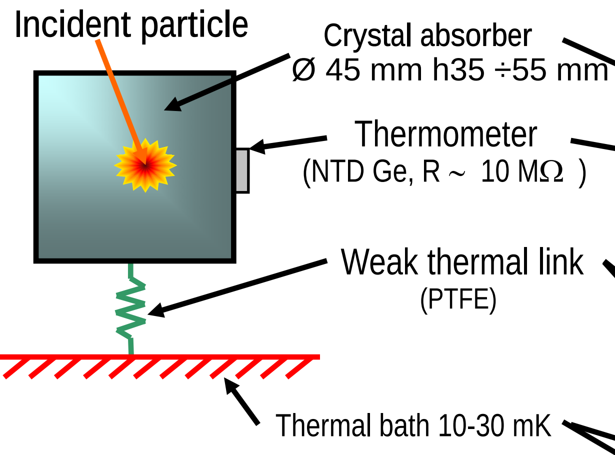
New Results on Double Beta Decay with CUPID-0

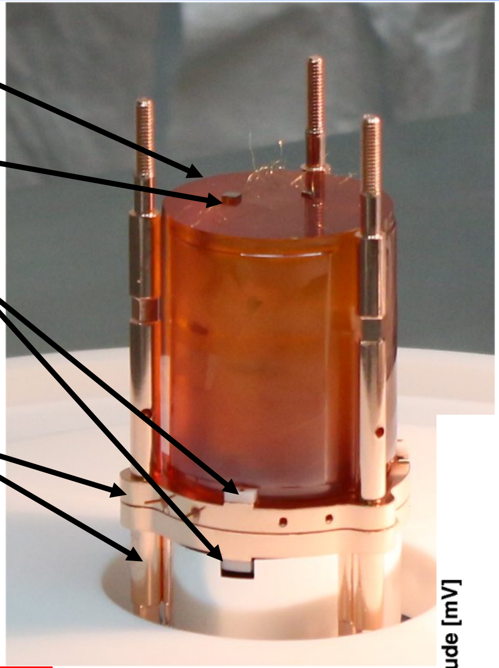
Stefano Pirro – INFN-LNGS
CUPID-0 Collaboration

NDM 2018
6th Symposium on Neutrinos and Dark Matter in Nuclear Physics 2018

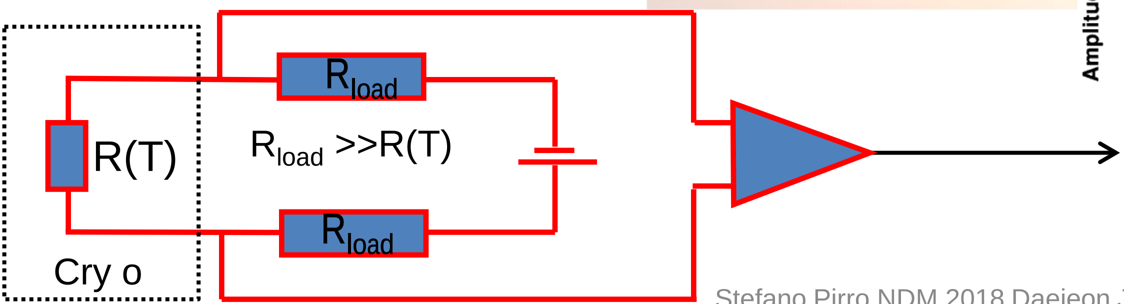
INFN
Istituto Nazionale di Fisica Nucleare

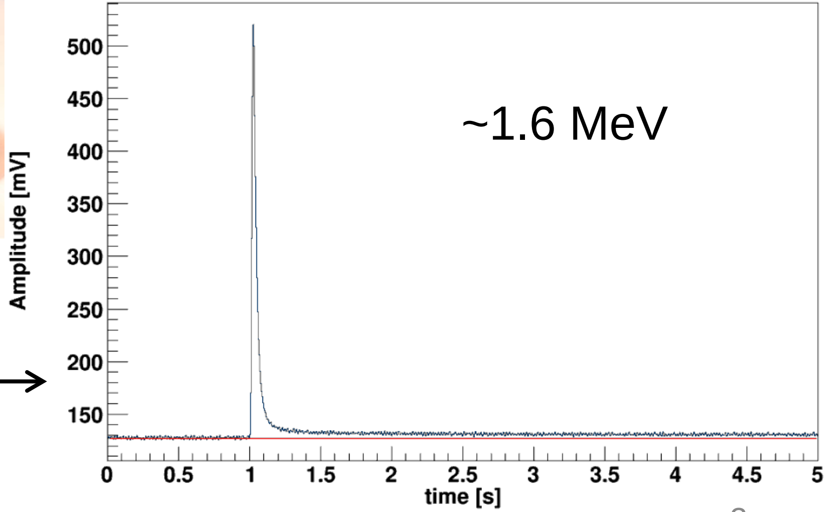
The Bolometric technique





dR/dE ≅ 5-20 kΩ/keV

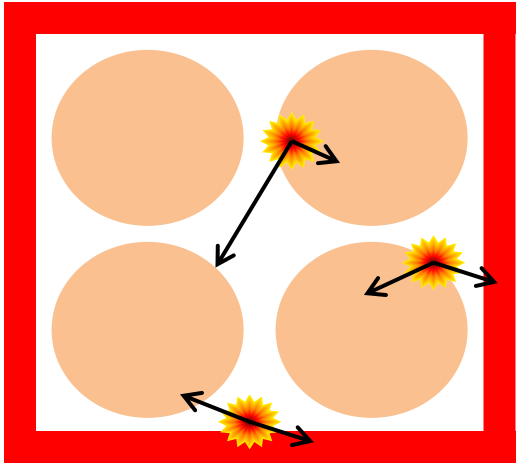


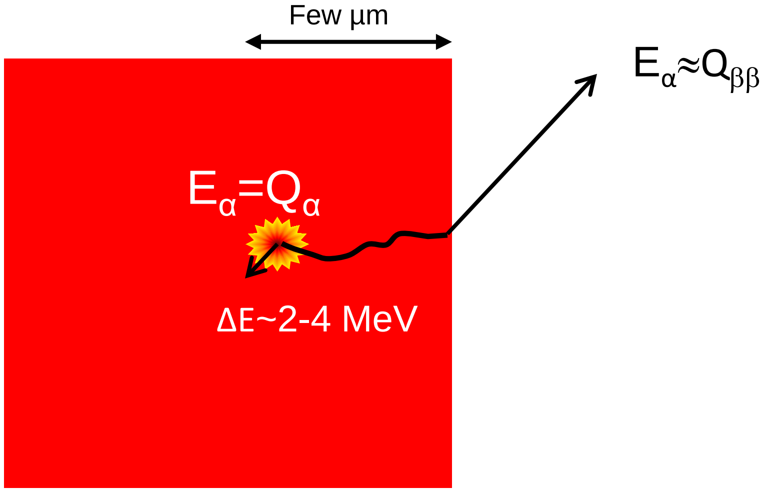


Bolometer: fully active detectors

Bolometer are total active detectors: they are *surface* sensitive

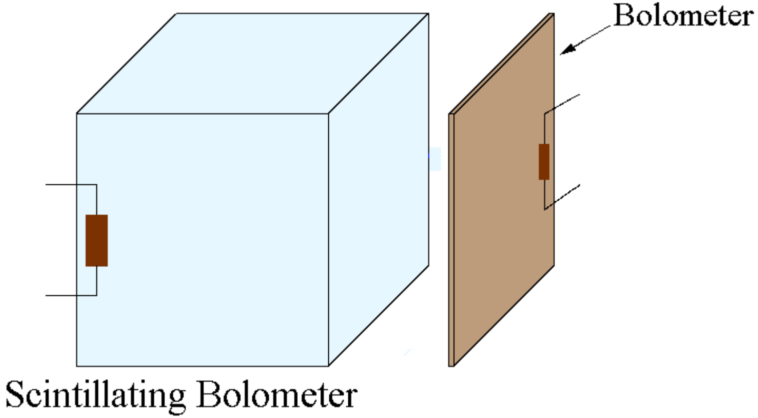
Most of the natural alpha decays has Q_α= 4-6 MeV

