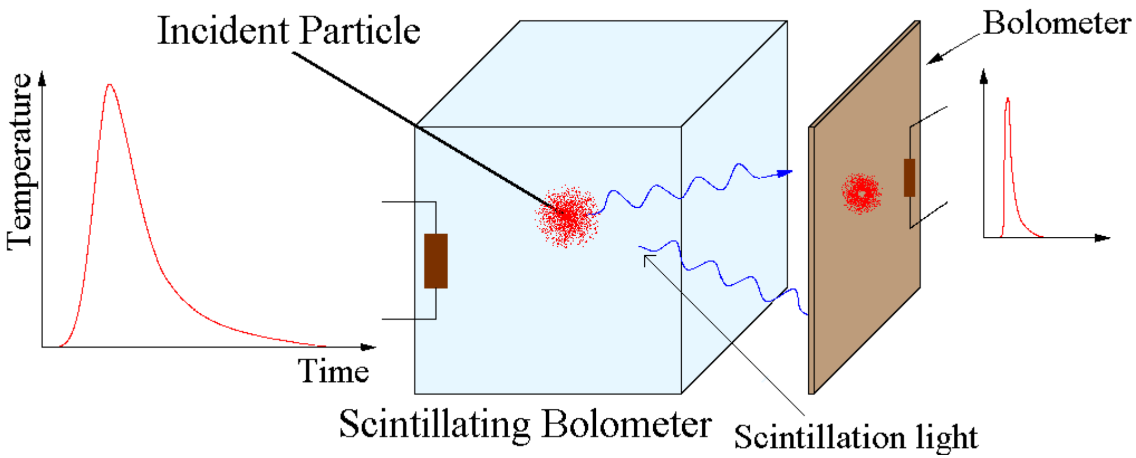
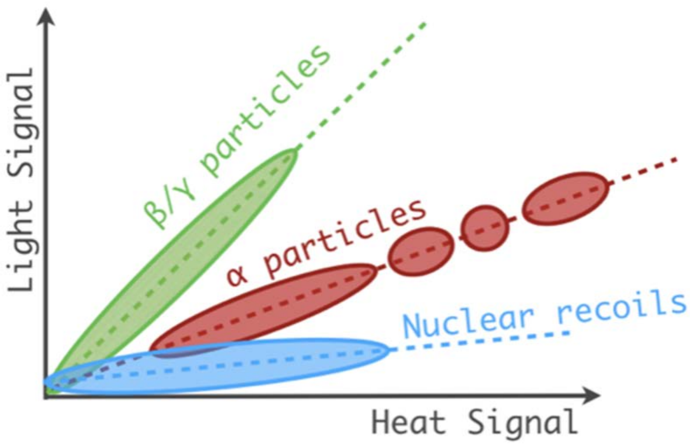
First results of CUPID-0

Stefano Pirro – INFN-LNGS
CUPID-0 Collaboration

Scintillating Bolometers: rudiments of operation

Operating Temperatures for *massive* detectors: 10÷30 mK





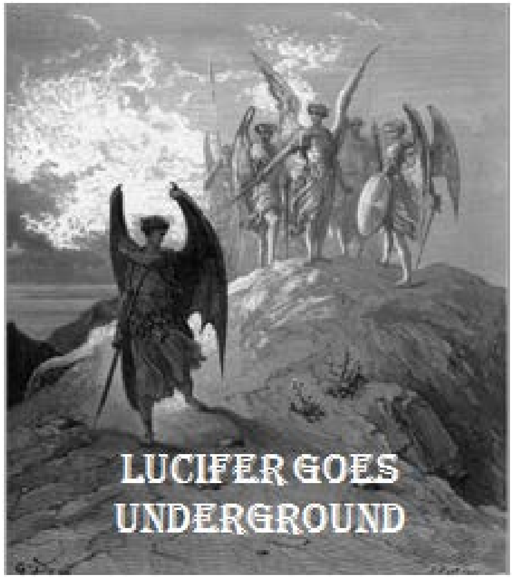
A Bolometric Light Detector is a fully active a particle detector

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

The QE of a BLD could, probably, be close to 1 but it is rather difficult to measure it

Lucifer

LUCIFER Low-background Underground Cryogenics Installation For Elusive Rates



https://web.infn.it/lucifer/

European Research Council erc

demonstrator

isotope: ^{82}Se , ^{100}Mo , ^{116}Cd

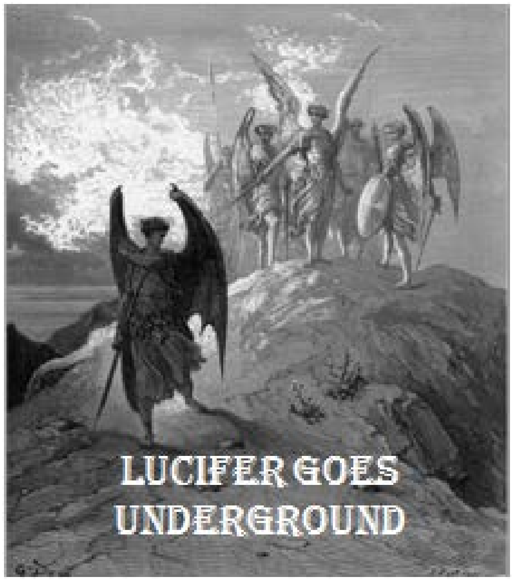
material: ZnSe , $ZnMoO_4$, $CdWO_4$

technique: scintillating bolmeter

The Lucifer Grant (2010-2015) was dedicated to R&D to be finalized in one enriched demonstrator made of enriched scintillating crystals in the order of few kg of enriched material. During the R&D several crystals containing ^{82}Se , ^{100}Mo , ^{116}Cd were tested an also the tiny Cherenkov light from a (non *scintillating*) TeO_2 was measured.

Lucifer

LUCIFER Low-background Underground Cryogenics Installation For Elusive Rates



Choice induced by non availability on the market (2012) of ^{100}Mo and ^{116}Cd

isotope: ^{82}Se , ^{100}Mo , ^{116}Cd

material: ZnSe , $ZnMoO_4$, $CdWO_4$

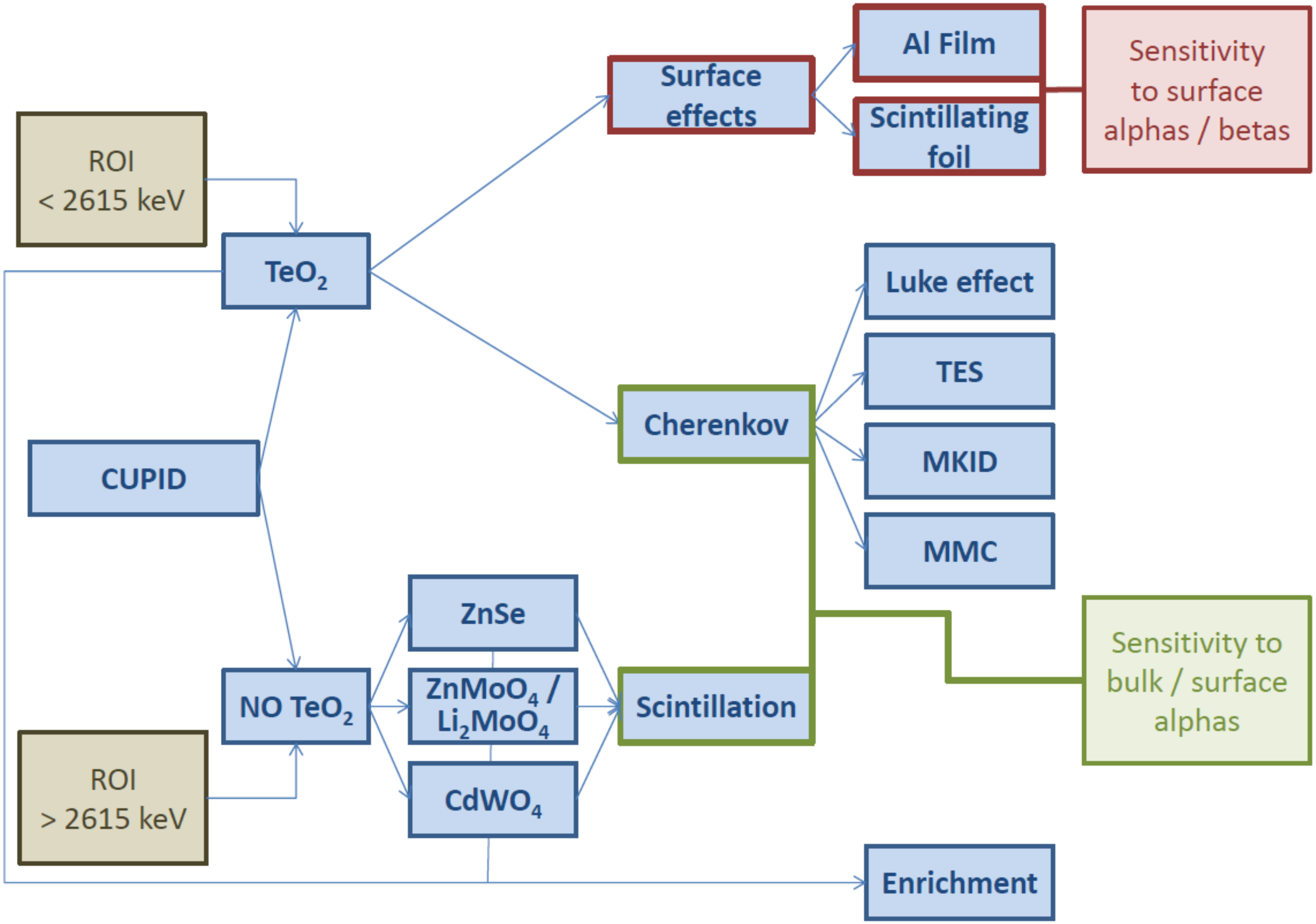
technique: scintillating bolmeter

From 2016 this activity is funded by INFN under the INFN-CUPID Project. For this reason, LUCIFER is called now **CUPID-0**, the first demonstrator in view of CUPID.

