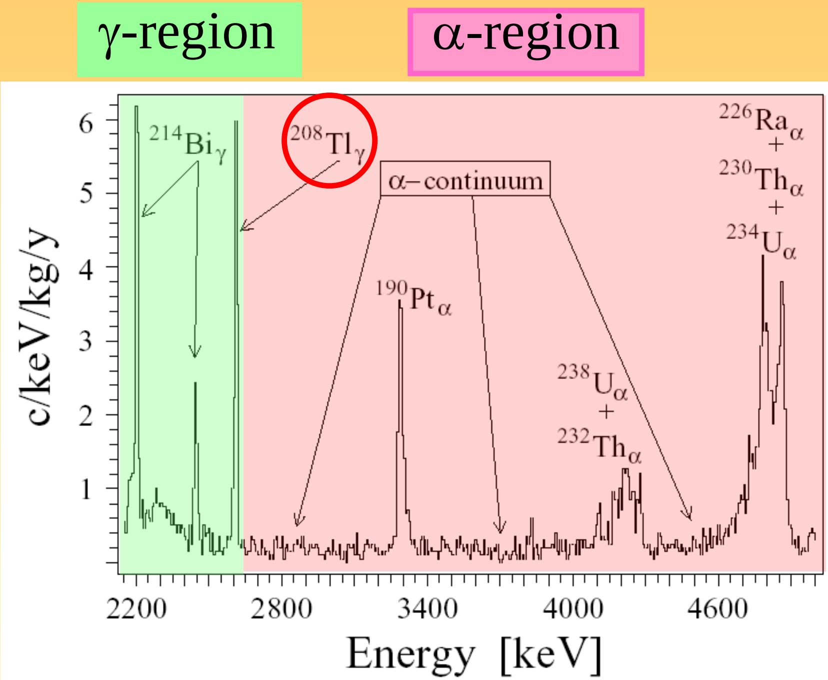
The idea is to recognize the α-induced background in bolometers thanks to the readout of the scintillation light

Three scintillating crystal were proposed to perform this experiment, **Cd**WO_4, Zn**Mo**O_4, and Zn**Se**.
The crystal that has been chosen is ZnSe, enriched in ^{82}Se.

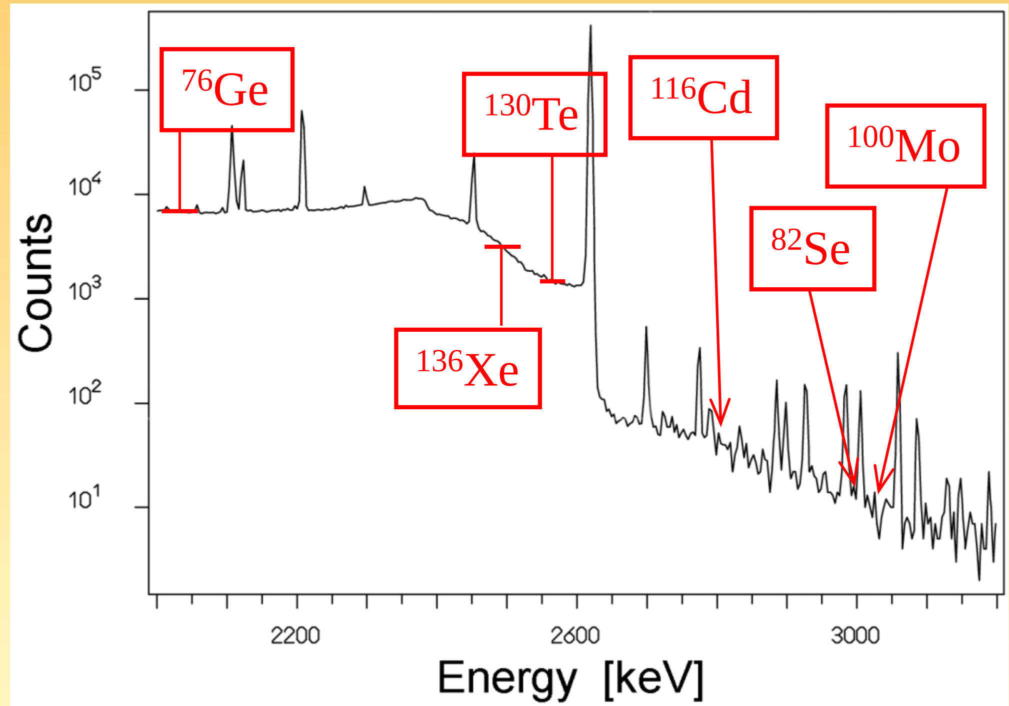
The target of Lucifer is an array composed by 36 (Ø=45mm, h= 55 mm) crystals, totaling 11.7 kg of ^{82}Se

The expected background in the ROI (2995 keV) is of the order of $1\div2\ 10^{-3}$ c/keV/kg/y

Motivations



CUORICINO α Background

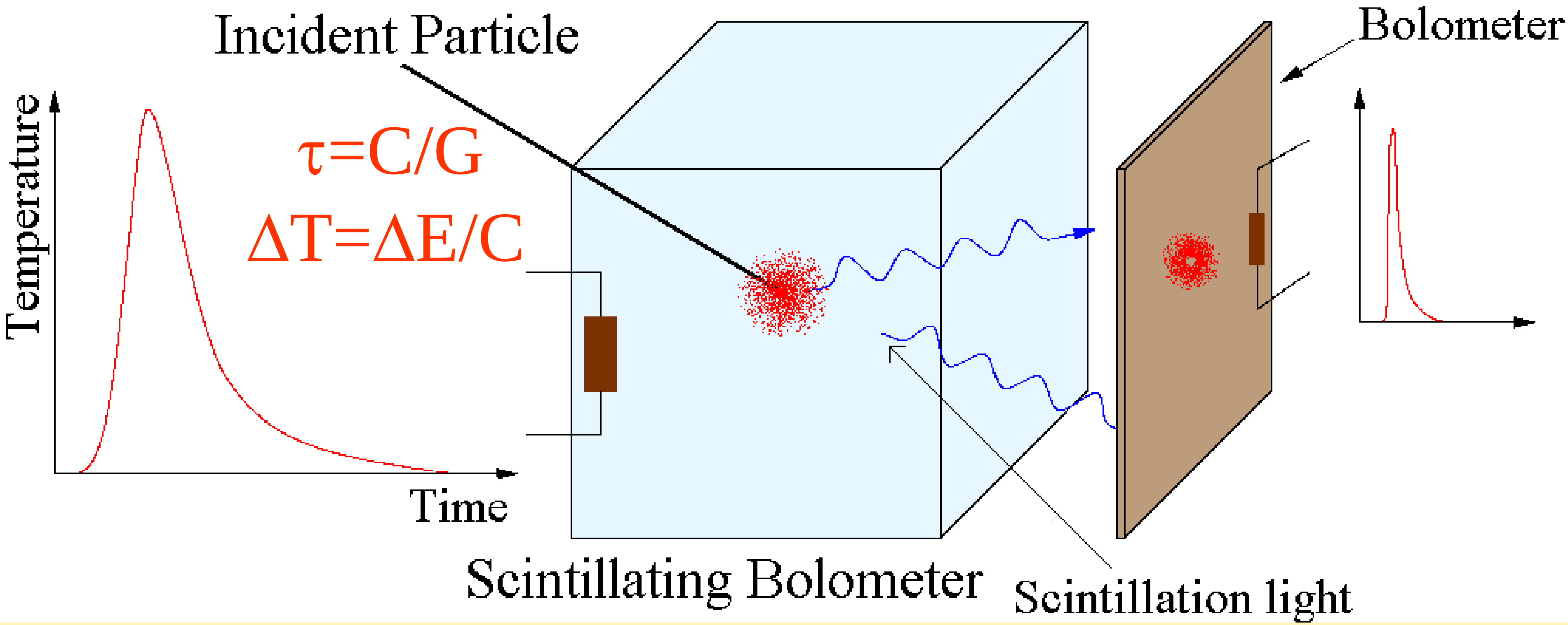


Environmental “underground” HPGE Background: ^{238}U and ^{232}Th trace contaminations

The aim is double… Reduce alpha background and choose a DBD emitter with $Q_{\beta\beta} > 2615$ keV