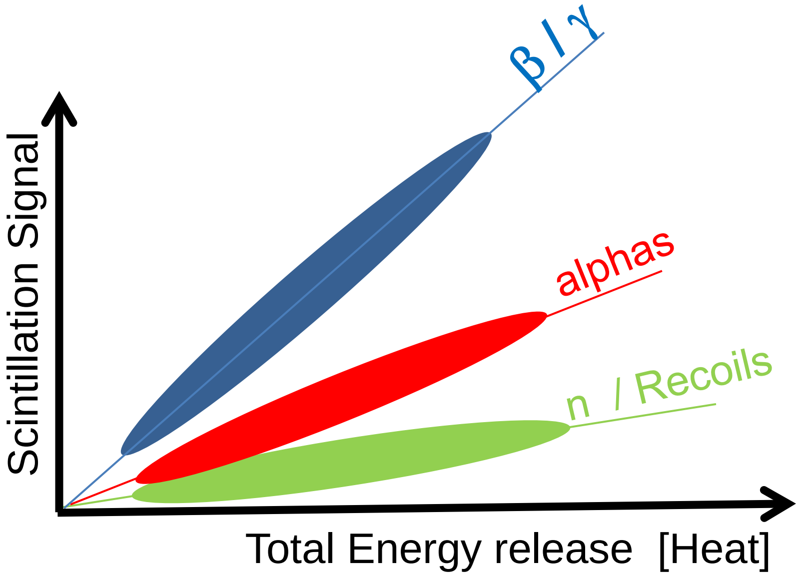




Scintillating Bolometers: rudiments of operation

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

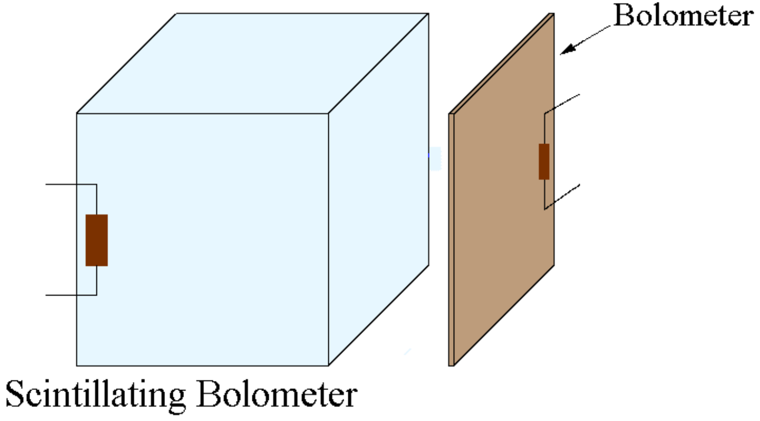


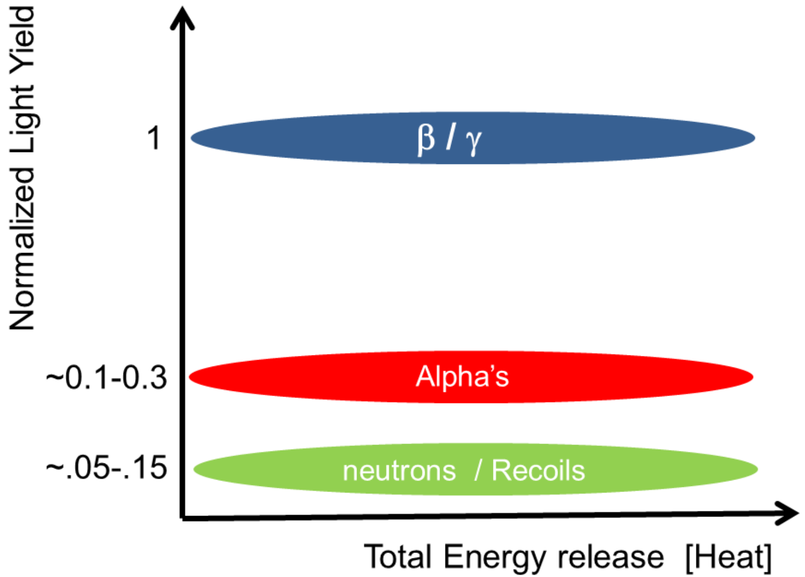


Scintillating Bolometers: rudiments of operation

Operating Temperature for <u>*massive*</u> detectors: 10÷30 mK

In the MeV region…





A Bolometric Light Detector (BLD) is a fully active a particle detector

The time response of a BLD is the same of a standard bolometer O ($\sim .1 - few$ ms)

The QE of a BLD is "simply" given by the absorption coefficient

LUCIFER Low-background Underground Cryogenics Installation For Elusive Rates

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

European Research Council

demonstrator

isotope:	^{82}Se , ^{100}Mo , ^{116}Cd
material:	$ZnSe$, $ZnMoO_4$, $CdWO_4$
technique:	scintillating bolmeter

The Lucifer ERC 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 and also the tiny Cherenkov light from a (non *scintillating*) TeO_2 was measured.