LUCIFER: the forerunner of CUPID

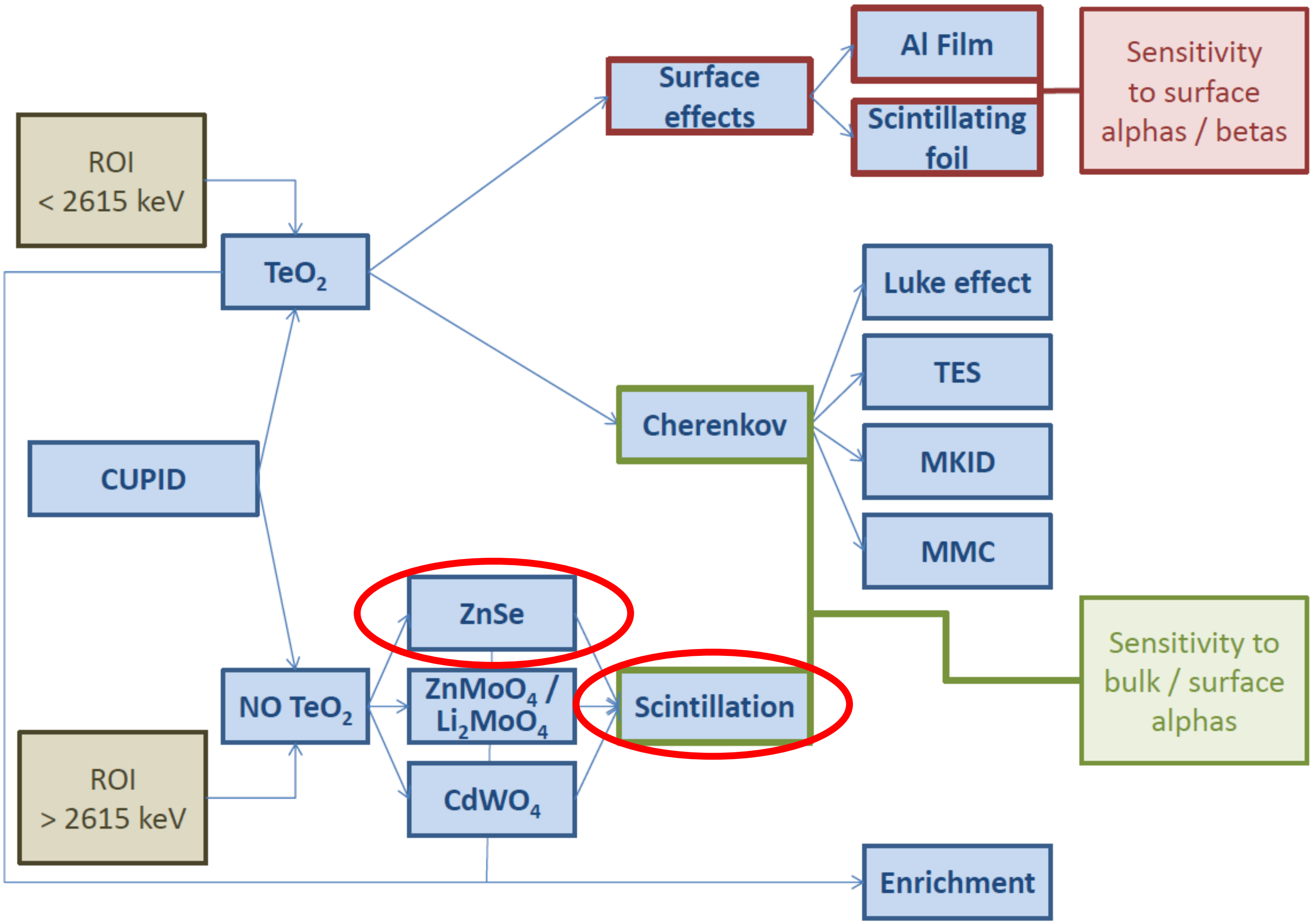
Cuore **U**pgrade with **P**article **ID**entification

R&D towards CUPID: arXiv:1504.03612 CUPID : arXiv:1504.03599



INFN-CUPID: CUPID-0 $Zn^{82}Se$

CUPID-0 will be the first enriched bolometer ββ experiment that will demonstrate the background rejection achievable for hybrid ββ scintillating bolometers



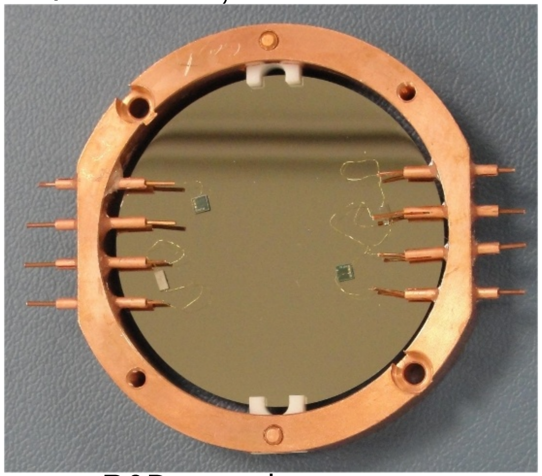
Bolometric Light Detectors

In case of scintillating crystals, even in case of "bad" scintillators (Light Yield ≈ 0.05 %), the scintillation light at $Q_{\beta\beta}$ results of the order O(1 keV). This amount of energy release can be "easily" readout by standard thermistor-based bolometers.

The light detector is a Ge thin wafer equipped with a small thermistor

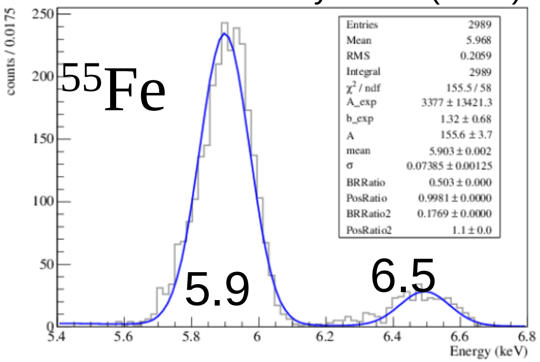
These devices are calibrated through an Ionizing ^{55}Fe sources