SP et al. Phys Atom Nucl 69 (2006):2109

Principles of operation



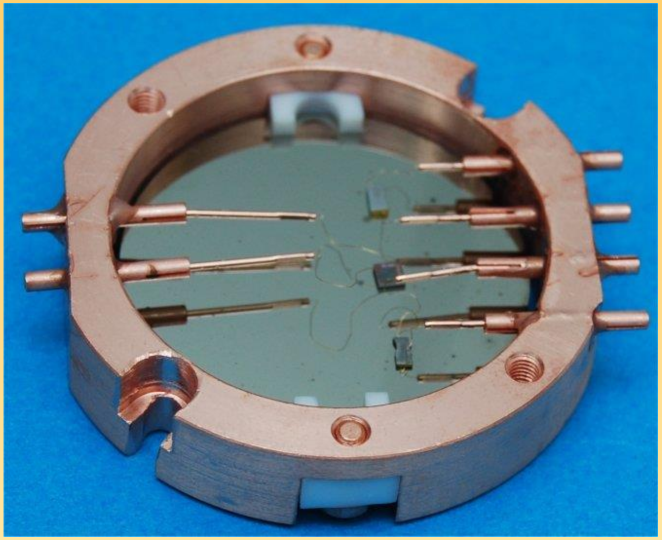
A bolometric Light detector is a fully active radiation detector

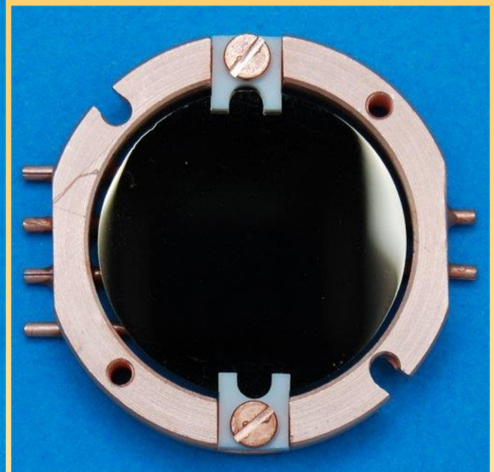
The time response of the thermal pulse is of the order of O (ms)

The evaluation of the quantum efficiency is not straightforward to be measured but should be comparable to the one of Photodiodes

Our Substrate is a pure (undoped) Germanium crystal wafer

Bolometric light detectors





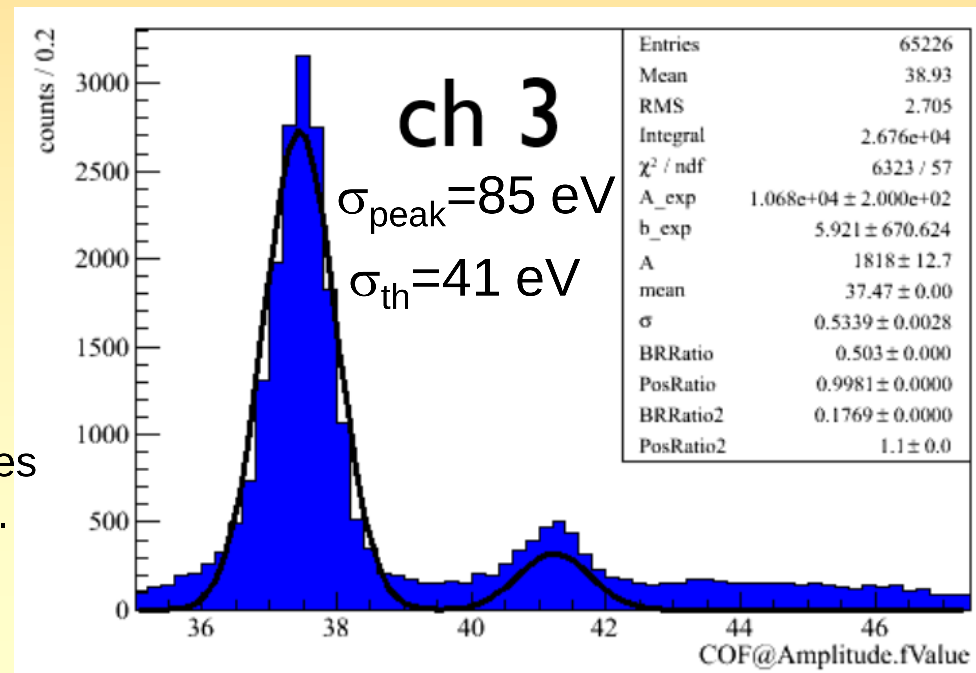
The light detector is a Ge thin crystal

Ø= 44 mm, h=0.18÷ mm

1 face is coated with 60 nm layer of SiO_2 to increase light absorption

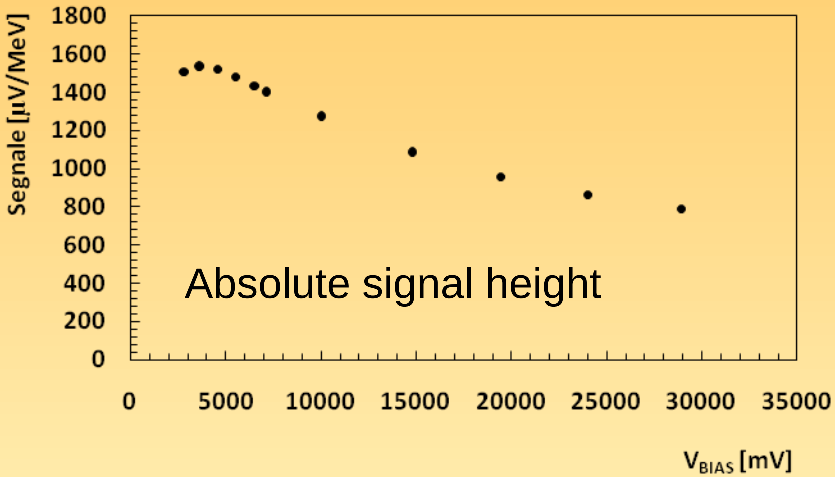
These devices are calibrated through an Ionizing ^{55}Fe source placed close to them; ^{55}Fe shows two X-lines at 5.9 and 6.5 keV

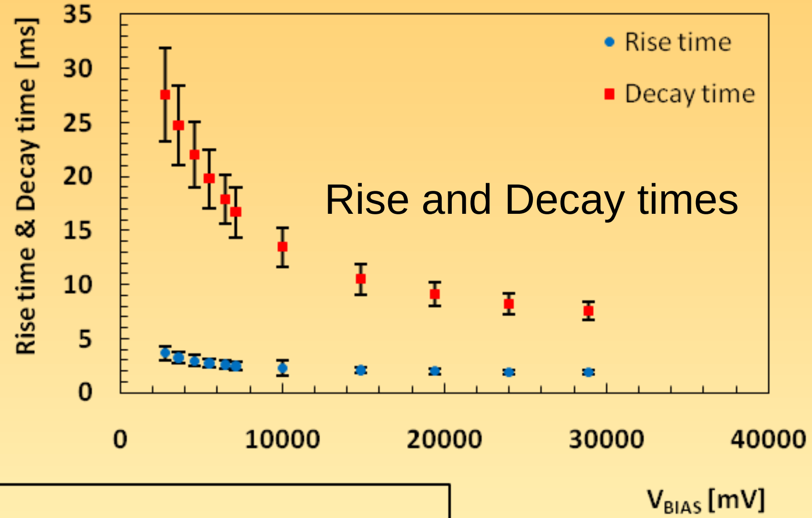
The ^{55}Fe gives the absolute calibration in terms of energy. While the resolution on the peaks gives a "rough" idea about the threshold ($\sigma_{peak} > \sigma_{noise}$).

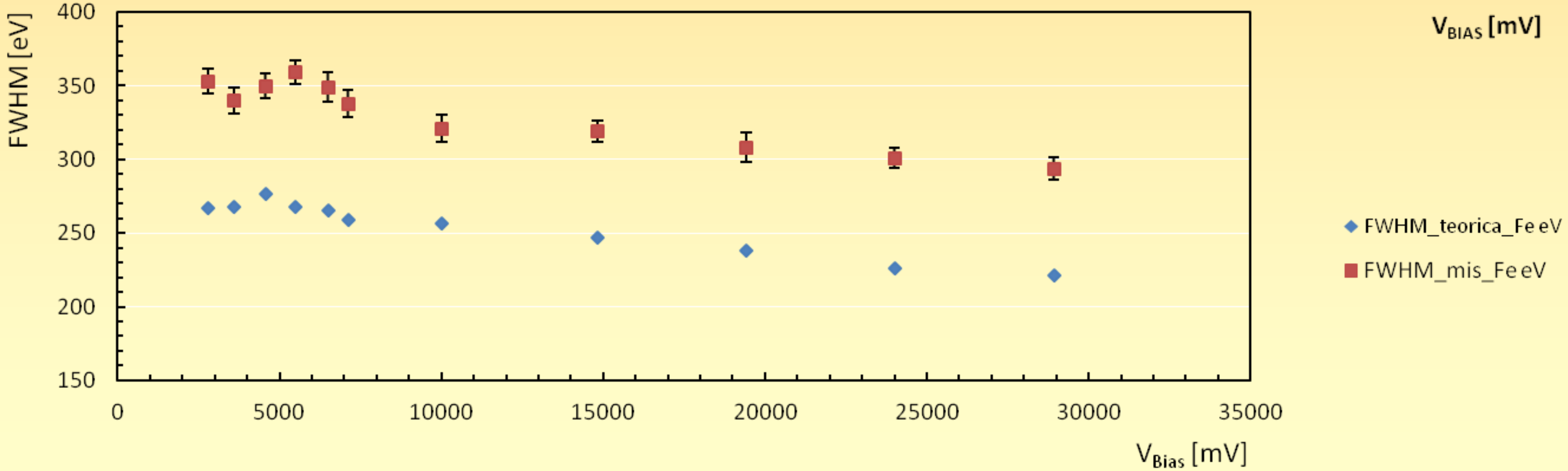


Operational working point

As PMT's, the bolometers are characterized by the bias current. The pulse shape STRONGLY depends on the bias current