LUCIFER Low-background Underground Cryogenics Installation For Elusive Rates

European Research Council erc

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

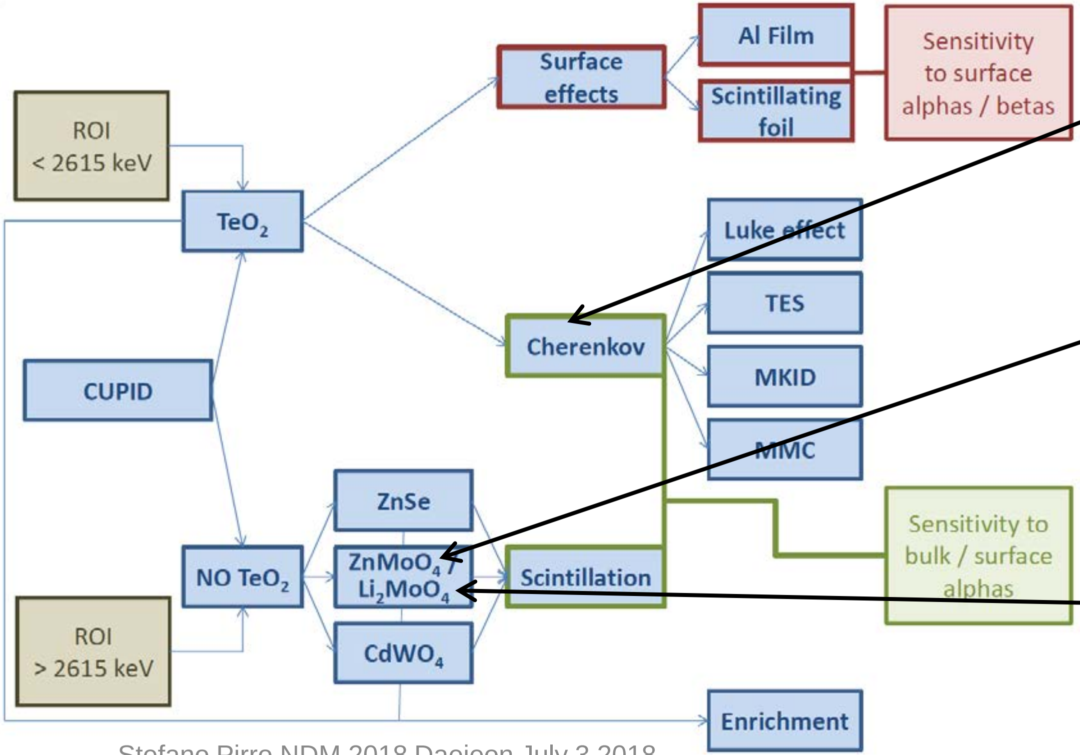
JW Beeman et al, Ad. in High Energy Phys. 2013, Article ID 237973

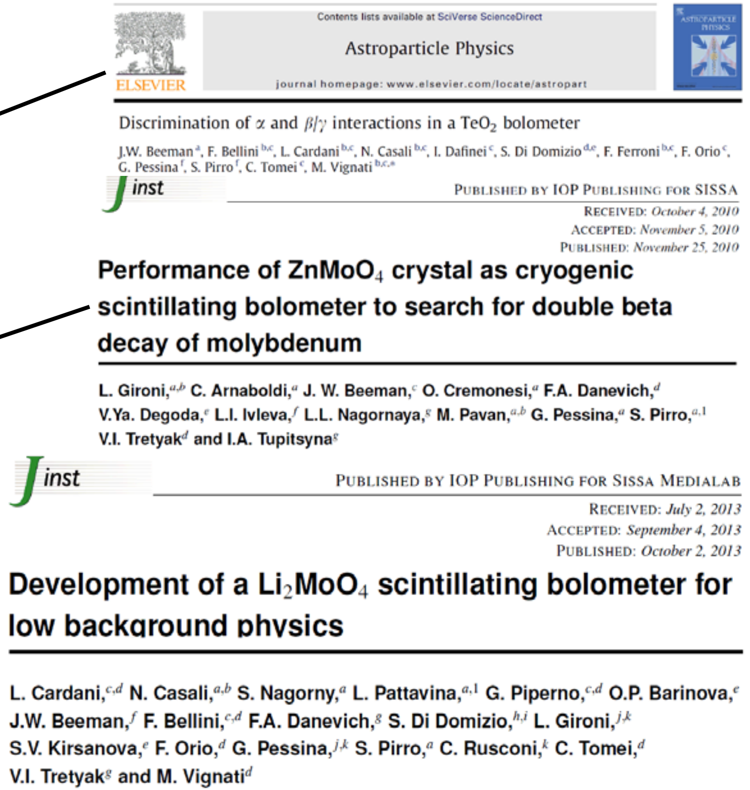
From 2016 this activity is funded by INFN under the INFN-CUPID Project. For this reason, LUCIFER is called now **CUPID-0**, the first demonstrator in view of CUPID.

Lucifer – The forerunner of CUPID

CUORE Upgrade with Particle IDentification

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





Astroparticle Physics 35 (2012) 558–562

Contents lists available at SciVerse ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart

Discrimination of α and β/γ interactions in a TeO_2 bolometer

J.W. Beeman[a], F. Bellini[b,c], L. Cardani[b,c], N. Casali[b,c], I. Dafinei[c], S. Di Domizio[d,e], F. Ferroni[b,c], F. Orio[c], G. Pessina[f], S. Pirro[f], C. Tomei[c], M. Vignati[b,c,*]

JINST

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PUBLISHED: November 25, 2010

Performance of $ZnMoO_4$ crystal as cryogenic scintillating bolometer to search for double beta decay of molybdenum

L. Gironi,[a,b] C. Arnaboldi,[a] J. W. Beeman,[c] O. Cremonesi,[a] F.A. Danevich,[d] V.Ya. Degoda,[e] L.I. Ivleva,[f] L.L. Nagornaya,[g] M. Pavan,[a,b] G. Pessina,[a] S. Pirro,[a,1] V.I. Tretyak[d] and I.A. Tupitsyna[g]

JINST

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

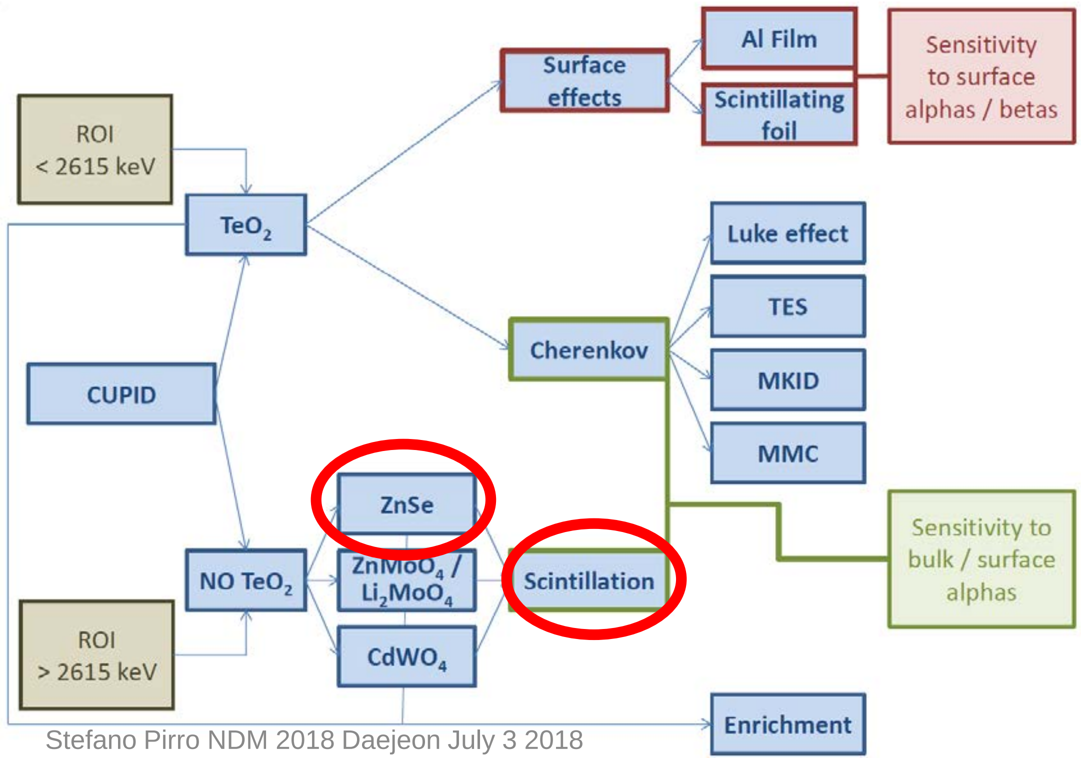
RECEIVED: July 2, 2013
ACCEPTED: September 4, 2013
PUBLISHED: October 2, 2013