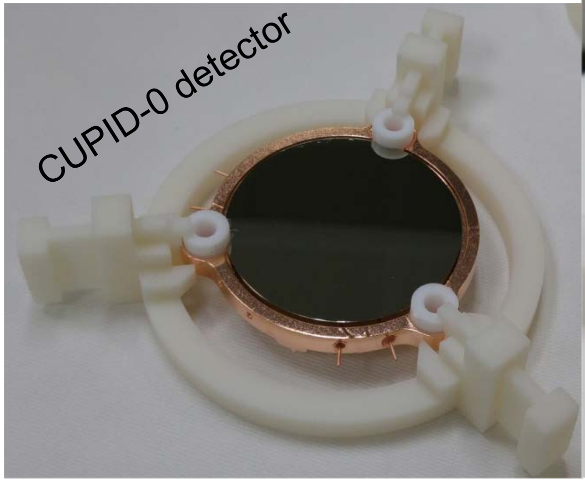
Ø=44.5 mm, h=0.175 mm

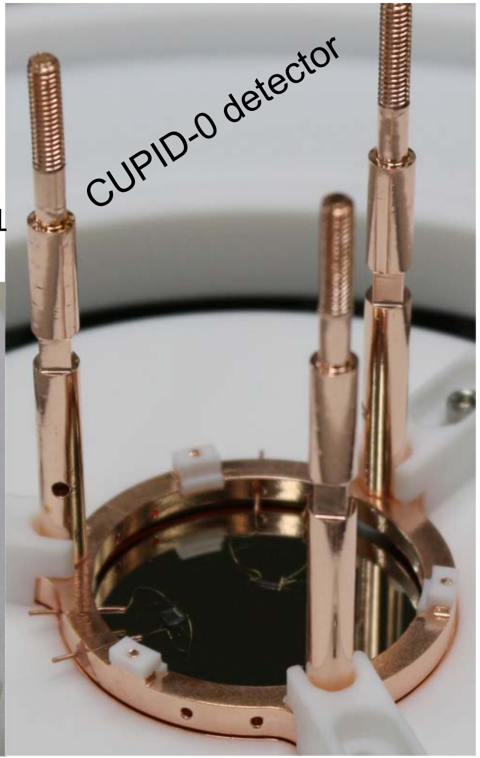


R&D mounting setup
JW Beeman *et al*. JINST 8(2013) P07021

DR Artusa *et al*. Eur. Phys. J. C (2016) 76







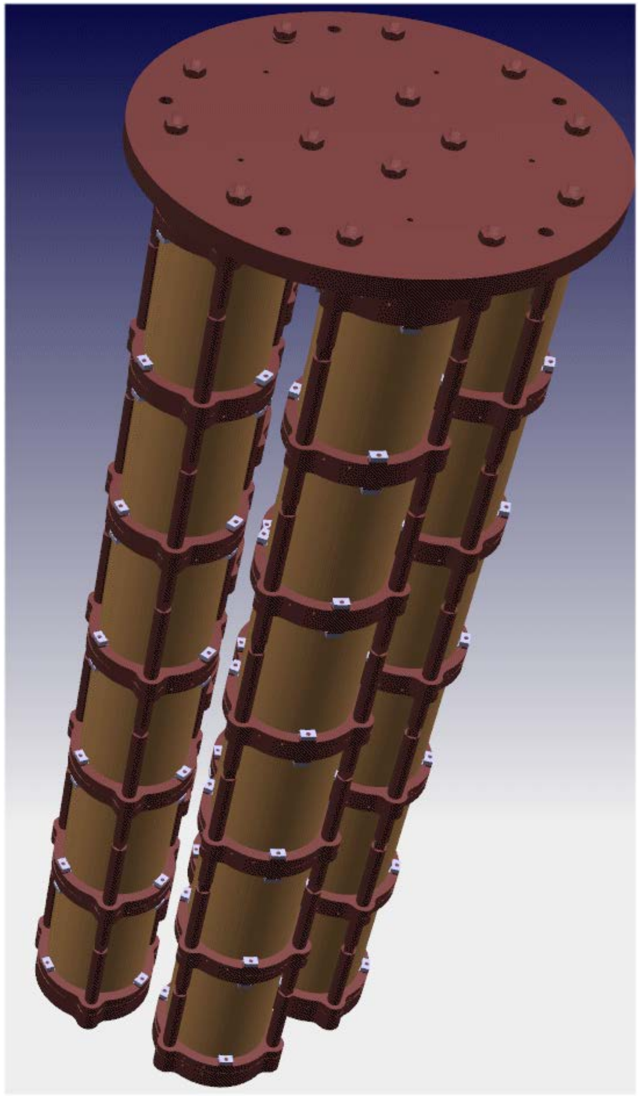
	$RMS_{baseline}$ [eV]	τ_r [ms]	τ_d [ms]
LD Top-1	32.5 ± 0.5	1.68	5.15
LD Top-2	39.3 ± 0.7	1.91	5.75
LD Top-3	57.1 ± 0.8	1.71	3.41
LD Bot-1	43.9 ± 0.7	1.83	5.45
LD Top-4	37.8 ± 0.6	1.66	5.23
LD Top-5	112.2 ± 2.0	1.81	9.17
LD Top-6	65.7 ± 1.0	1.88	10.96
LD Bot-6	46.1 ± 0.7	1.82	5.39

$< \sigma >= 55$ eV ~ 25 γ

CUPID-0 Mechanical structure

The mechanical configuration of the CUPID-0 tower was designed by the LNGS Mechanical workshop and 3D printing service. *Driving Idea: minimize frame mass, type of pieces, use only certified (large slab) copper*

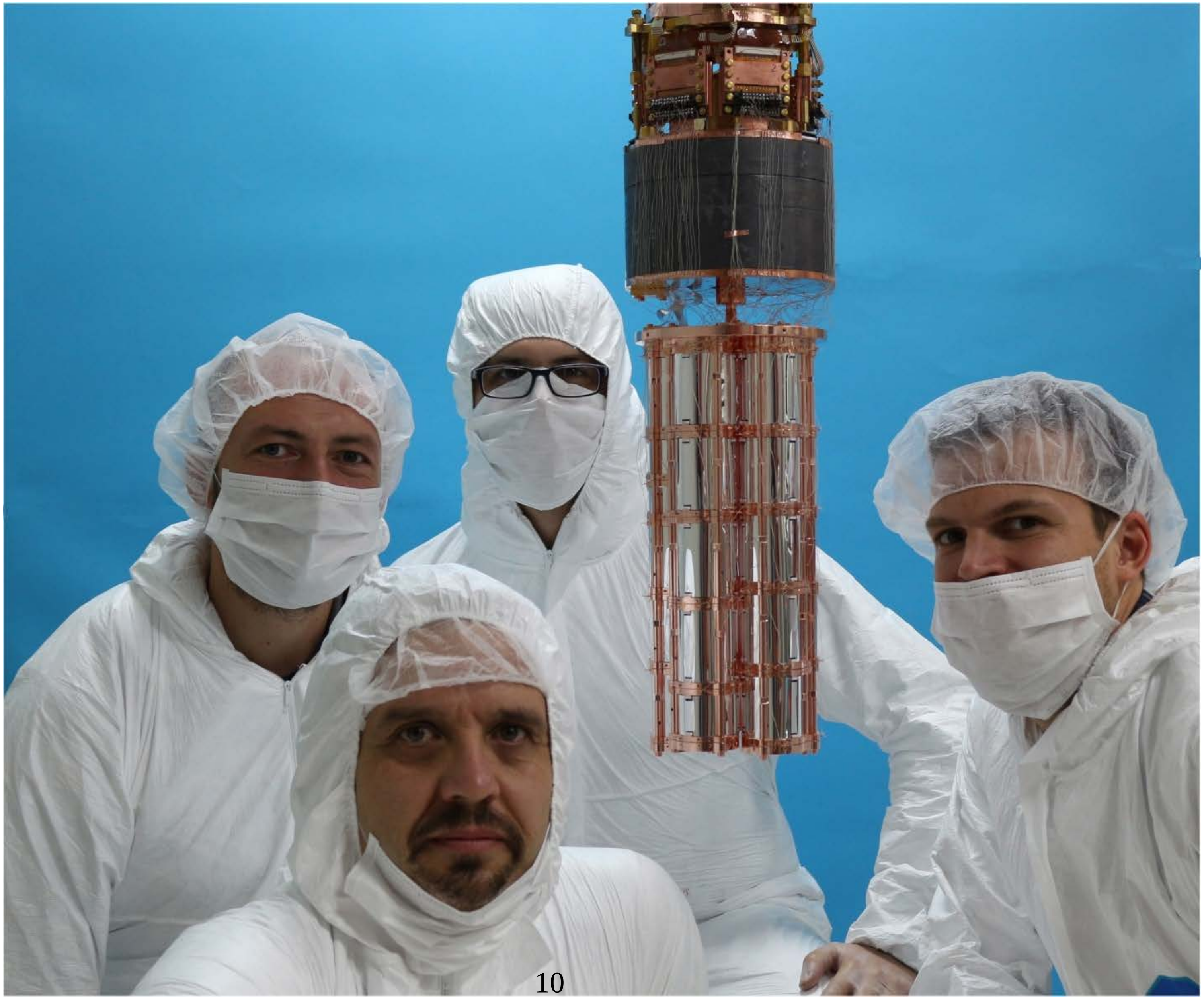
ZnSe 78 %
Cu 22%
PTFE 0.1%



CUPID-0 Construction

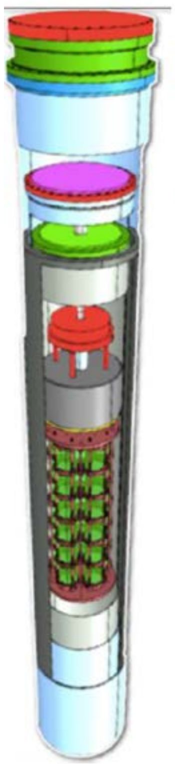
The detectors were assembled in the Low Rn content Dark Side clean room @LNGS

The fully mounted CUPID-0 detector



CUPID-0: Location and main features

24 **$Zn^{82}Se$** bolometers, for a total mass **≈ 5.1 kg of ^{82}Se**
2 ZnSe bolometer ≈400 g each, not enriched in ^{82}Se
$Q_{\beta\beta}(^{82}Se)$ = 2998 keV
Light detectors high purity Ge wafers with antireflecting coating
Thermal sensors made with NTD thermistors
Detector assembled in 5 towers in Cuoricino/CUORE-0 cryostat
Total active **mass of the detector ~10.5 kg**



CUPID-0 is installed in the ***Old*** Mibeta-Cuoricino-CUORE-0 dilution refrigerator placed in the Hall A of LNGS

Some upgrades were done on the cryogenic system:

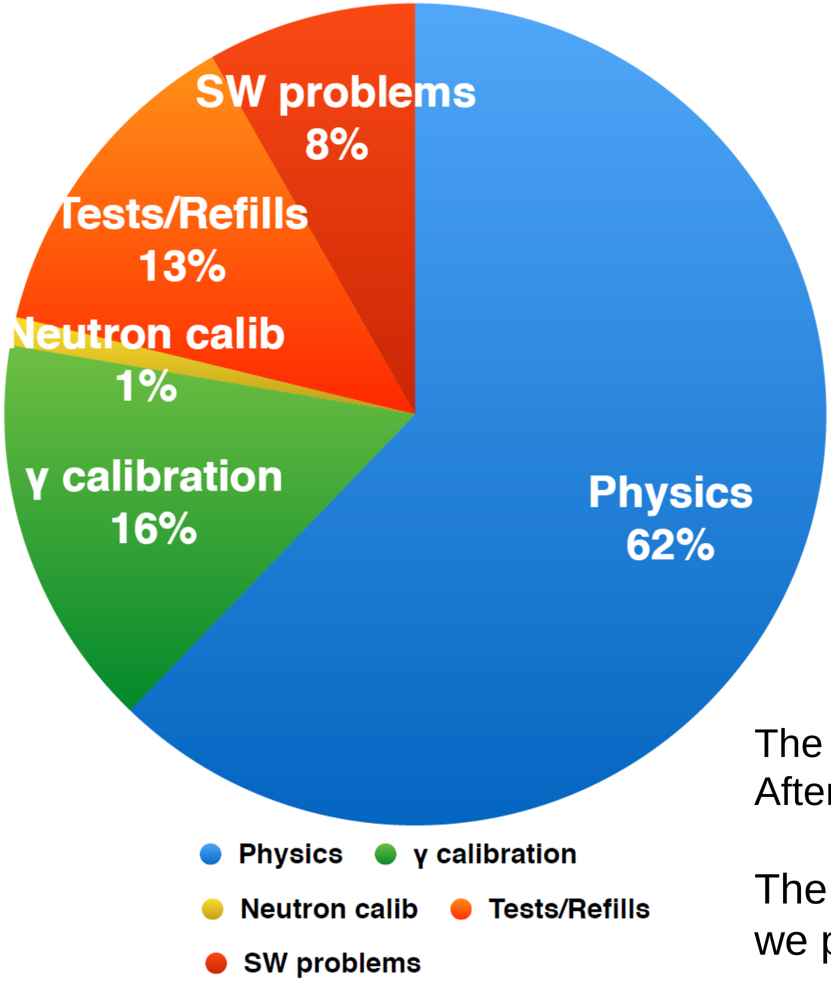
- **New double pendulum system** to reduce vibrational noise
- Upgrade of the **radon abatement system to reduce ^{214}Bi**
- Improvements **in the injection line** of the mixture
- **New cryostat wiring** to measure up to 120 detectors
- A completely new FE electronics