JW Beeman et al. JINST 8 P07021 (2013)

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

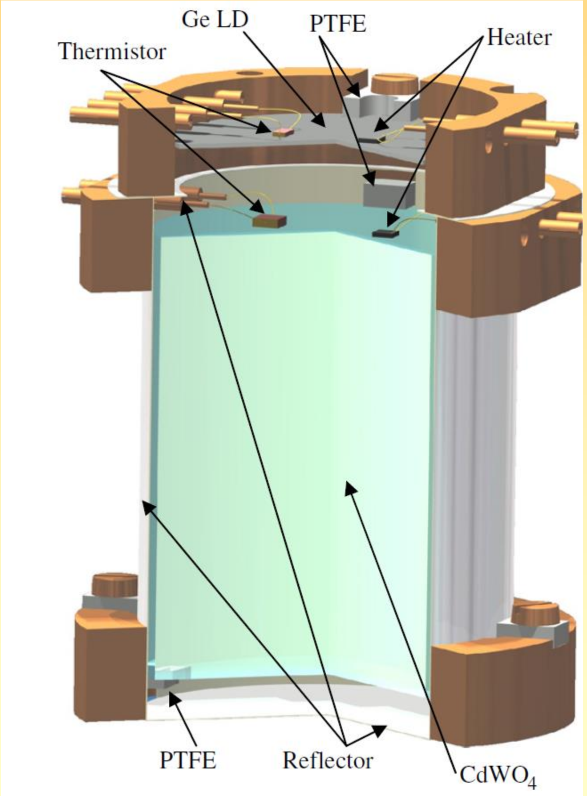
$CdWO_4$

$CdWO_4$ crystals are several advantages:

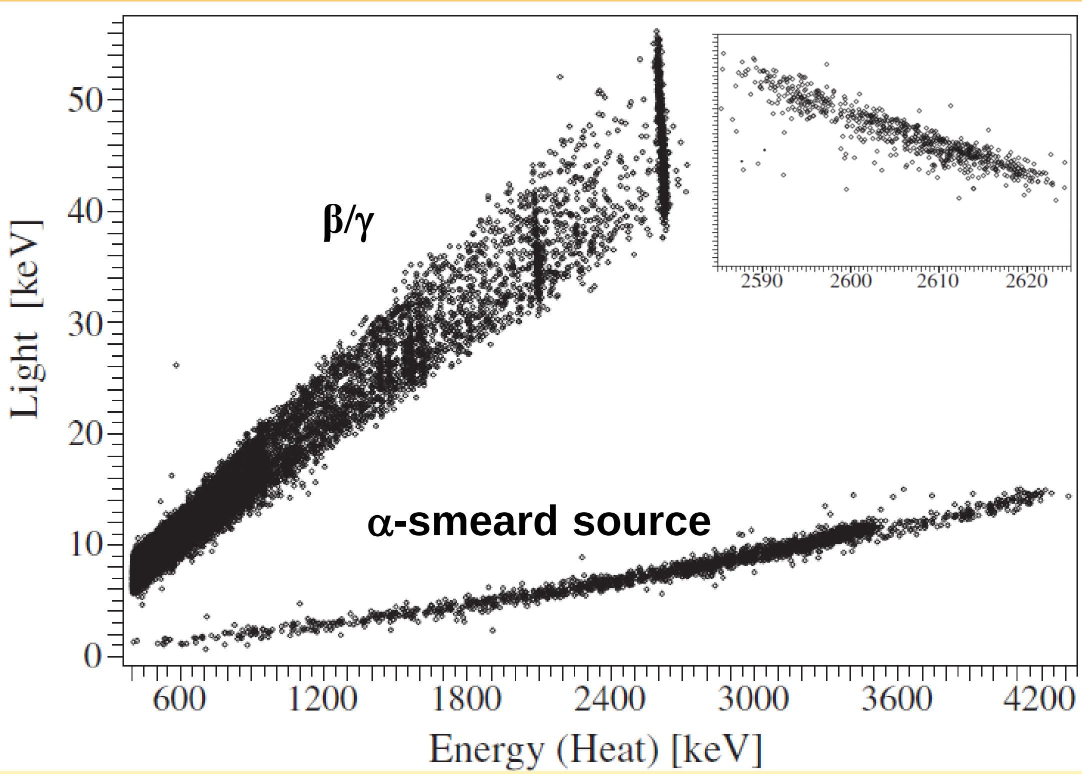
- it is a “standard” scintillating crystal
- it is a rather “radiopure” compound

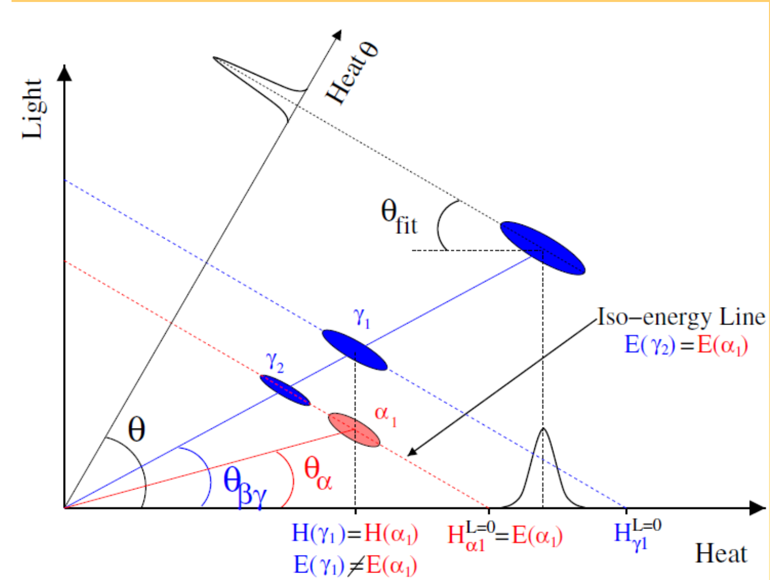
But also some disadvantages :

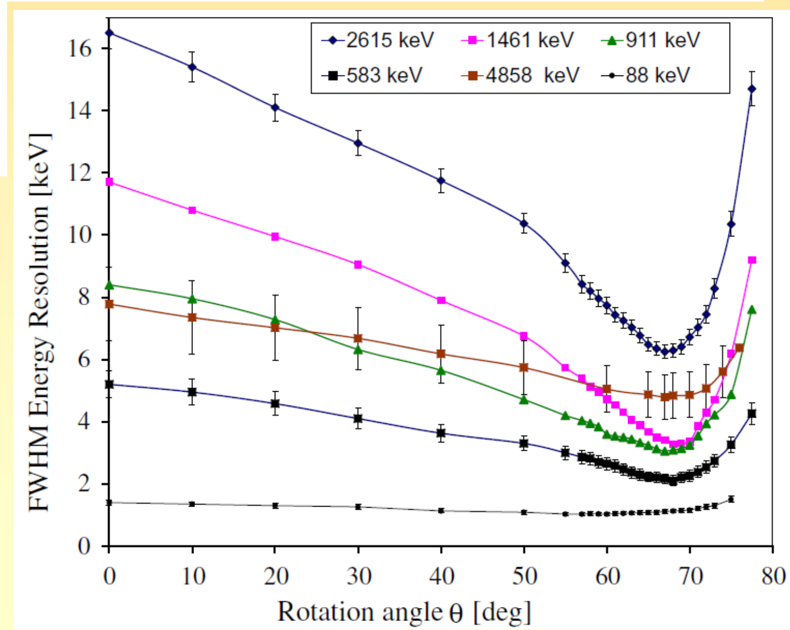
- Cd is an “expensive” isotope to enrich (hazardous)
- ^{113}Cd is a pure beta emitter (pilup problems)
- ^{113}Cd has a huge neutron absorption cross section