Development of a Li_2MoO_4 scintillating bolometer for low background physics

L. Cardani,[c,d] N. Casali,[a,b] S. Nagorny,[a] L. Pattavina,[a,1] G. Piperno,[c,d] O.P. Barinova,[e] J.W. Beeman,[f] F. Bellini,[c,d] F.A. Danevich,[g] S. Di Domizio,[h,i] L. Gironi,[j,k] S.V. Kirsanova,[e] F. Orio,[d] G. Pessina,[j,k] S. Pirro,[a] C. Rusconi,[k] C. Tomei,[d] V.I. Tretyak[g] and M. Vignati[d]

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

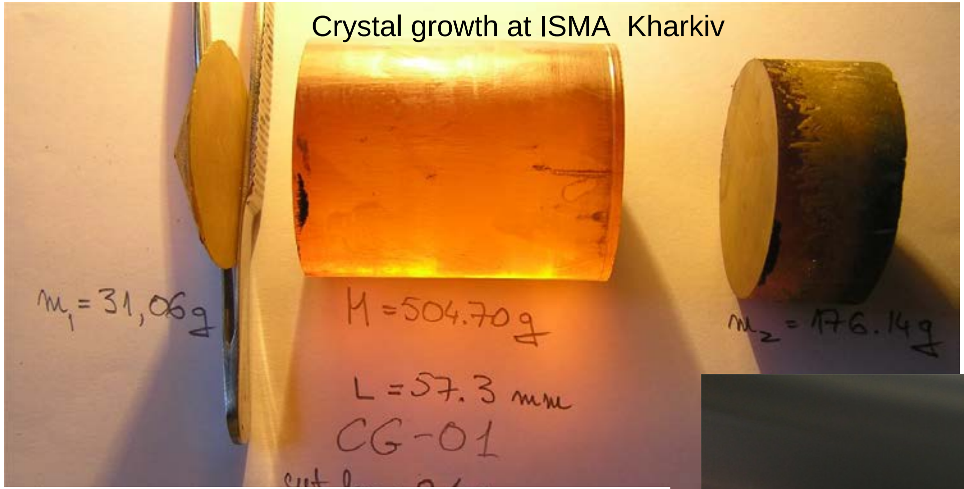
CUPID-0 represent the first enriched bolometer $\beta\beta$-experiment that is demonstrating the background rejection achievable for hybrid $\beta\beta$ scintillating bolometers



Cuoricino/CUORE-0 cryostat

The enriched $Zn^{82}Se$ crystals

The enriched Selenium (96.5%) was provided by URENCO stable Isotopes



Crystal growth at ISMA Kharkiv

I. Dafinei et al., *J of Cryst. Growth* **475** (2017):158

Chain	Nuclide	Activity (μBq/kg)	Concentration (ppb)
^{232}Th	^{228}Ra	< 61	< 0.015
	^{228}Th	< 110	< 0.026
^{238}U	^{226}Ra	< 110	< 0.009
	^{234}Th	< 6200	< 0.500
	^{234m}Pa	< 3400	< 0.280
^{235}U	^{235}U	< 74	< 0.13
	^{40}K	< 990	< 32
	^{60}Co	< 65	$< 1.6 \cdot 10^{-12}$
	^{75}Se	110 ± 40	$(2.0 \pm 0.7) \cdot 10^{-13}$

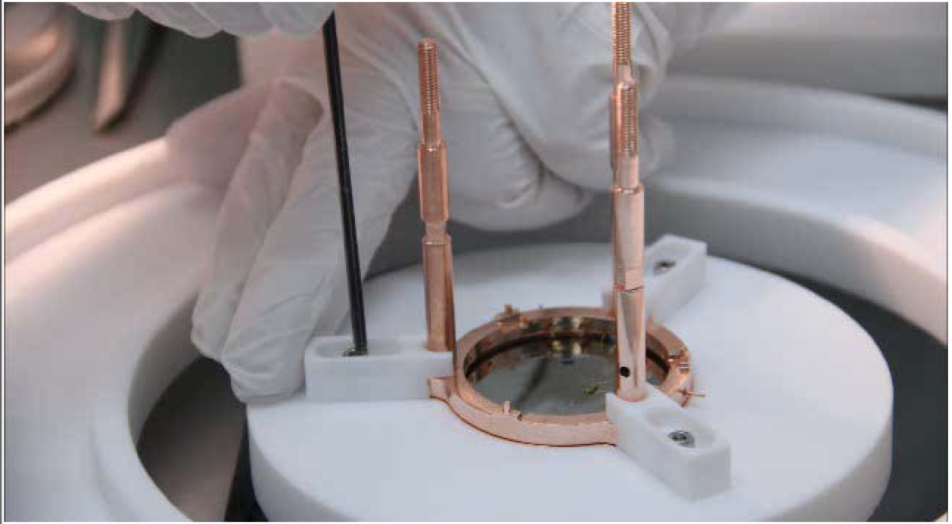
^{82}Se

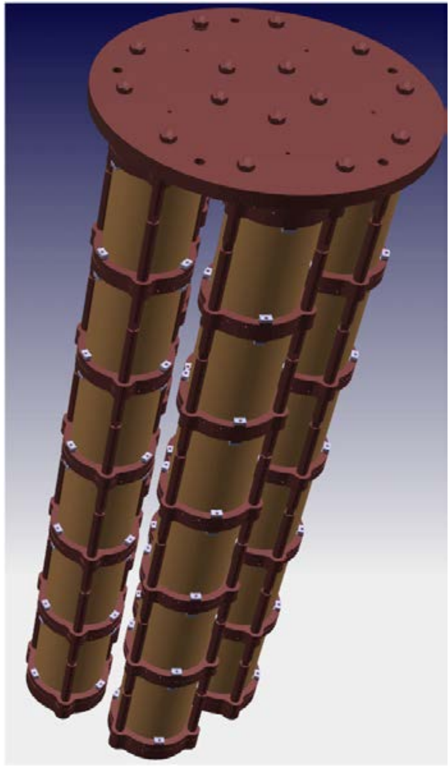
JW Beeman et al, . Eur. Phys. J. C (2015) 75: 591

Crystal polishing made in Clean Room @ LNGS

The CUPID-0 tower

26 ZnSe Crystal 24 enriched 2 natural : *Driving Idea: minimize frame mass, type of pieces, use **only** certified (large bar) copper*