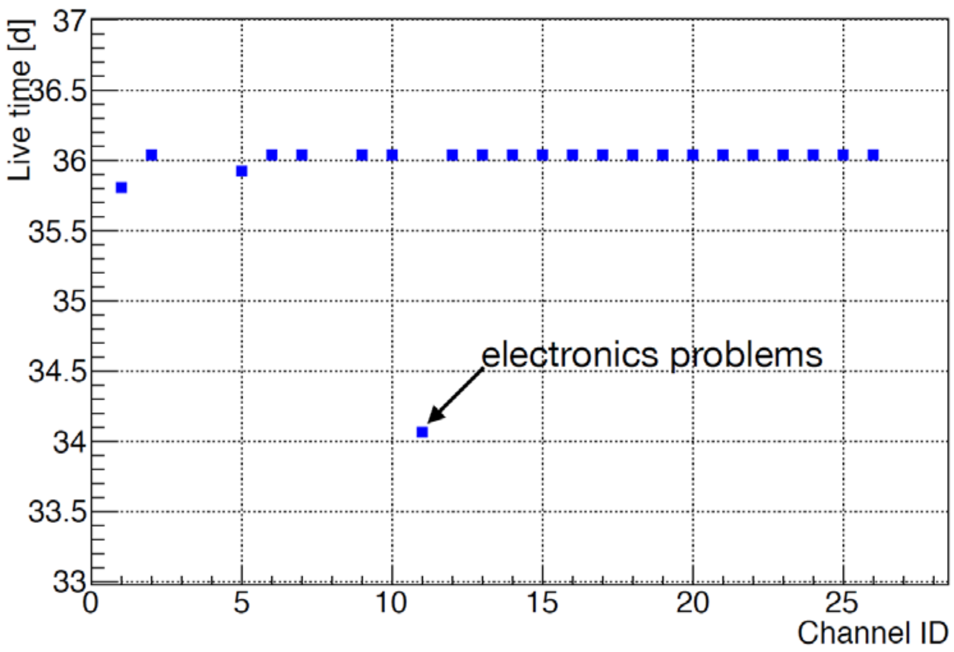
https://www.lngs.infn.it/en/cupid

Science RUN 0 – Collected statistics

Science Run 0
(17 March – 15 May)

0.89 kg x y exposure of ZnSe
0.47 kg x y exposure of ^{82}**Se**

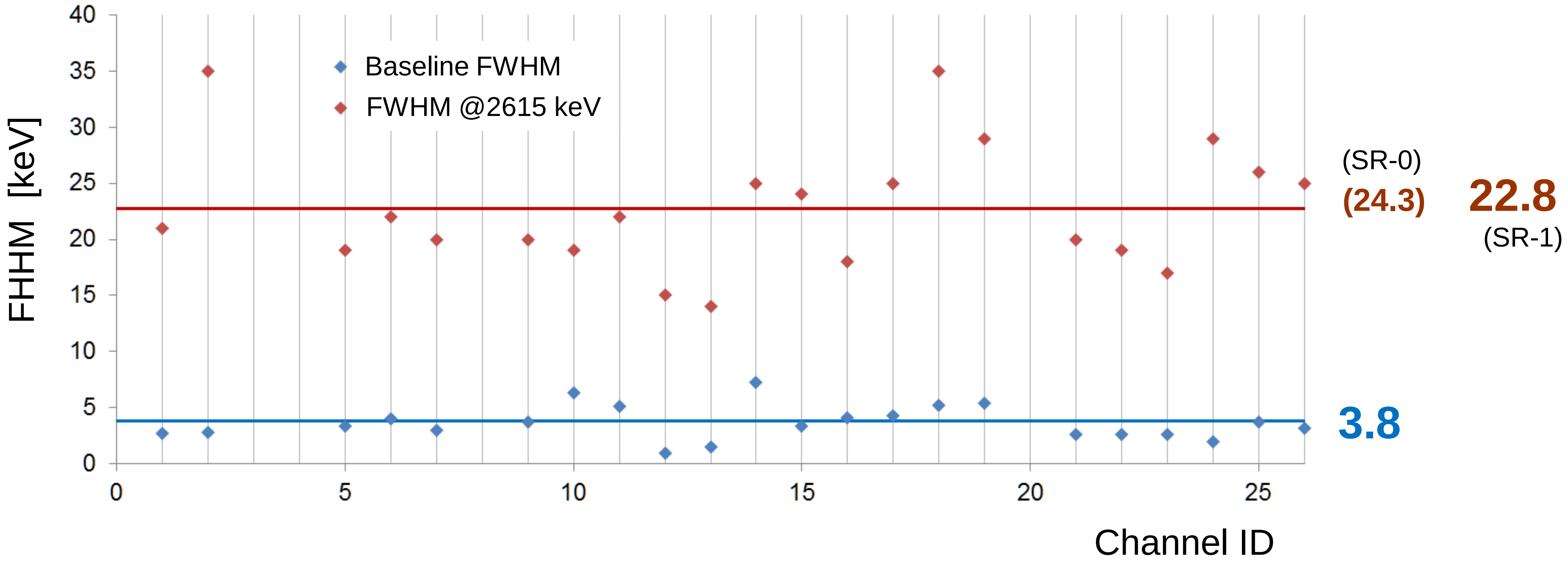




The **SR-0** enabled us to fix several bugs of electronic and SW.
After the stop we implemented few major changes.

The **SR-1** started 3 June 2017
we presently have **(Physics+Calibrations) > 93 %**

$Zn^{82}Se$ Energy resolution



It is clear that the abrupt difference between the baseline resolution of the detector and the effective energy resolution @2615 keV is due to the *non perfect quality* of the crystals

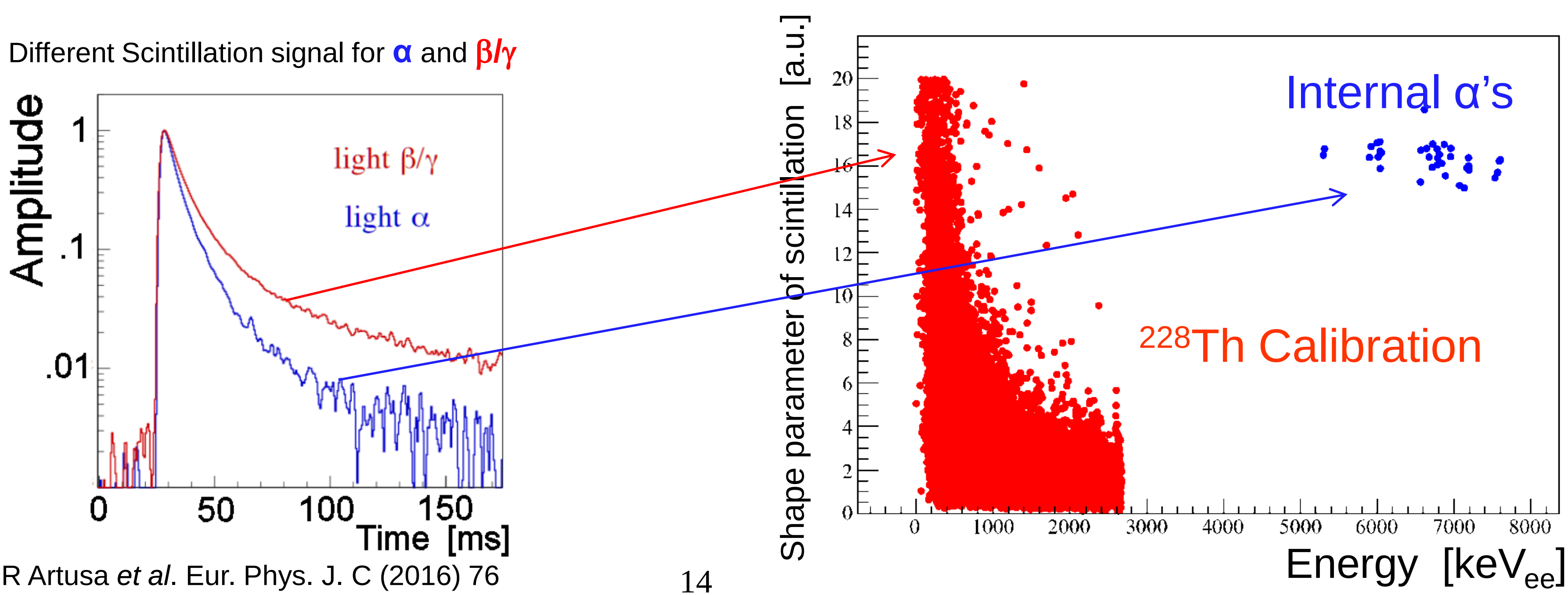
Energy resolutions are still (slightly) improving...

Light Detectors at first glance

LDs work extremely good.