$CdWO_4$







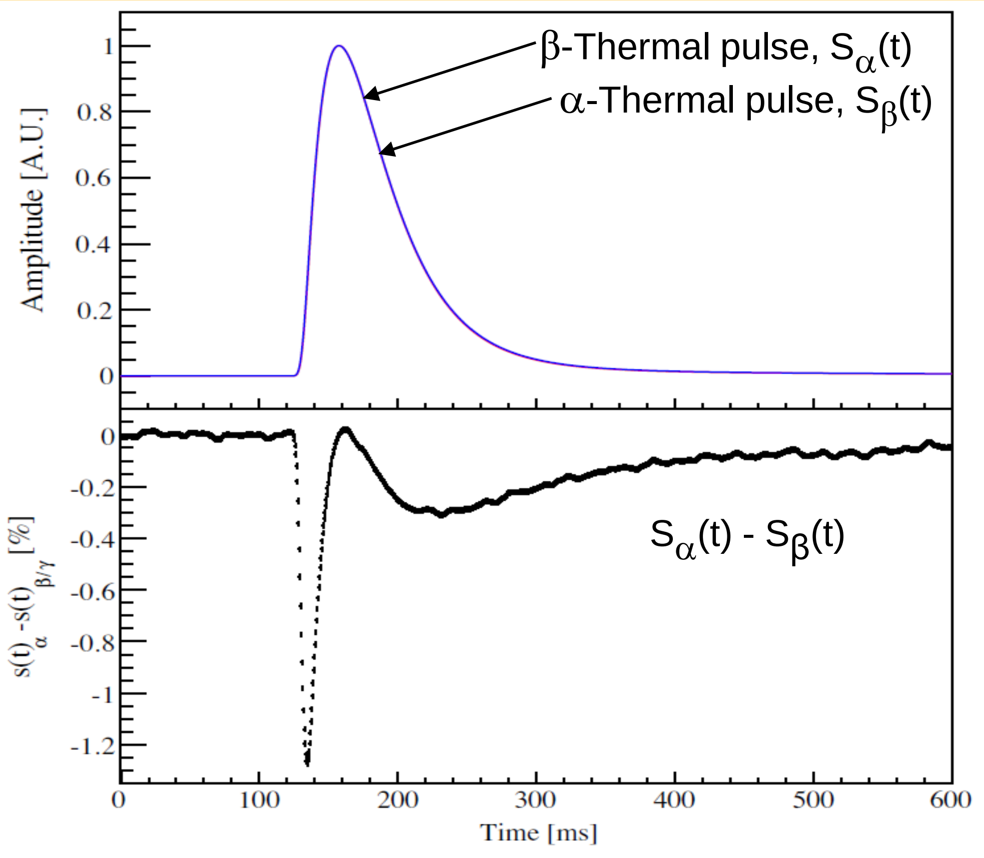
Scintillating bolometers show directly the energy partition that takes place in a calorimeter between different systems (lattice and scintillation groups)

C. Arnaboldi et al, Astrop. Phys 34 (2010) 143

$ZnMoO_4$ – A "shape discriminating" bolometer

Within molybdates, $ZnMoO_4$ is a very promising and interesting compound, even if the scintillation light (1-2 keV/MeV) is rather poor. This crystal was grown and tested only very recently (*L. Gironi et al, JINST 5 2010 P11007*).

A very important characteristics of Molybdate crystals is that they show the appealing feature that α and β/γ interactions produce a slightly different thermal signal. This is driven by the "long" decay constant of the scintillation light (*L. Gironi, Journal of Low Temp. Phys., 167 (2012):504)*

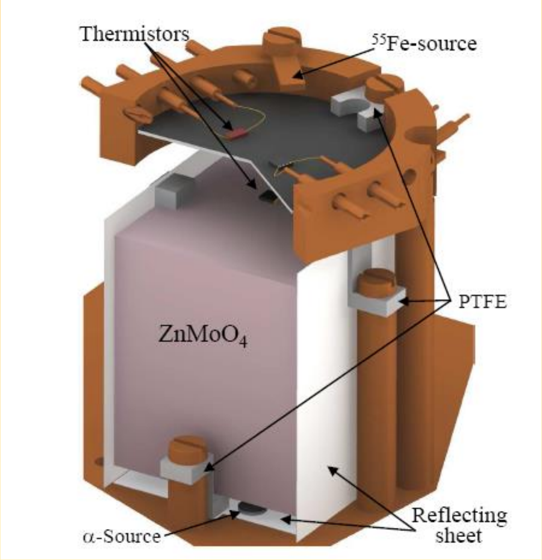


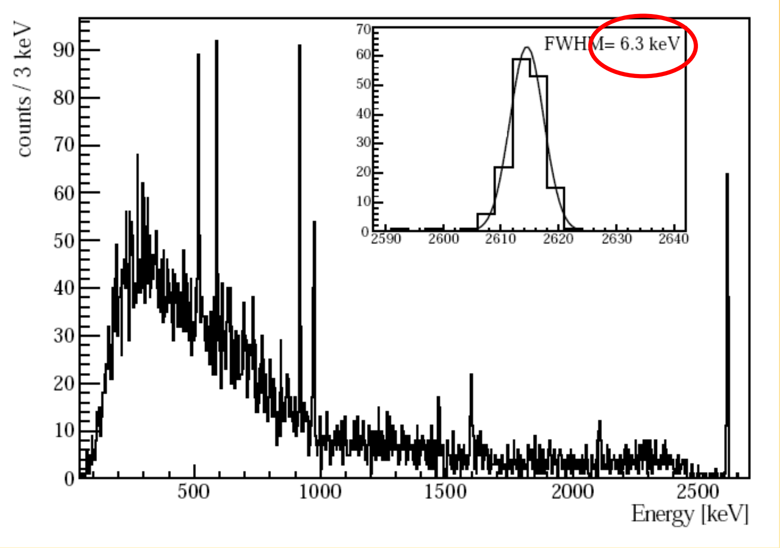
J.W. Beeman et al, Astrop. Phys. 35 (2012):813

$ZnMoO_4$ – first test on a large crystal (330 g)

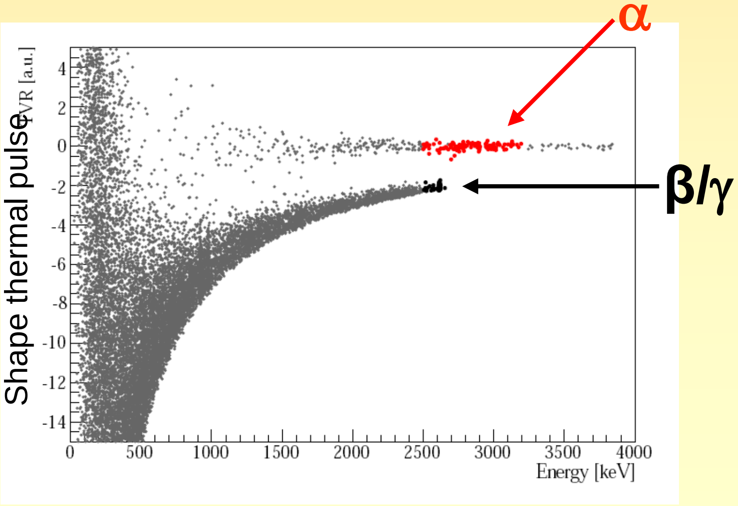
JW Beeman *et al.*, EPJ C **72**, 2142 (2012)