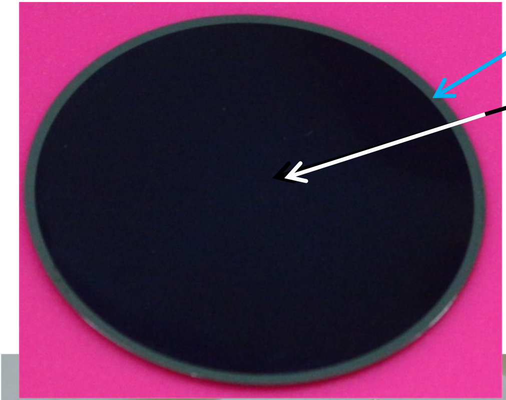




ZnSe 78 % Cu 22% PTFE 0.1% 0.14% VIKUTI™ reflector

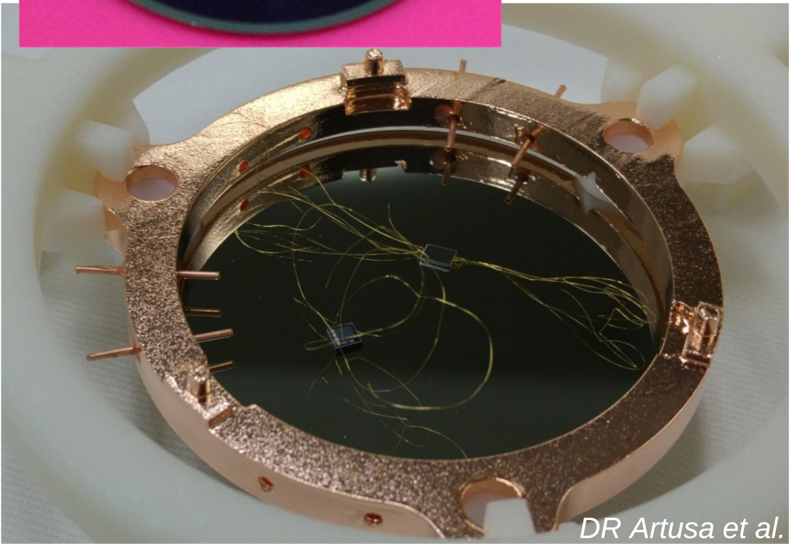
The light detectors (bolometers)

Light detectors are the fundamental part of the experiment since they permit the alpha background discrimination