- Presently we cannot give the actual performance since, for obvious reasons, no ^{55}Fe sources where mounted on CUPID-0.
- Nevertheless the performances can be inferred by roughly looking at the S/N ratio at the scintillation signal @2615 keV: it is very good for all the detectors.
- Moreover, the discrimination factor evaluated on internal α-lines is completely satisfying

Different Scintillation signal for α and β/γ



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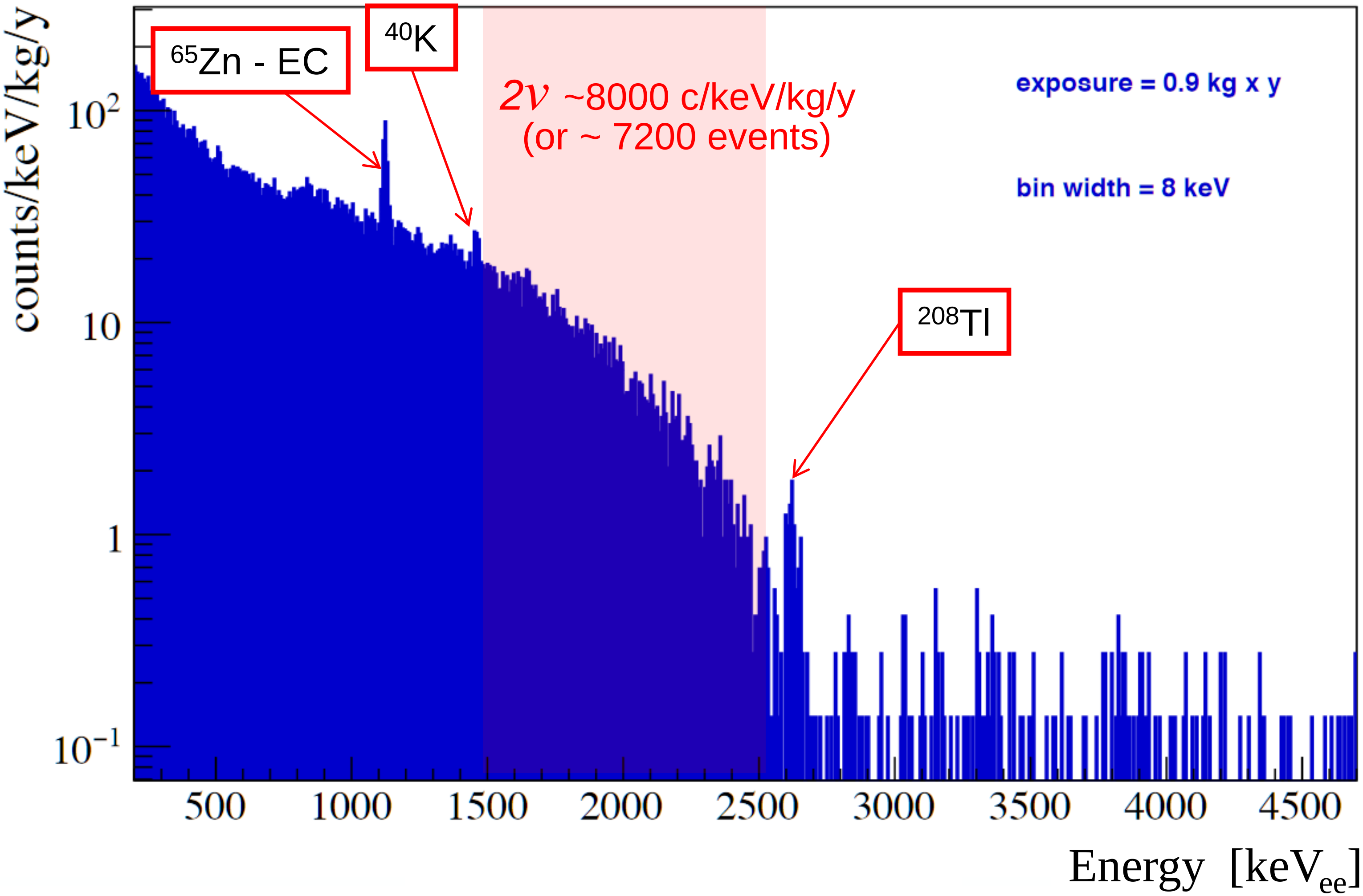
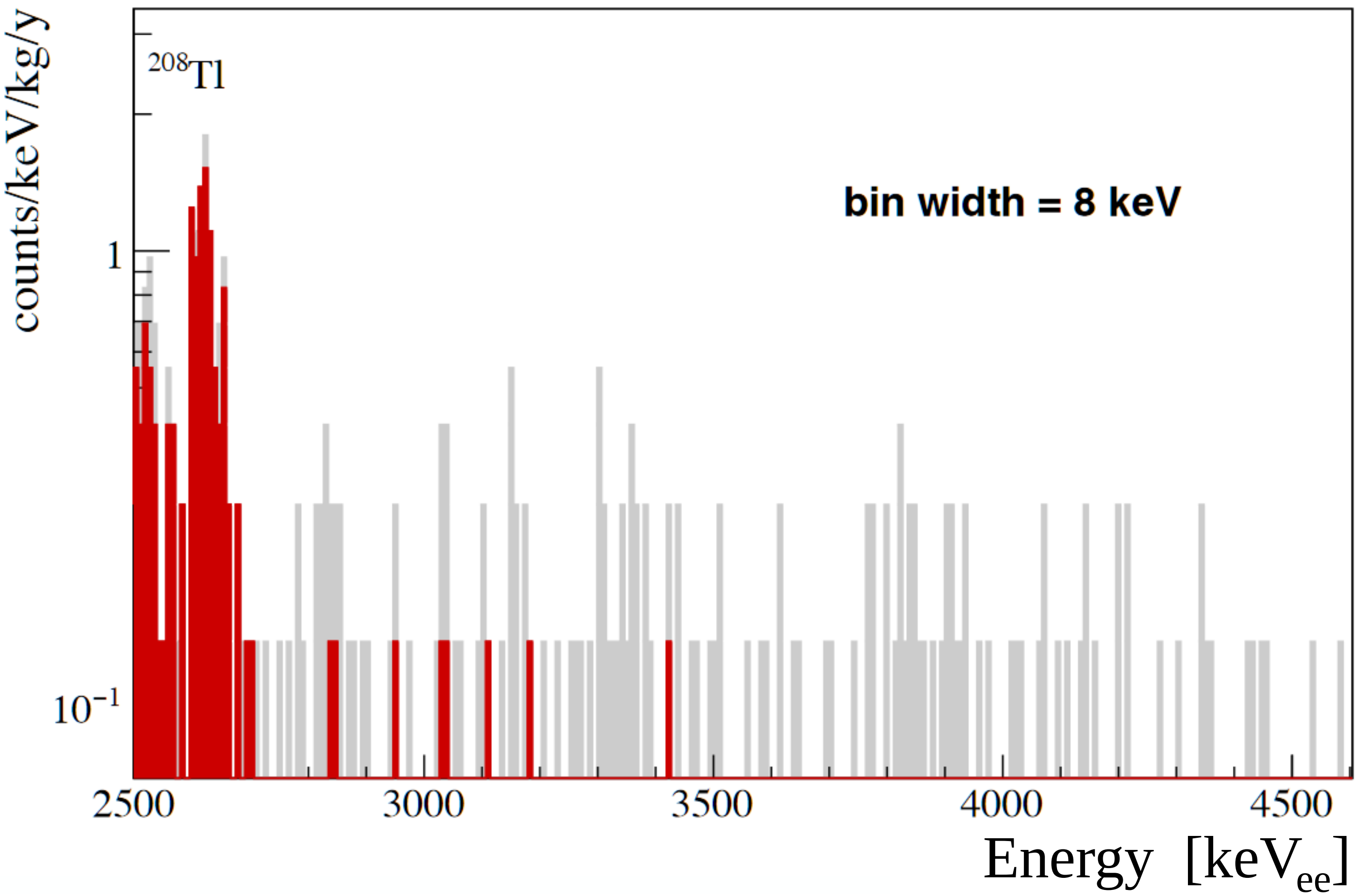
Total Background Spectrum, no cuts



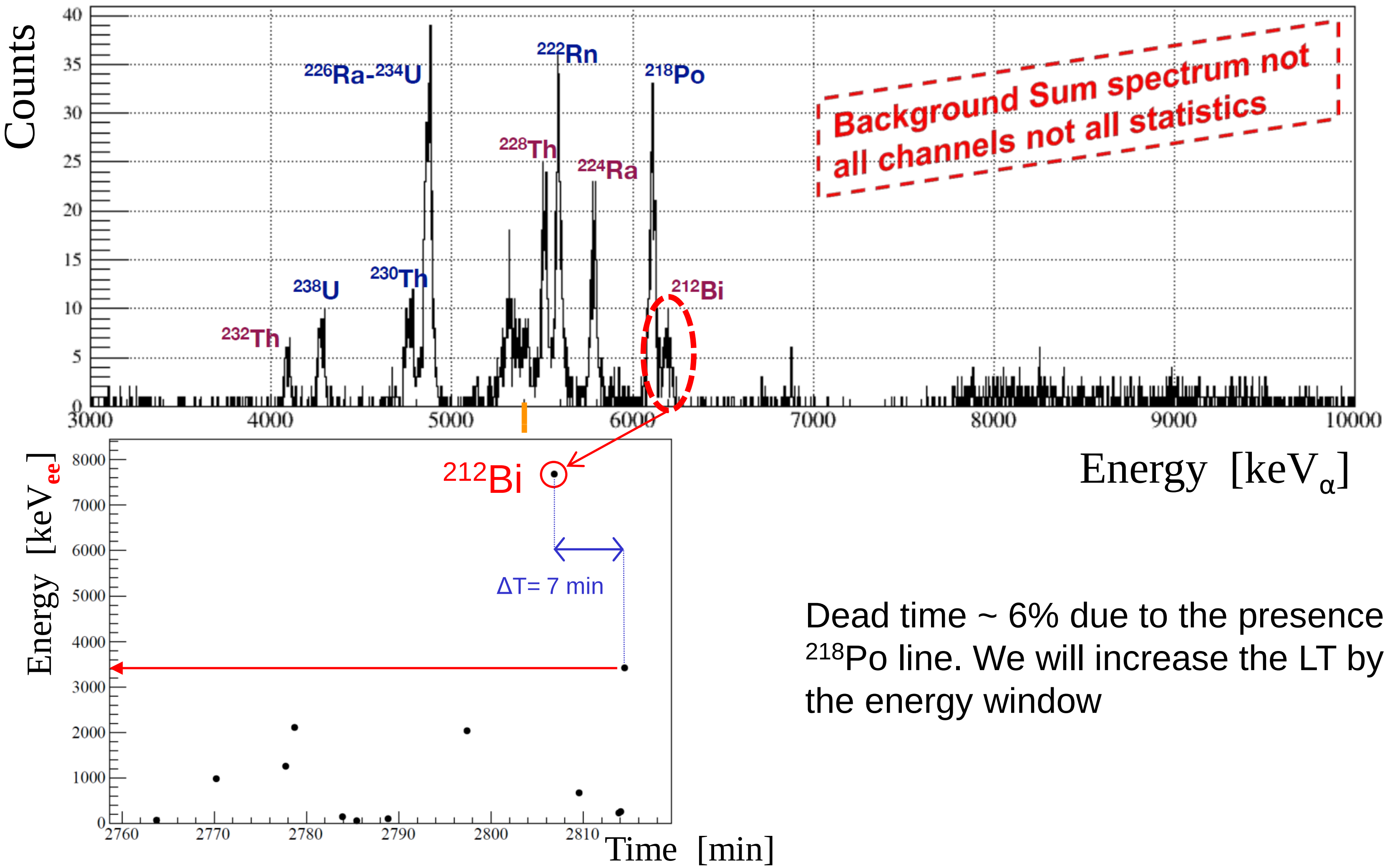
Total Background Spectrum, Anticoincidence and α-cut



Cut efficiency of the order of ~93 %. Will slightly increase after optimization of the coincidence jitter time (in progress).