Energy resolution comparable with CUORE crystals

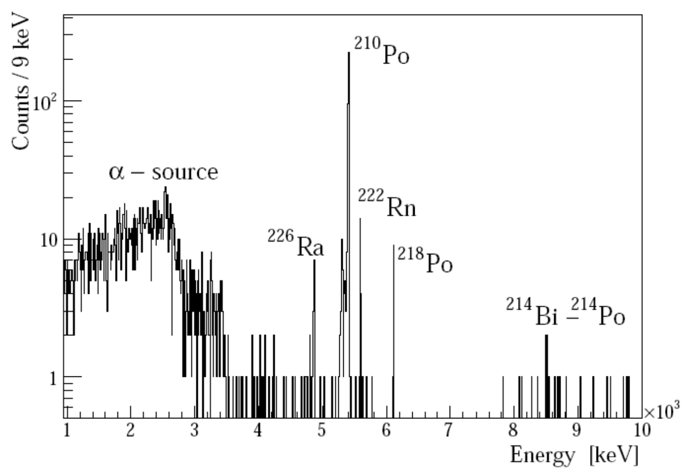




α discrimination without light detection

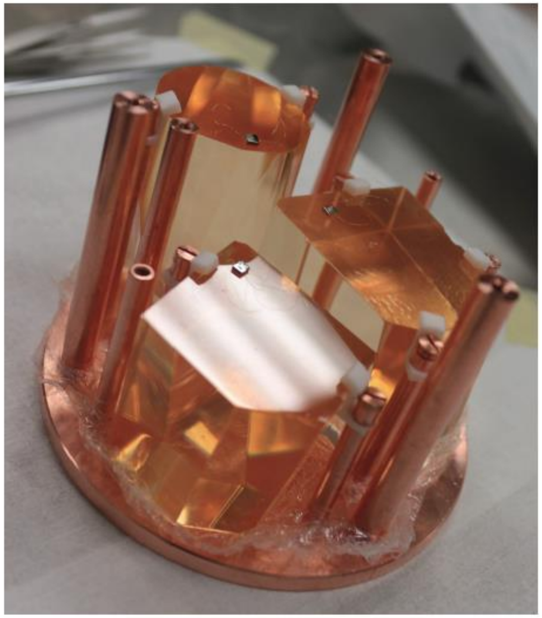


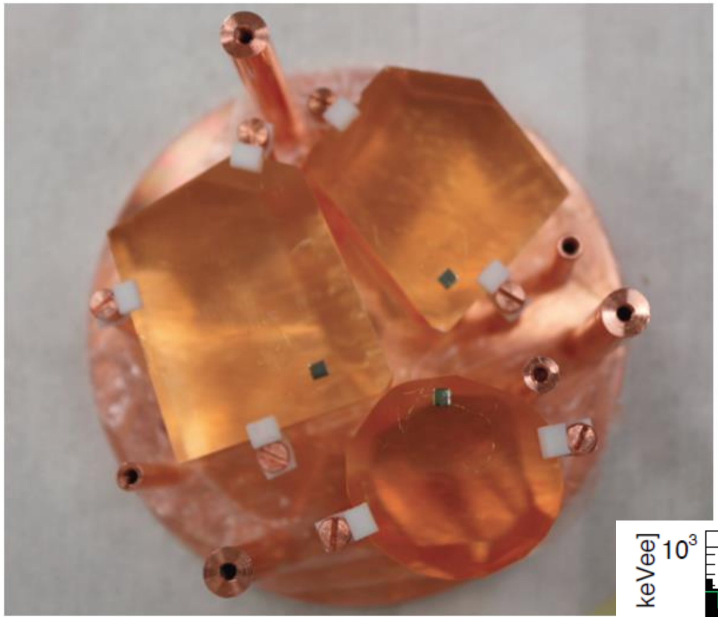
Extreme radiopurity ^{232}Th **<1.4x10^{-12} g/g**



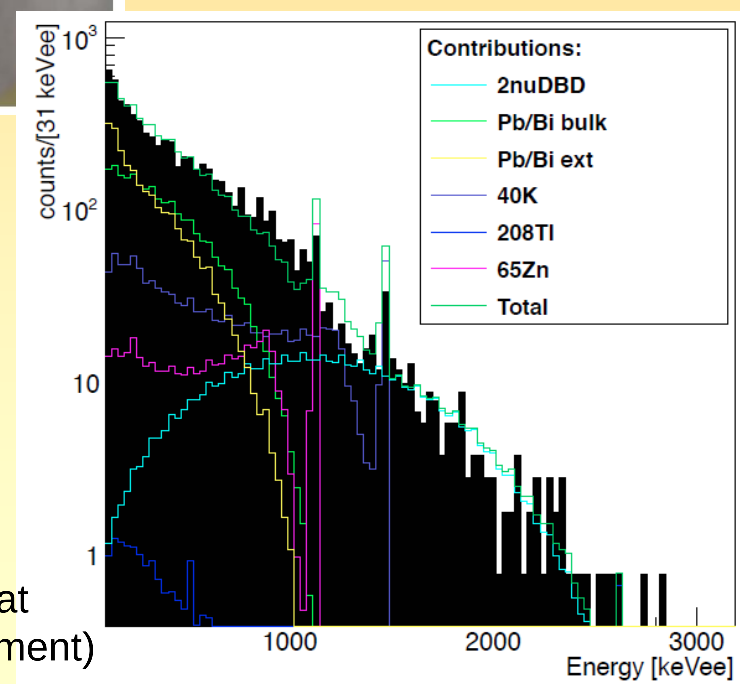
$ZnMoO_4$ – Measurement of the 2νDBD

In Spring 2013 a background masurement was performed with 3 ZnMoO4 crystals (339,247 and 235 g)





÷900 h of measurements



$T^{1/2}(2\nu) = (6.89 \pm 0.33(stat)) \times 10^{18}$ y (preliminary)

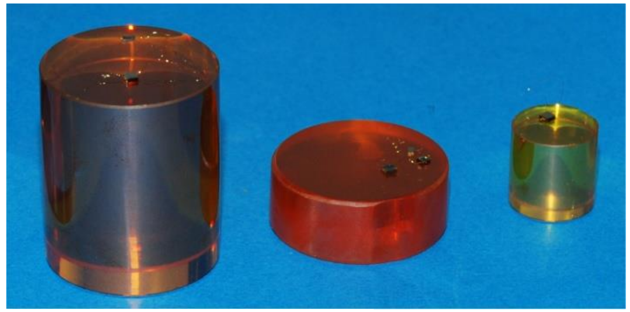
The systematic error has to be evaluated

An MoU is being signed between INFN, CNRS and ITEP aiming at performing an experiment with 9 kg of ^{100}Mo (former nemo experiment)

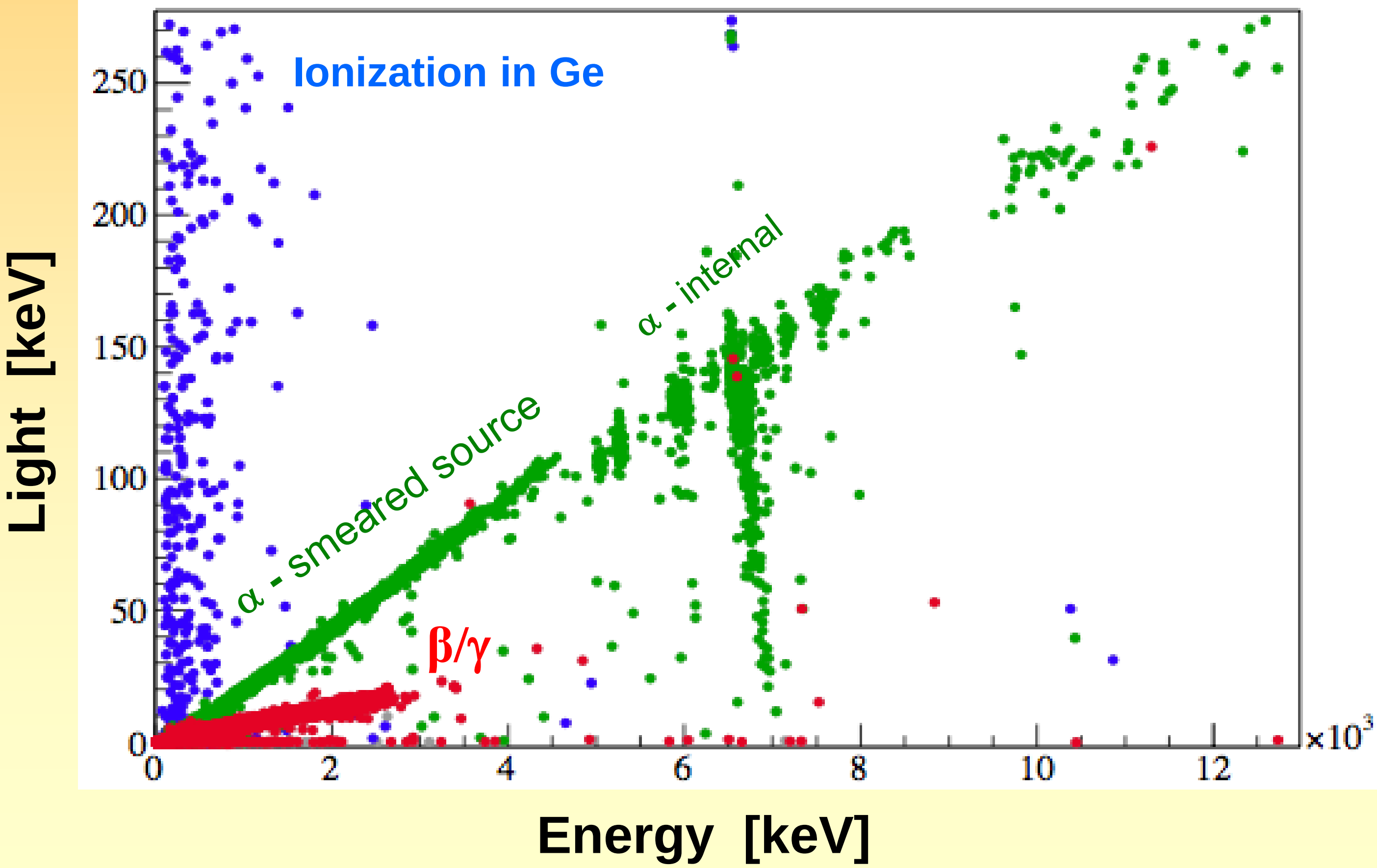
ZnSe

ZnSe is a rather bizarre compound …It is well know as one of the best scintillators (doped with Te)