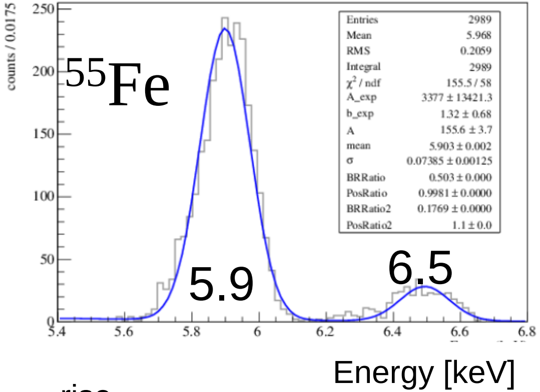


44.5 mm dia, 170 µm thick pure Ge wafer

SiO_2 coating to increase light absorption



Performance evaluated with ^{55}Fe source



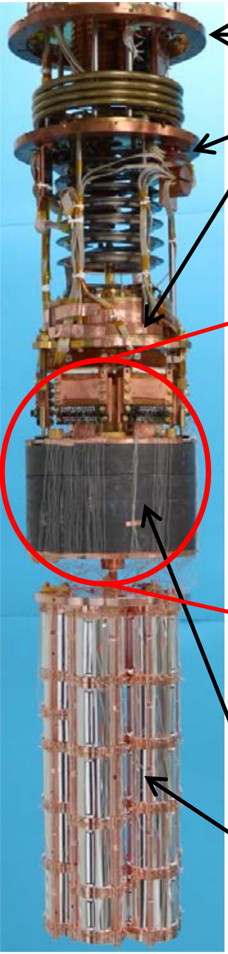
$\tau^{rise}_{(10\text{-}90)}$~1.8 ms

$\tau^{decay}_{(90\text{-}30)}$~ 6 ms

σ~ 50 eV

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

The overall detector



← 600 mK

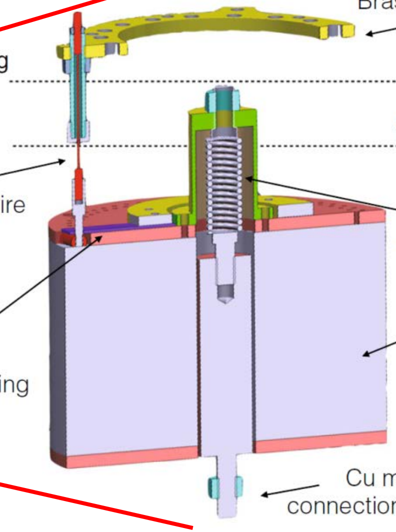
50 mK

^3He - ^4He MC

Roman Lead 10 cm

CUPID-0

5 tower, 26 ZnSe

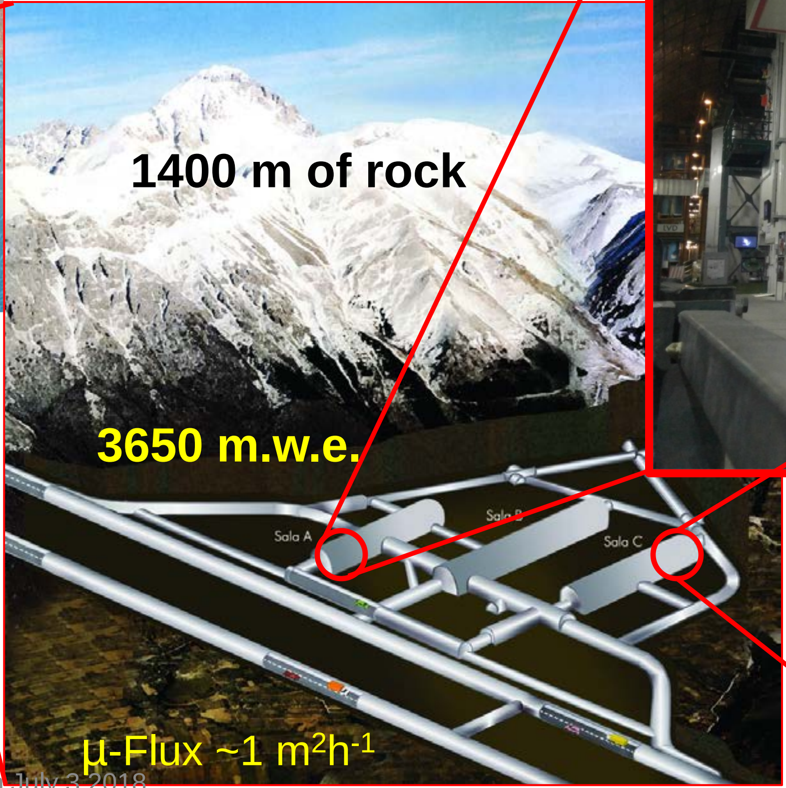


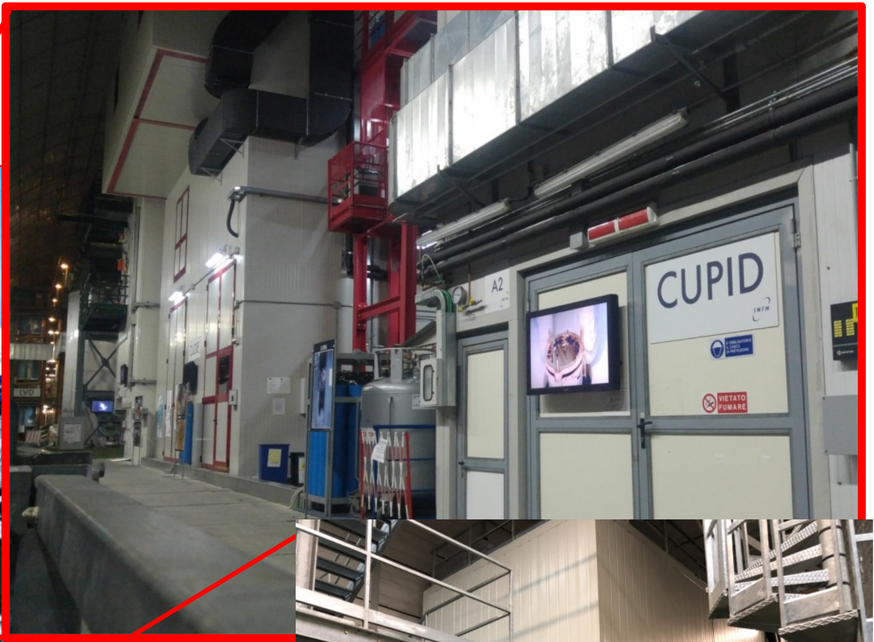
CUPID-0: the first array of enriched scintillating bolometers for 0νββdecay investigations
A. Azzolini et al. , Eur. Phys. J. C (2018) 78:428 *(https://arxiv.org/abs/1802.06562)*

CUPID @ LNGS

3 main halls 100x20x18 m^3

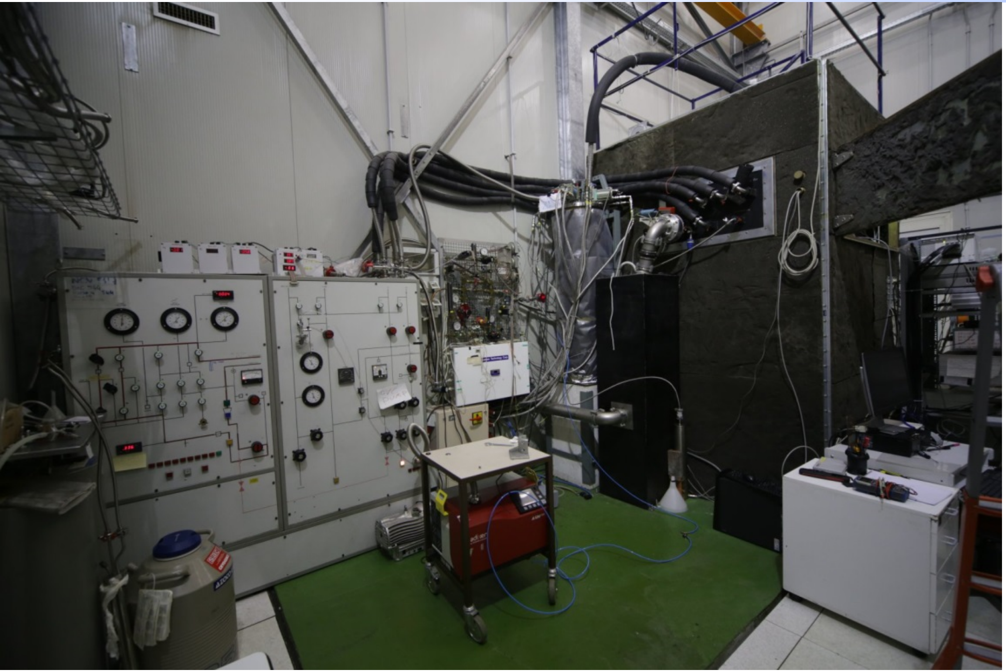
100 km east from Rome





Easy access from Highway tunnel

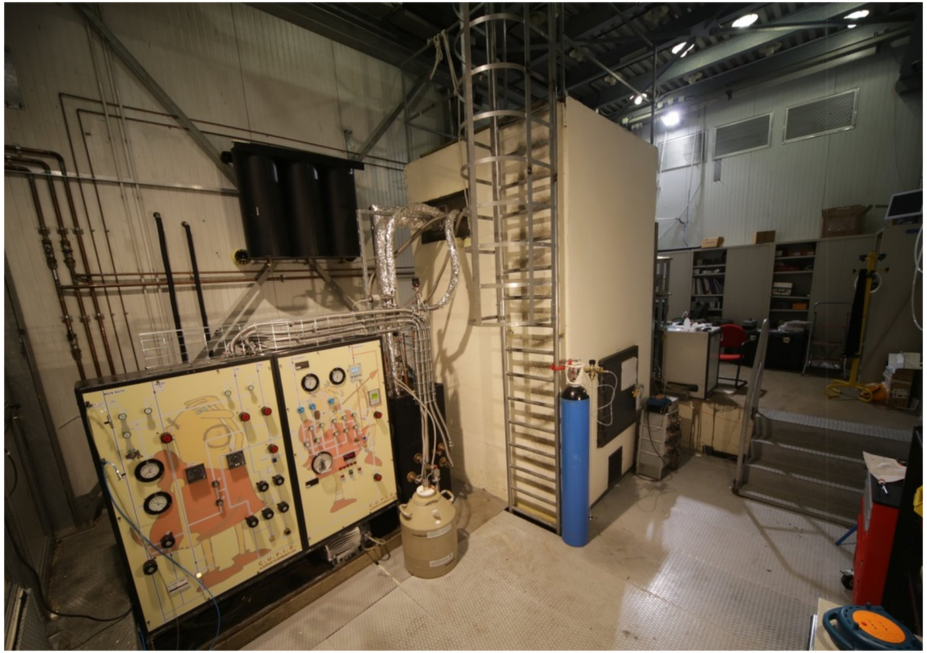
CUPID-RD @ LNGS Hall C



Low radioactive custom wet Oxford 200 (9 mK) (1988)

Completely customized Leiden dry 400 (6.8 mK) 2012

CUPID-0 experimental hut & dates

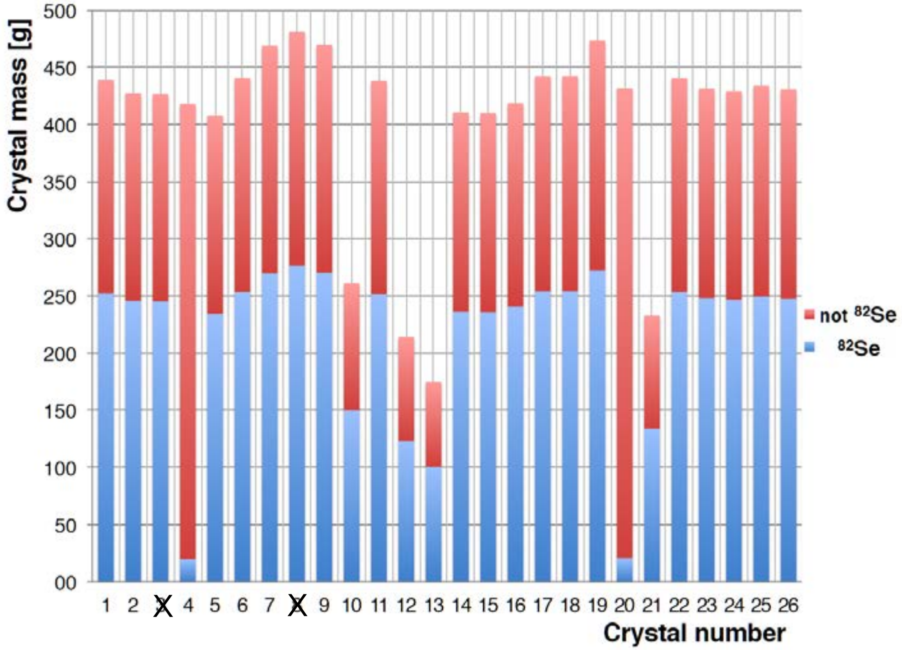


The CUPD-0 experimental hall and Faraday cage

Cooldown **February 2017**
Detector commissioning **March-May 2017**
Background data since **June 2017**