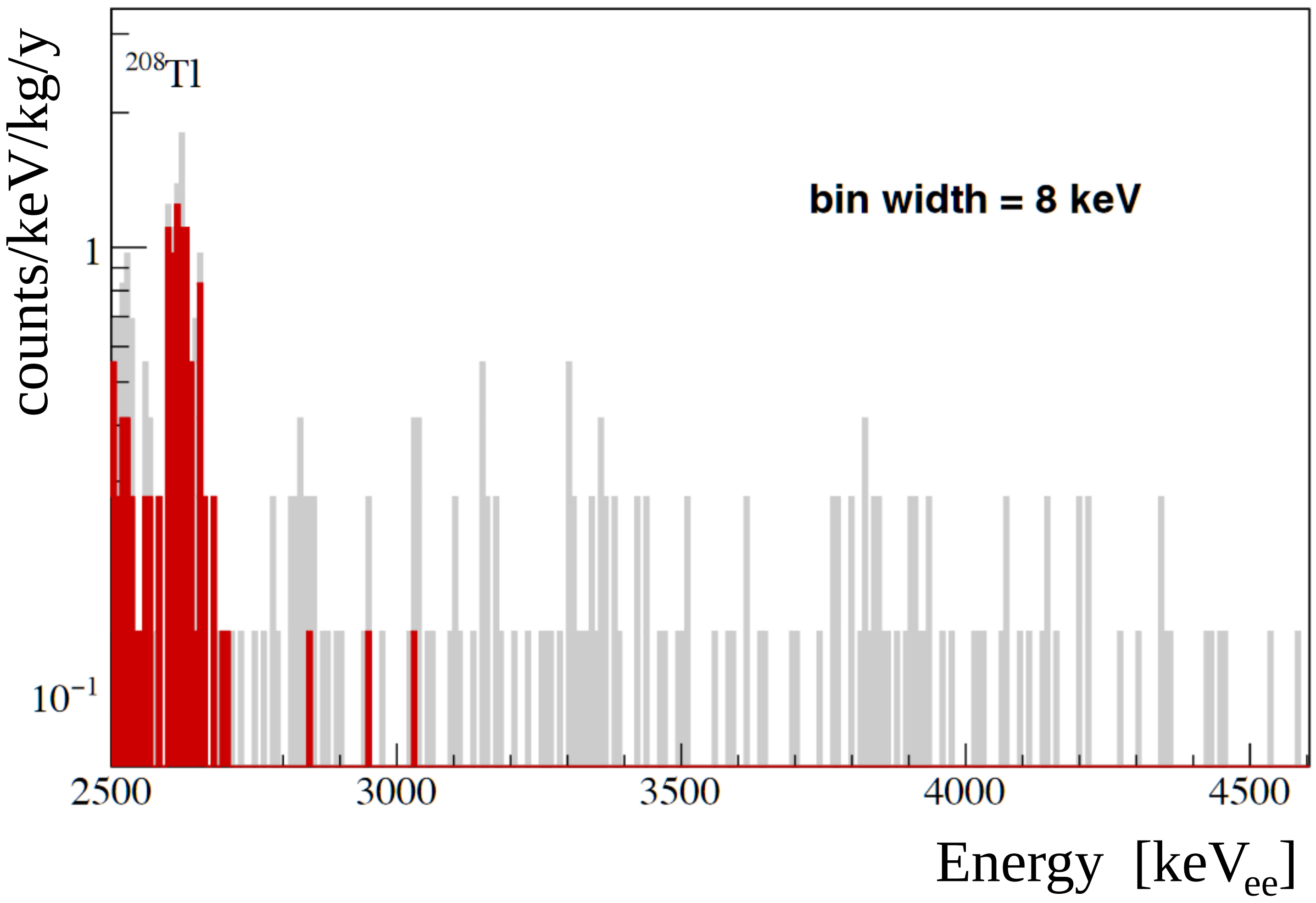
α-delayed coincidence- Internal background

A not negligible background is induced by internal contamination belonging to the ^{232}Th chain, through the decay of ^{208}Tl with Q-Value of 5 MeV. The decay is preceded ($T_{1/2} \cong 3$ min) by the α-decay of ^{212}Bi, with Q-value 6.2 MeV.



Dead time ~ 6% due to the presence of the ^{218}Po line. We will increase the LT by optimizing the energy window

Final preliminary background Sum Spectrum



Total cut efficiency of SR-0 is 87 % (evaluated at ^{65}Zn -1135 keV). We are working to reach a cut efficiency >90%

Conclusions

- ✓ The α-rejection technique works at best
- ✓ The SR-0 shows the extremely low background in the 2ν region
- ✓ The first **background** in the **0νDBD ^{82}Se** is promising
- ✓ The first reliable evaluation of the BI will be released as soon as our background model will be ready and the statistics has increased at least by a factor three (September)

The CUPID-0 collaboration

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BACKUPS

The final choice of LUCIFER

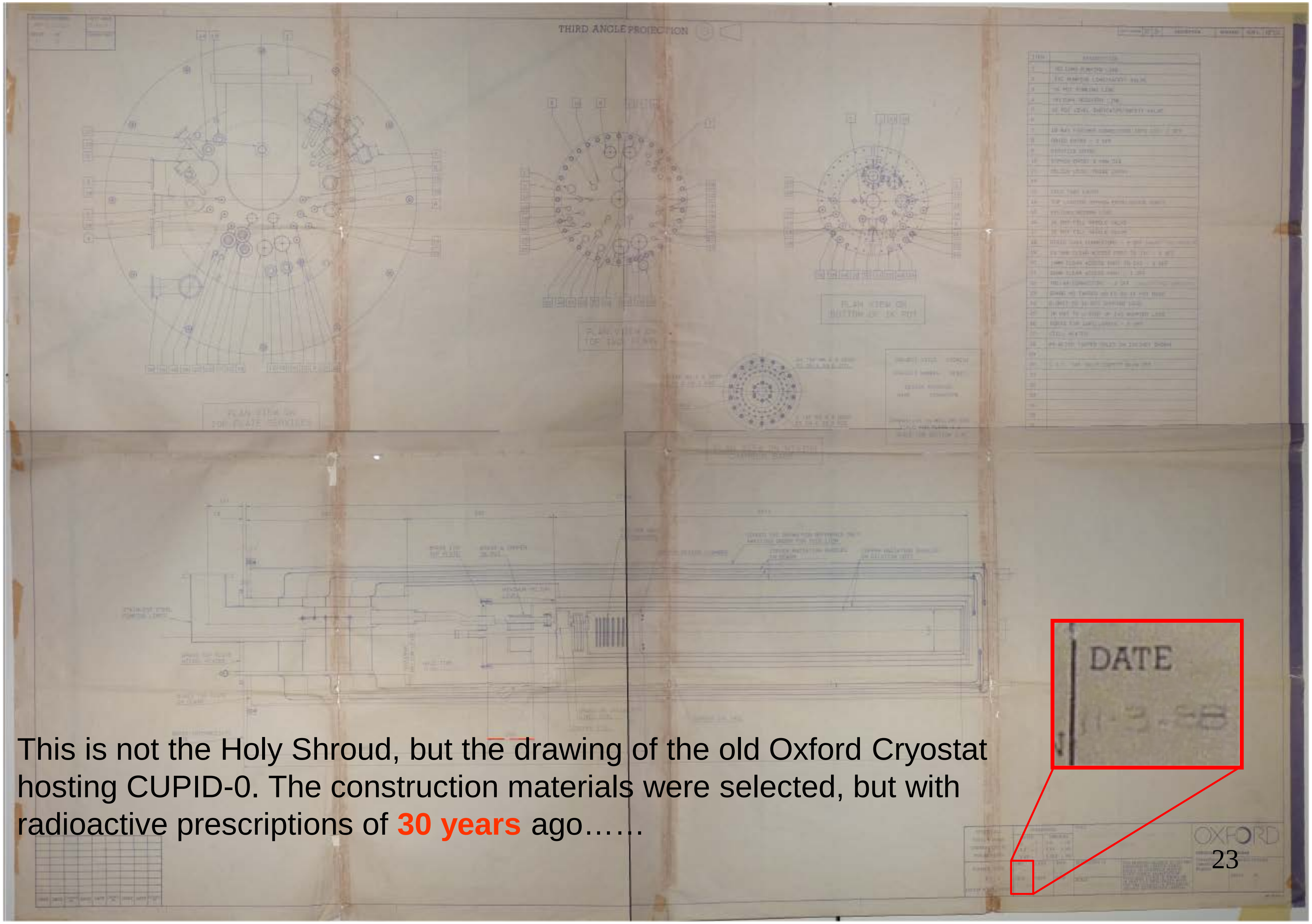
The “final” decision of the LUCIFER detector was due, finally to the market availability of enriched material. At that time (2010-2011) we didn’t succeed to get any kind of feedback from Russia.