Unfortunately the absorption length is dramatically close to the emission band. At cryogenic temperatures, fortunately, the crystal becomes “transparent”

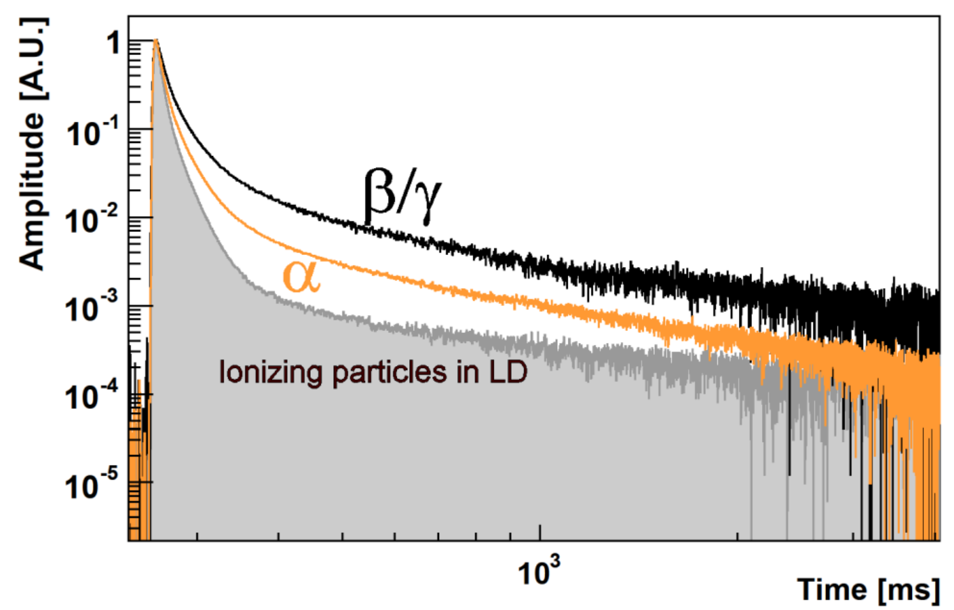


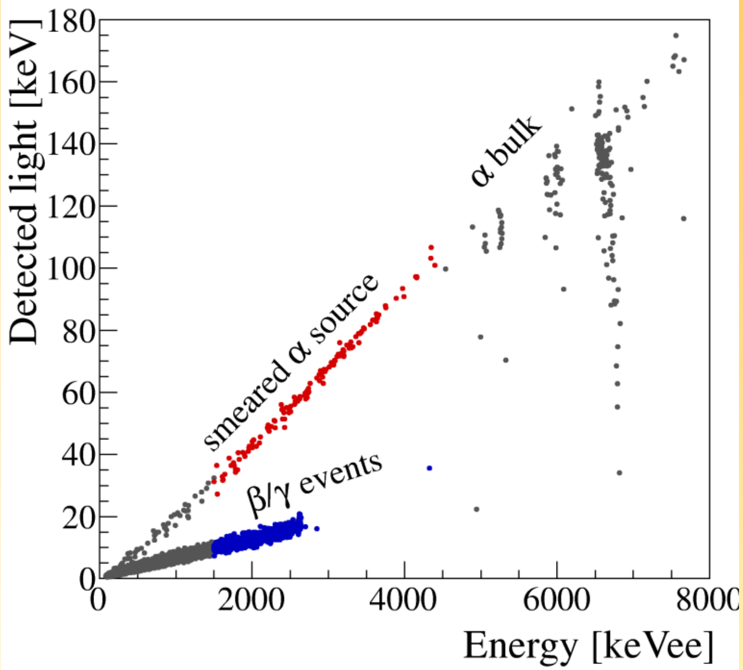
The ZnSe shows an inversed QF (α’s scintillates ~4 times more than β’s (*Astrop. Phys. 34 (2011) 344*)

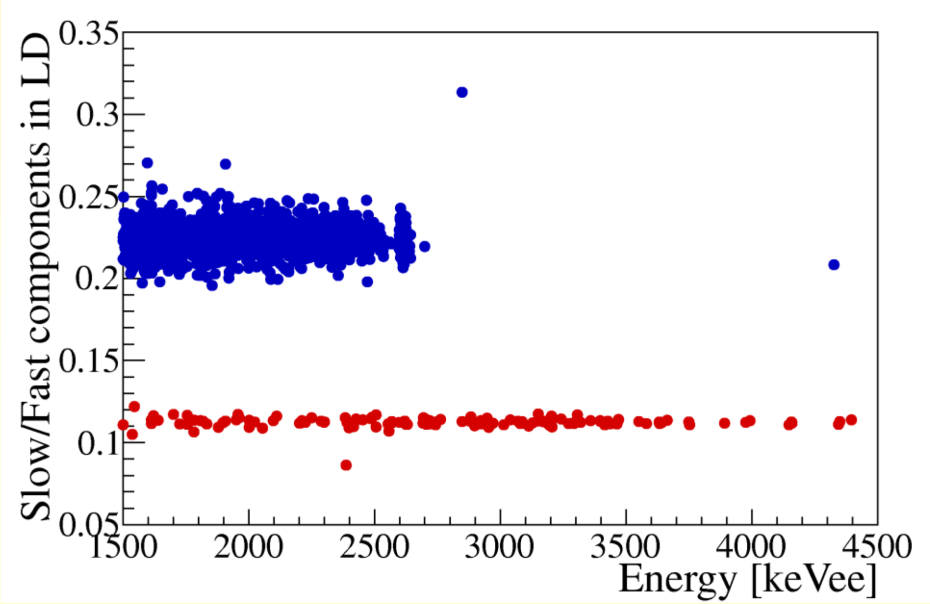


ZnSe-Particle identification

The light signal from ZnSe permits to discrimitate between γ/β, α and ionization signals.