CUPID-0 Numbers

- Q-Value 2997.9 ± 0.3 keV
- 95 % enriched Zn^{82}Se crystal
- 26 crystals (2 natural)
- 10.5 kg of ZnSe, 5.17 kg of ^{82}Se
- 2 enriched crystal excluded from analysis (bad quality)
- Total ββ nuclei for analysis **3.41·10 ^{25}**



Data-taking June-December 2017

Editors' Suggestion

First Result on the Neutrinoless Double-β Decay of ^{82}Se with CUPID-0

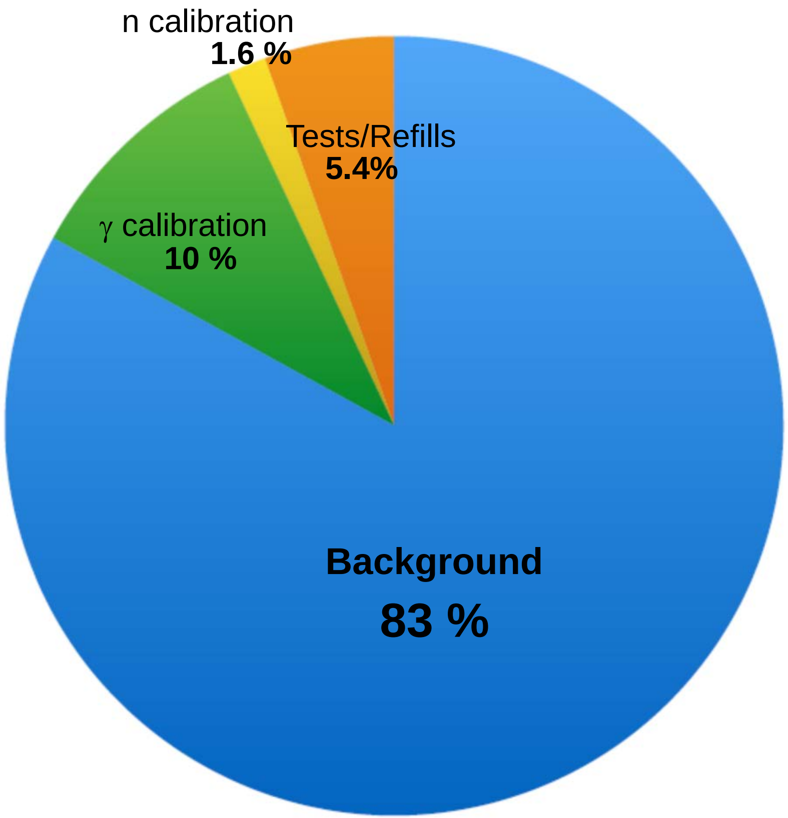
O. Azzolini *et al.*

Phys. Rev. Lett. **120**, 232502 (2018) – Published 5 June 2018

The CUPID-0 experiment improves the half-life limit of the ^{82}Se neutrinoless double beta decay by almost an order of magnitude.

https://arxiv.org/abs/1802.07791

Livetime



The achieved live time is extraordinary high for a bolometric experiment. It Is mainly due to the work devoted to

- Double stage damping system
- refurbished/improved mixture injection line
- Improved He refill procedure
- Tower+MC temperature stabilization system

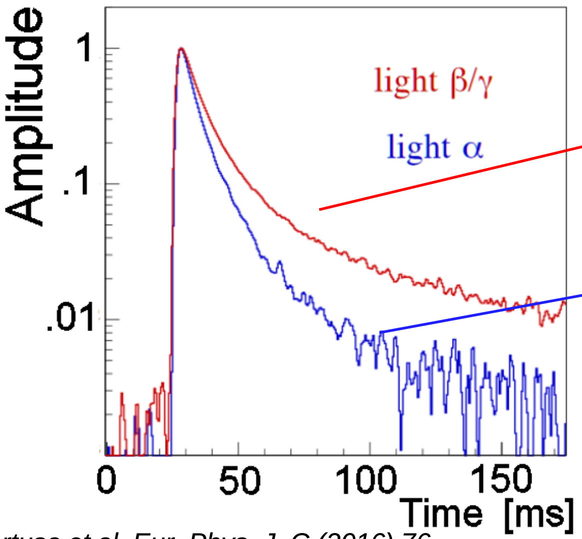
A not negligible fraction of dead time (within the Tests/Refills) was/is induced by earthquakes

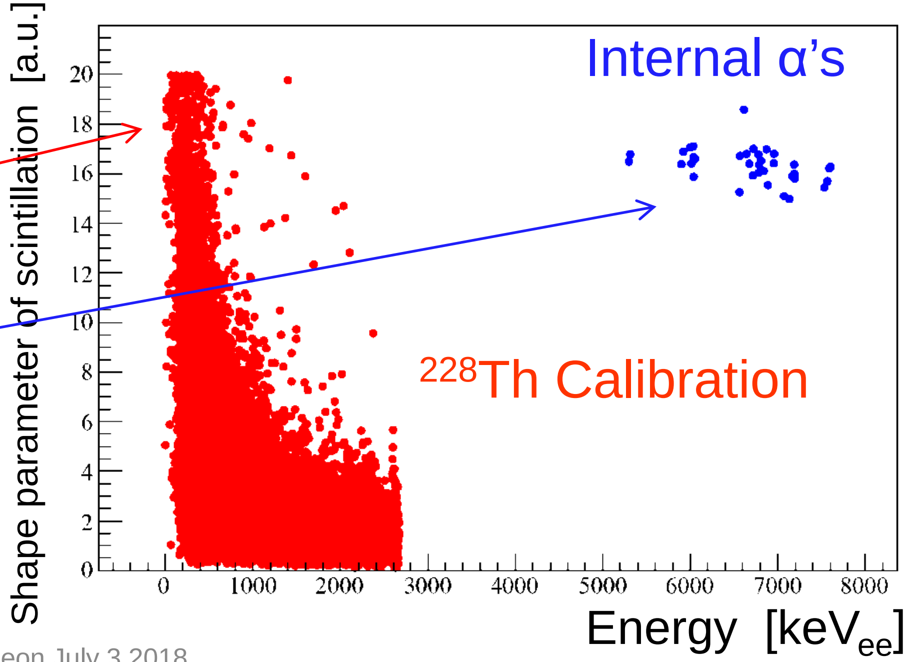
Total Exposure = 3.44 kg y ZnSe

Light detectors

- 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.
- The discrimination factor evaluated on internal α-lines is completely satisfying