The only “feasible” producer was, therefore, URENCO in Holland.
URENCO did not have any kind of production line of Mo-isotopes (due to the not- easy to handle- gas phase of Mo isotopes), so that **the only possibility was ^{82}Se** (that is enriched trough the *standard* Hexafluoride technique)
The contract for the delivery of 10+5 kg ^{82}Se was signed in mid 2011. The price for the production was fixed at 70kEuro /kg @> 95 % i.a.

The ^{82}Se production went on rather smooth. After the delivery of the first 5 kg, we recognized a trace contamination of the enriched metal beads both in U and Th.
URENCO therefore developed in 2014 **a small vacuum distillation set-up** to decrease the contamination (also of Na and S used for the $^{82}SeF_6$ to ^{82}Se metal conversion)

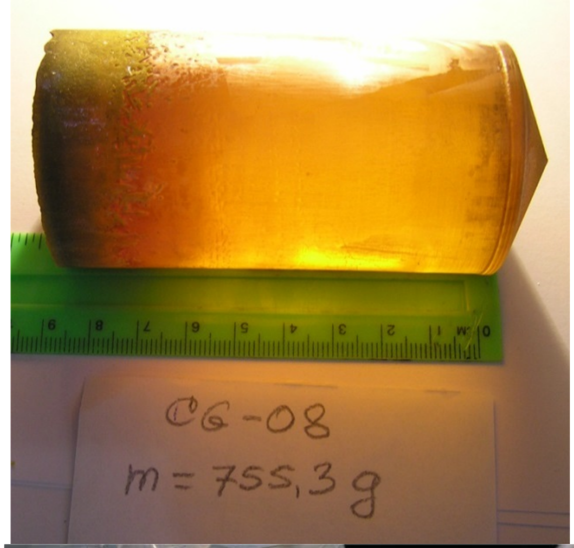
	Se(Enr.)	Se(enr-Dist.)	Se(enr-Dist.)	Zn (nat)	Zn (nat)
	[mBq/kg]	[mBq/kg]	[g/g]	[mBq/kg]	[g/g]
^{238}U / ^{226}Ra	<0.41	< 0.11	$< 9.0\ 10^{-12}$	< 0.066	$< 5.4\ 10^{-12}$
^{232}Th / ^{228}Th	1.4 ± 0.2	< 0.11	$< 2.6\ 10^{-11}$	< 0.036	$< 8.9\ 10^{-12}$
^{40}K	3 ± 1	< 0.99	$< 3.2\ 10^{-8}$	< 0.38	$< 1.2\ 10^{-8}$

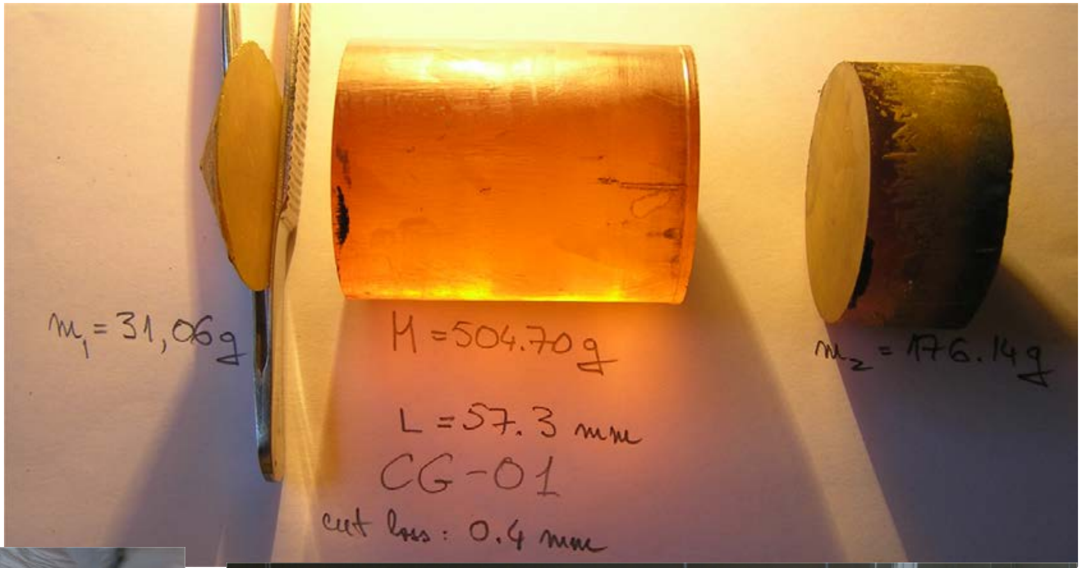
Background consideration: the "old" cryostat

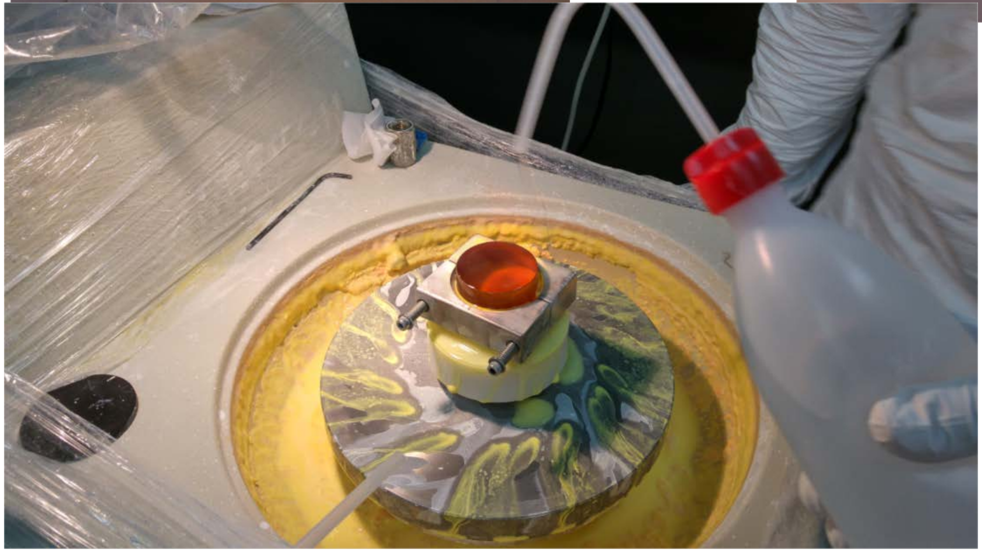


This is not the Holy Shroud, but the drawing of the old Oxford Cryostat hosting CUPID-0. The construction materials were selected, but with radioactive prescriptions of **30 years** ago……