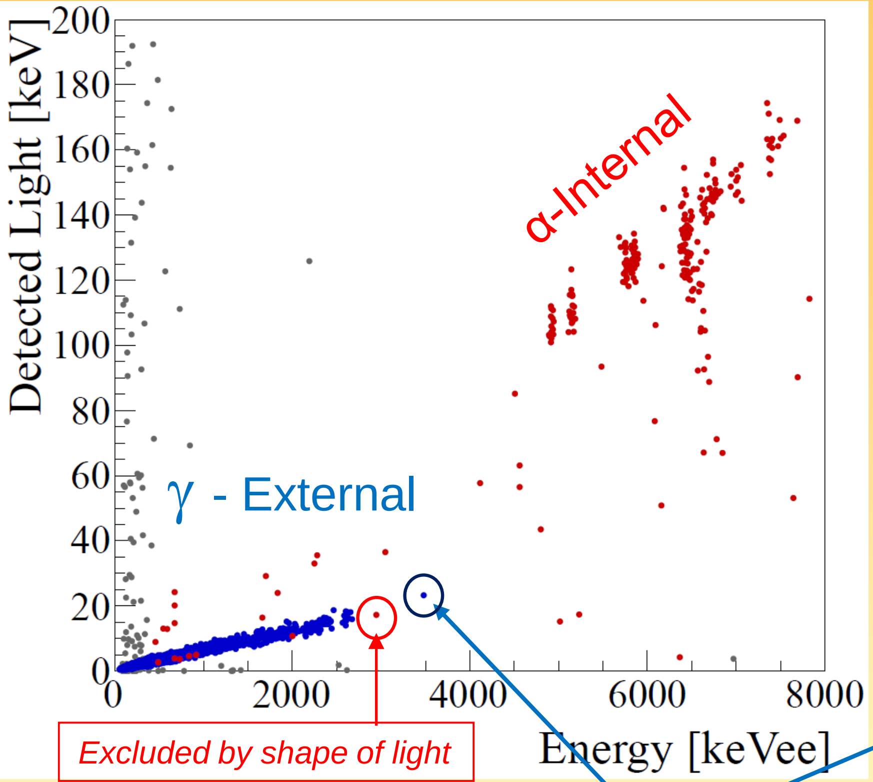


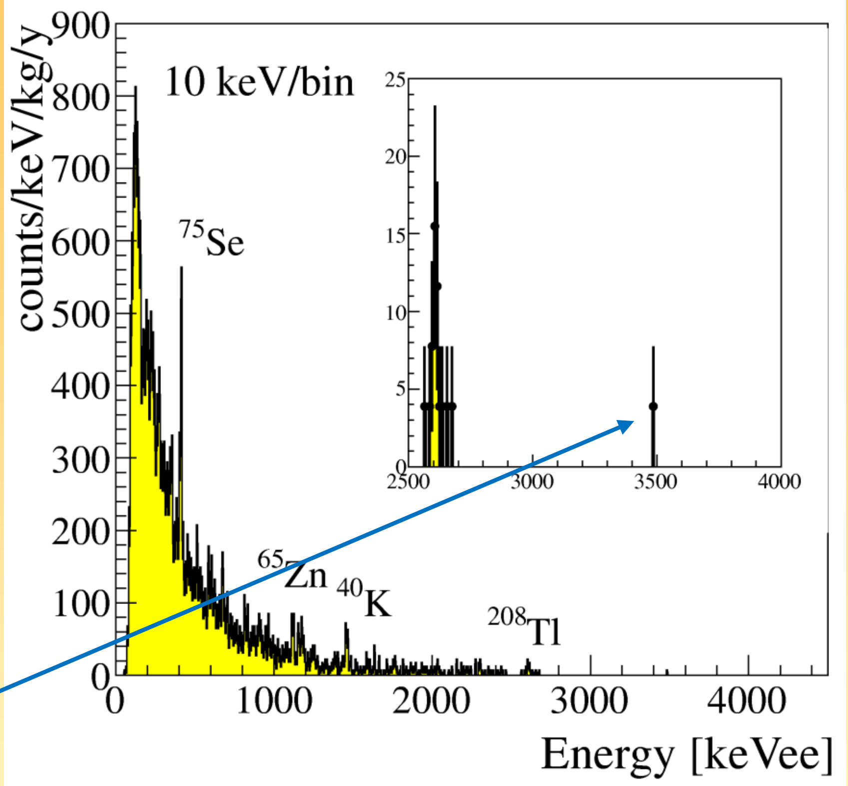




- Cuts performed on a shape parameter of the light pulses.
- The events selected by means of the cuts are reported in the light vs heat scatter plot.
- The decay time of the light pulses shows also that the ionizing events are faster with respect to the scintillation.

ZnSe – 524 hours Background measurement





1 Event survives above 2615 keV. But it is tagged as induced by a cosmic μ, that generated a triple coincidence with other detectors present in the setup

Activity of the isotopes belonging to ^{232}Th and ^{238}U chains.

Chain	Nuclide	Activity [μBq/kg]
^{232}Th	^{232}Th	17.2 ± 4.6
	^{228}Th	11.1 ± 3.7
^{238}U	^{238}U	24.6 ± 5.5
	^{234}U	17.8 ± 3.3
	^{230}Th	24.6 ± 5.5
	^{226}Ra	17.8 ± 3.3
	^{210}Po	90.9 ± 10.6

J.W. Beeman et al, JINST 8 (2013) P05021

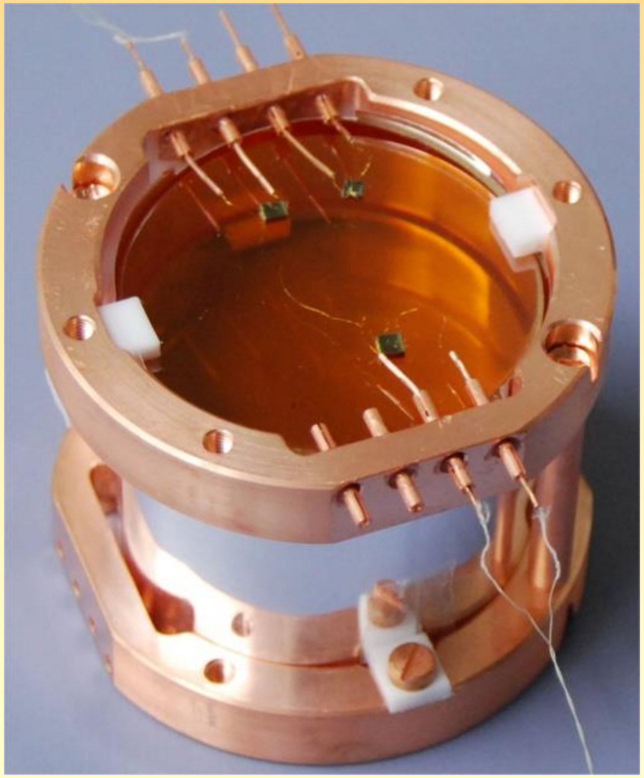
LUCIFER

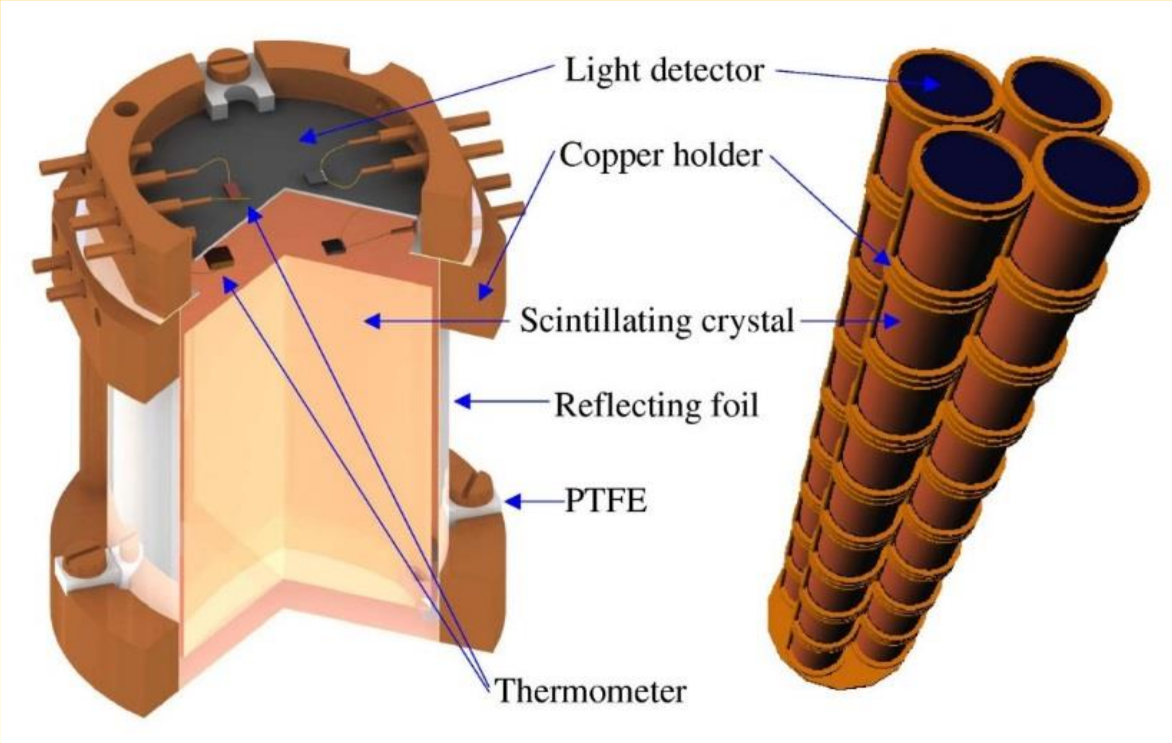
Lucifer will be composed by an array of 32÷36 enriched (95%) $Zn^{82}Se$ crystals.
The total ^{82}Se nuclei will be (6.7÷8.0) 10^{25}