The crystals were polished in the Low Rn Dark Side Clean Room @LNGS



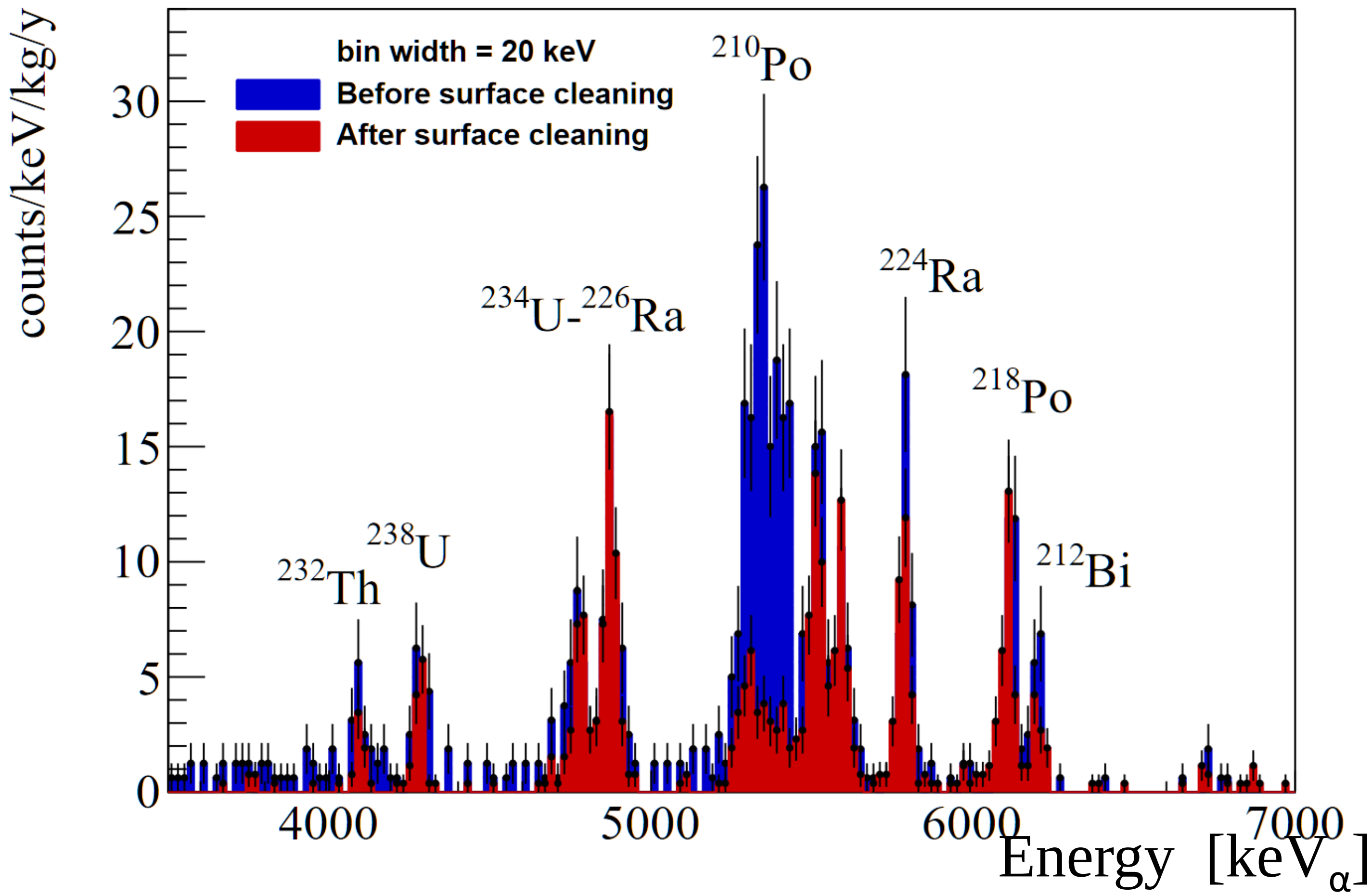




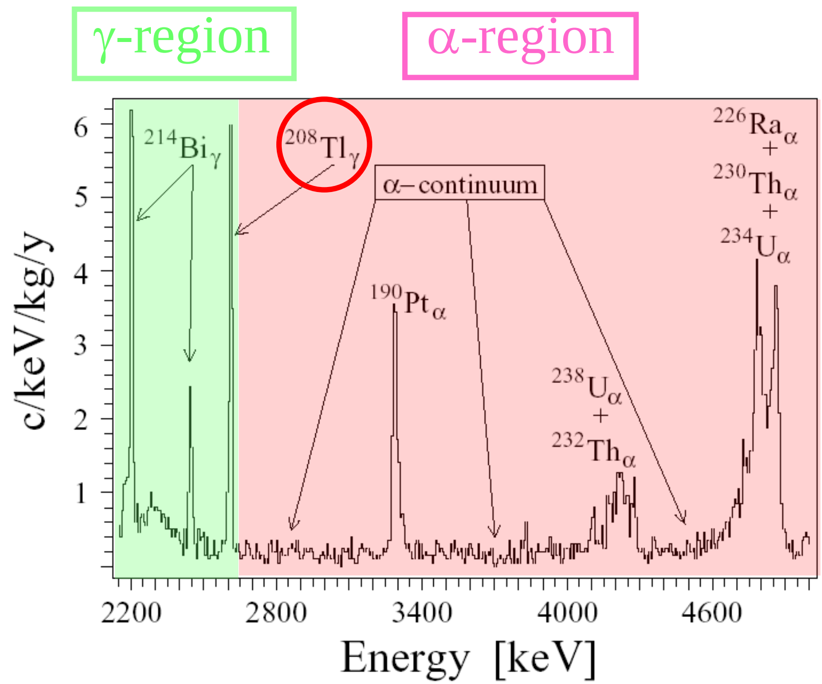
I. Dafinei *et al,* J of Crystal growth **475** (2017) 158-170)

Surface Polishing – Effects on Radioactivity

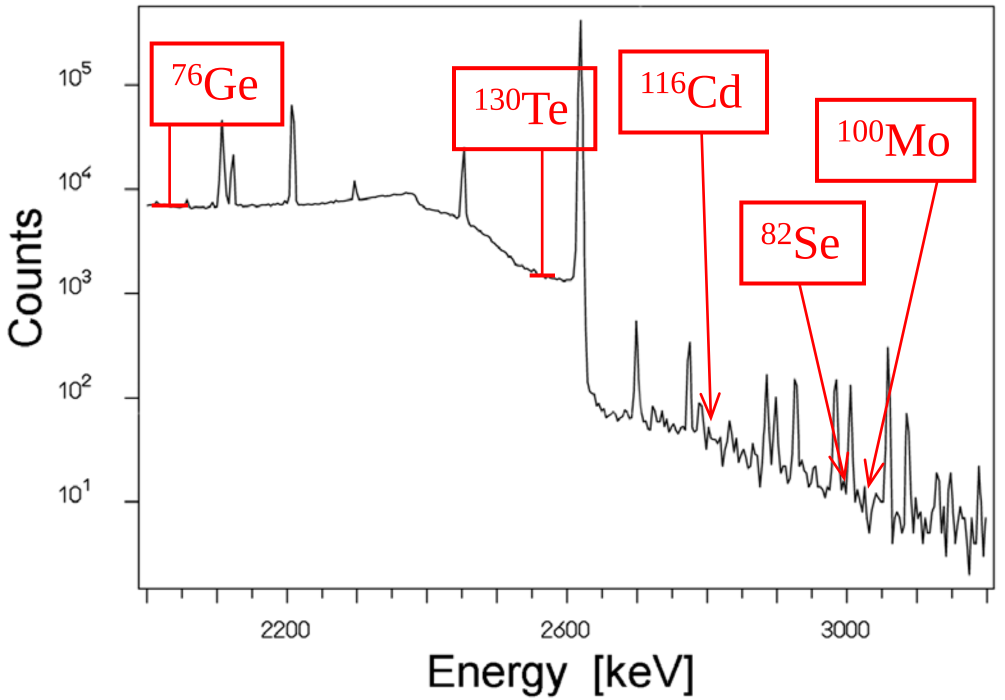
Background spectrum of three $Zn^{82}Se$ crystals before and after the surface polishing with Ultrapure SiO_2 powder



Surface and Bulk contaminations



CUORICINO α Background



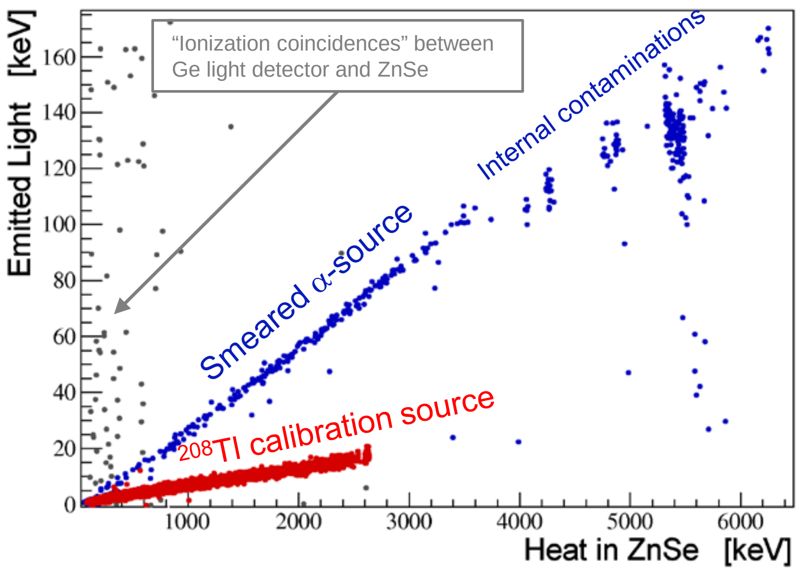
Environmental "underground" Background:
^{238}U and ^{232}Th trace contaminations

ZnSe crystals and α discrimination

ZnSe crystals shows an "inverse" QF, i.e. α-particles scintillate more than β/γ's (C. Arnaboldi *et al.*, Astrop. Phys. **34**(2011)

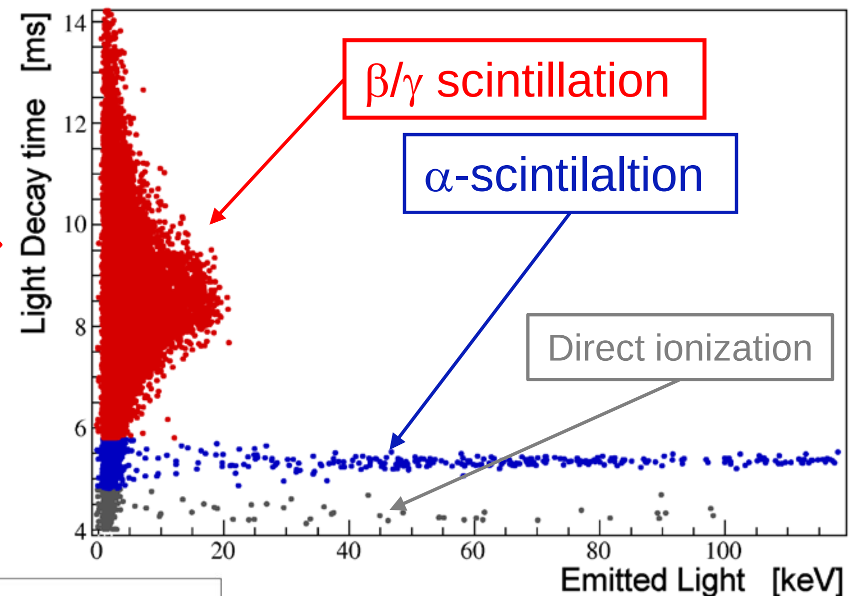
The α-induced background is recognized through two independent measurements: 1) the decay time of the scintillating signal 2) the different scintillation yield between α and γ/β particles (the "usual" light Vs Heat scatter plot)

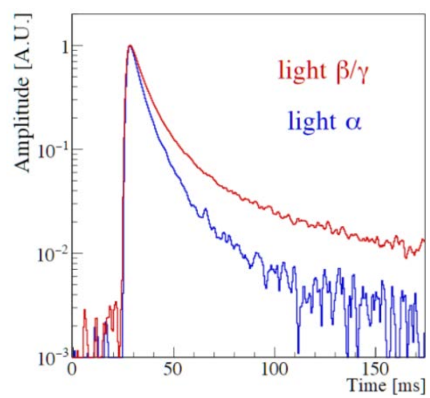
(2) Light Vs Heat scatter Plot



JW Beeman *et al.*, JINST **8** (2013) P05021

(1) Decay time of the scintillation light





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TeO_2… Not TeO_2… This is the problem !!!

CUPID

CUPID	Pros	Cons
TeO_2	✓Well defined and known compound ✓ large commercial crystal production ✓ high reproducibility	✓$Q_{\beta\beta}$ **below** 2516 keV ✓ α and srface ID needs extremely performing technologies ✓Crystals yield is presently low (30%)
Non TeO_2	✓$Q_{\beta\beta}$ **above** 2516 keV ✓ α Id is straightforward ✓ enriched material already pure ✓ crystal growth yield can reach 85 %	✓Not commercial crystals ✓ larger enrichment price ✓ not yet proved crystal growth reproducibility (demonstrator)