The mass of the single detector will be 460 g

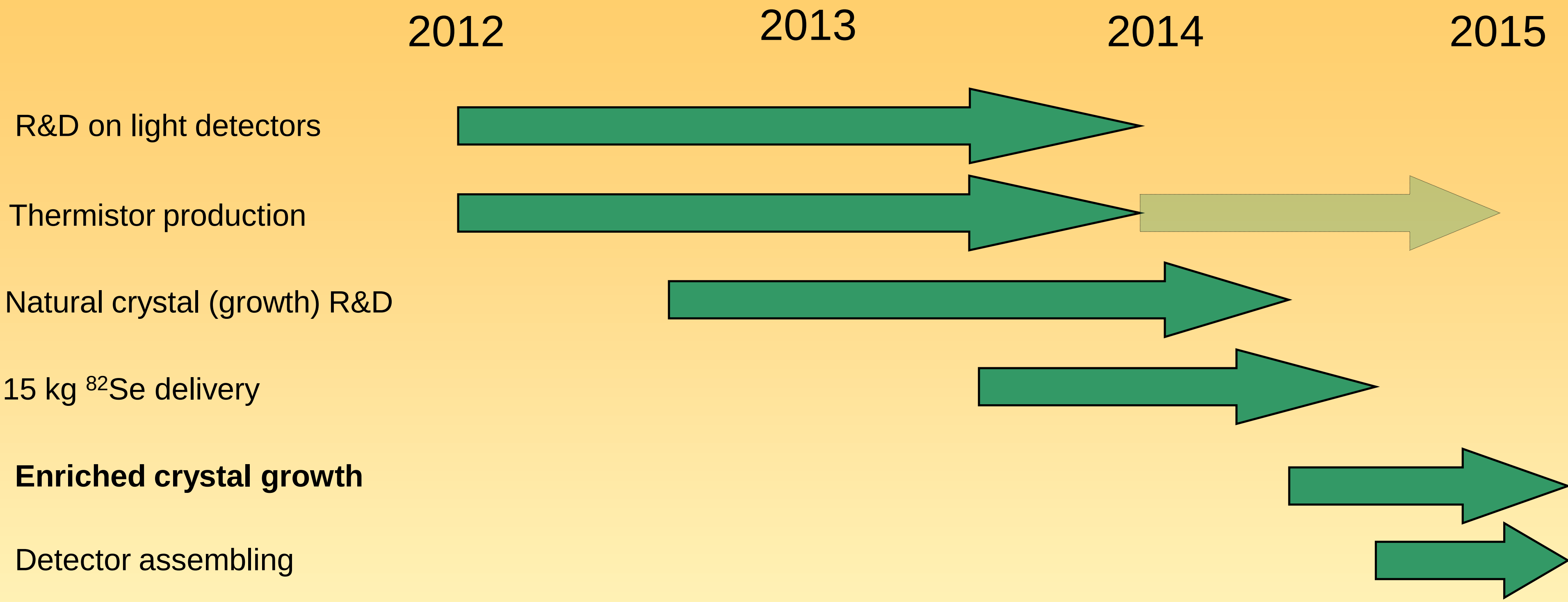
The expected background in the ROI (2995 keV) is of the order of 1÷2 10^{-3} c/keV/kg/y

The energy resolution of the single detector is expected to be ~ 10÷15 keV FWHM





Lucifer – time-schedule

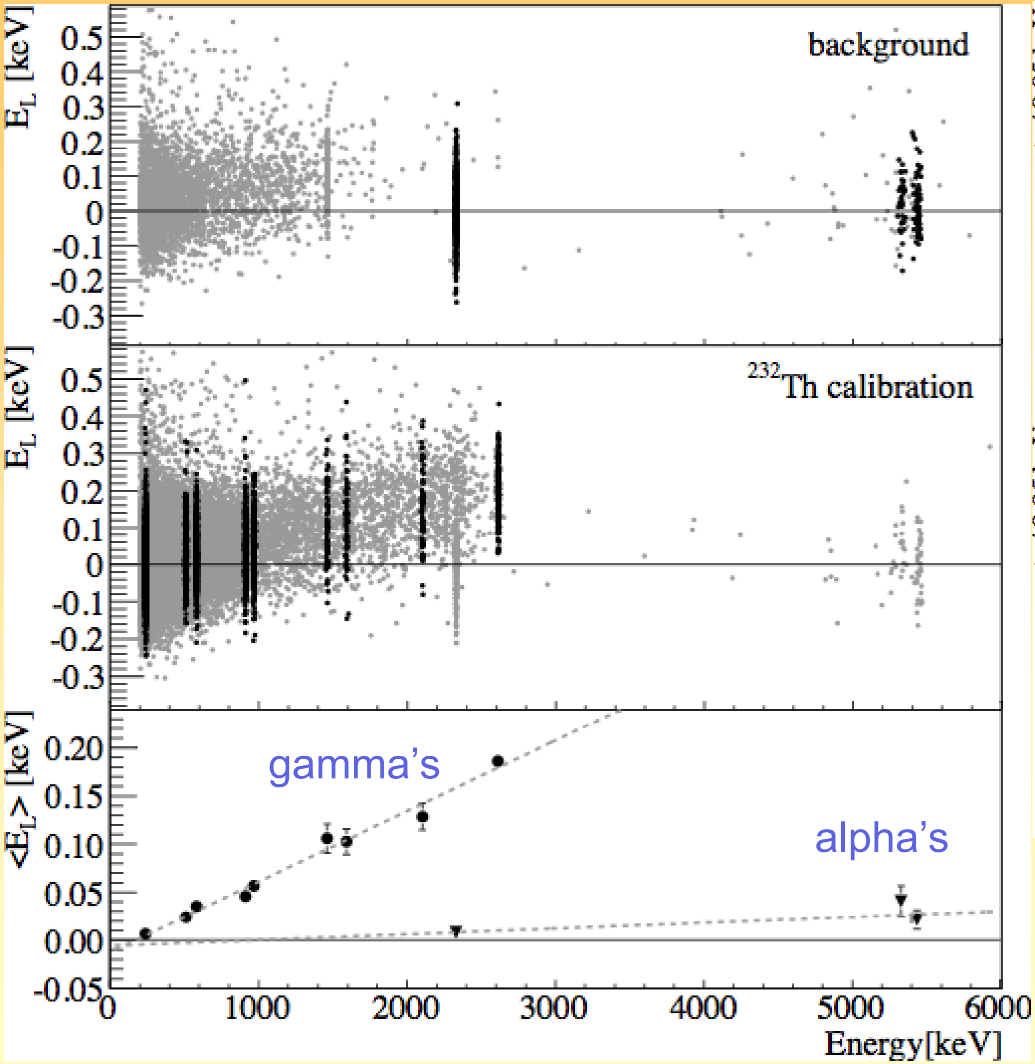


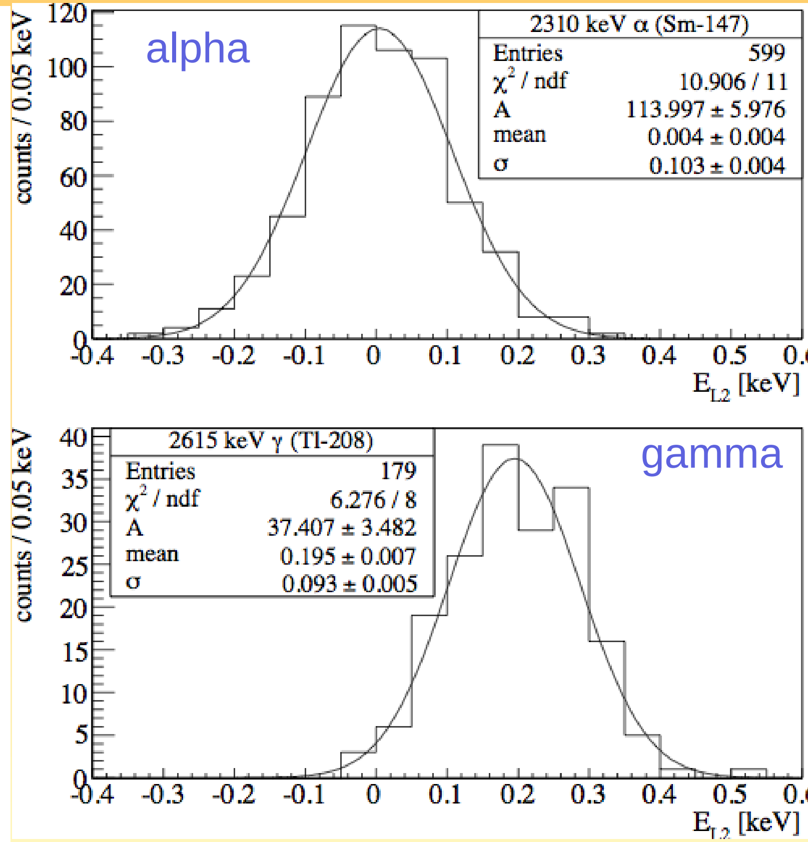
The most crucial part is represented by the crystal growth. The supplier (Ukraine) is presently fine-tuning the (complicate) procedure (that starts with metal Zn and metal Se). The request of minimizing the ^{82}Se waste is a fundamental, complicate issue. The target is to reach > 75 % efficiency.

The expected sensitivity of the experiment will be 3÷6 10^{25} y that corresponds to (92 -270)÷(65-200) meV

The location of the experiment *should* be the CUORICINO (now CUORE-0) cryostat, once CUORE-0 will finish his data taking.

TeO_2: Čerenkov light detection: α identification in a 117 g TeO_2





JW Beeman et al, Astropart.Phys. 35 (2012) 558

195 eV from a 2615 keV gamma, ~zero light from alpha's (117 gr crystal)

98 eV from a 2615 keV gamma, (CUORE crystal) paper in prep.

Conclusions - Lucifer

The Lucifer project is going on, with some delay induced by crystal growth optimization.

The enriched selenium delivery has started, 2.5 kg so far…

Internal backgrounds and alpha particle identifications in ZnSe crystal will imply in a background index for the experiment close to 10^{-3} c/keV/kg/y

The possibility of using other interesting "golden Isotopes" (Cd, Mo) was proven.

The prove of the effectiveness of the Cherenkov light detection to decrease the background level in TeO_2 is not yet satisfactory, needs further improvements on Light Detectors (work in advanced progress).