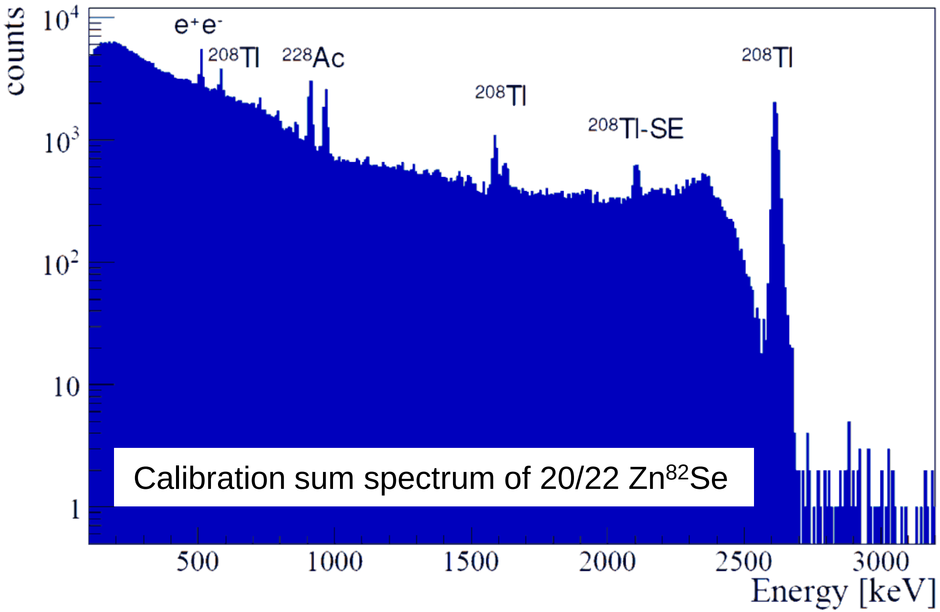
Different Scintillation signal for α and β/γ

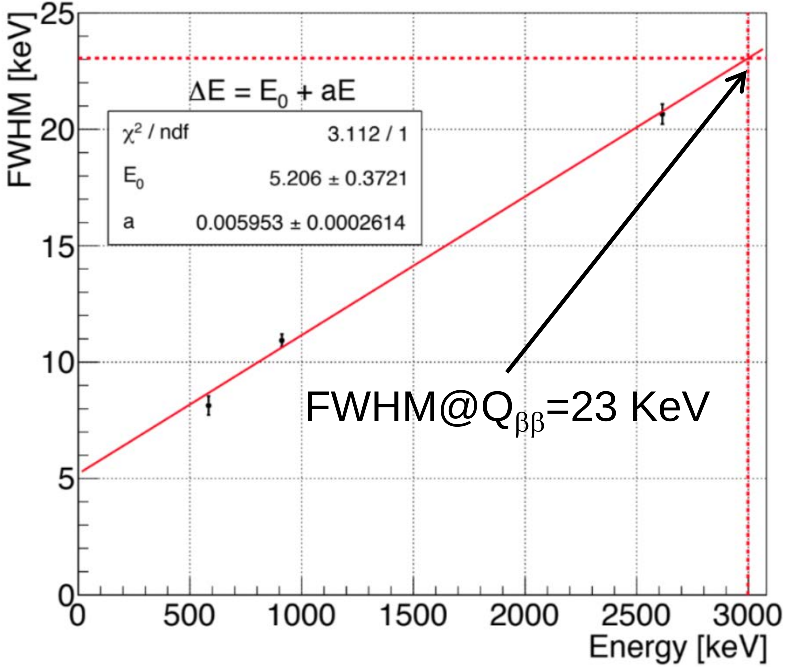




DR Artusa et al. Eur. Phys. J. C (2016) 76

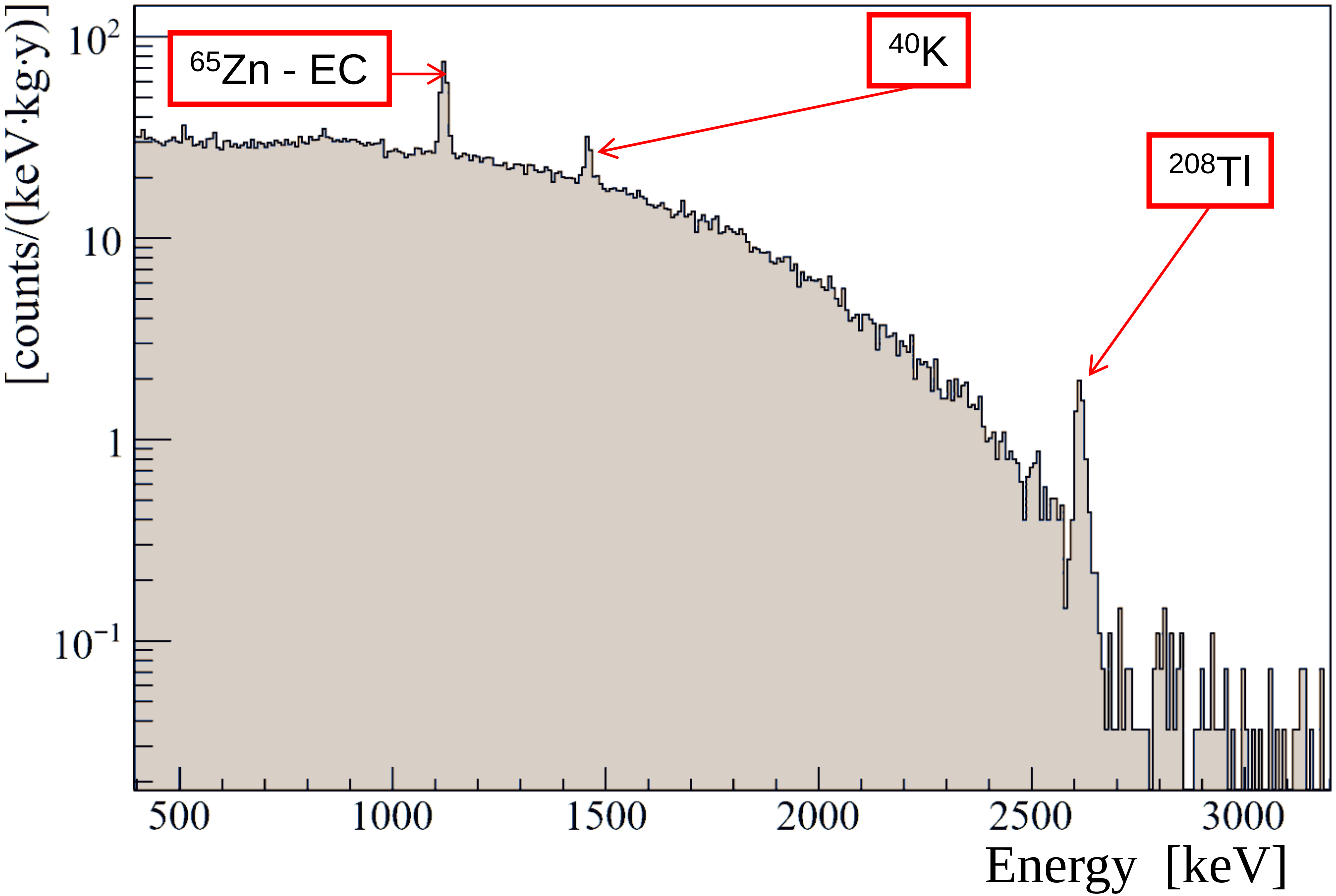
Energy calibration



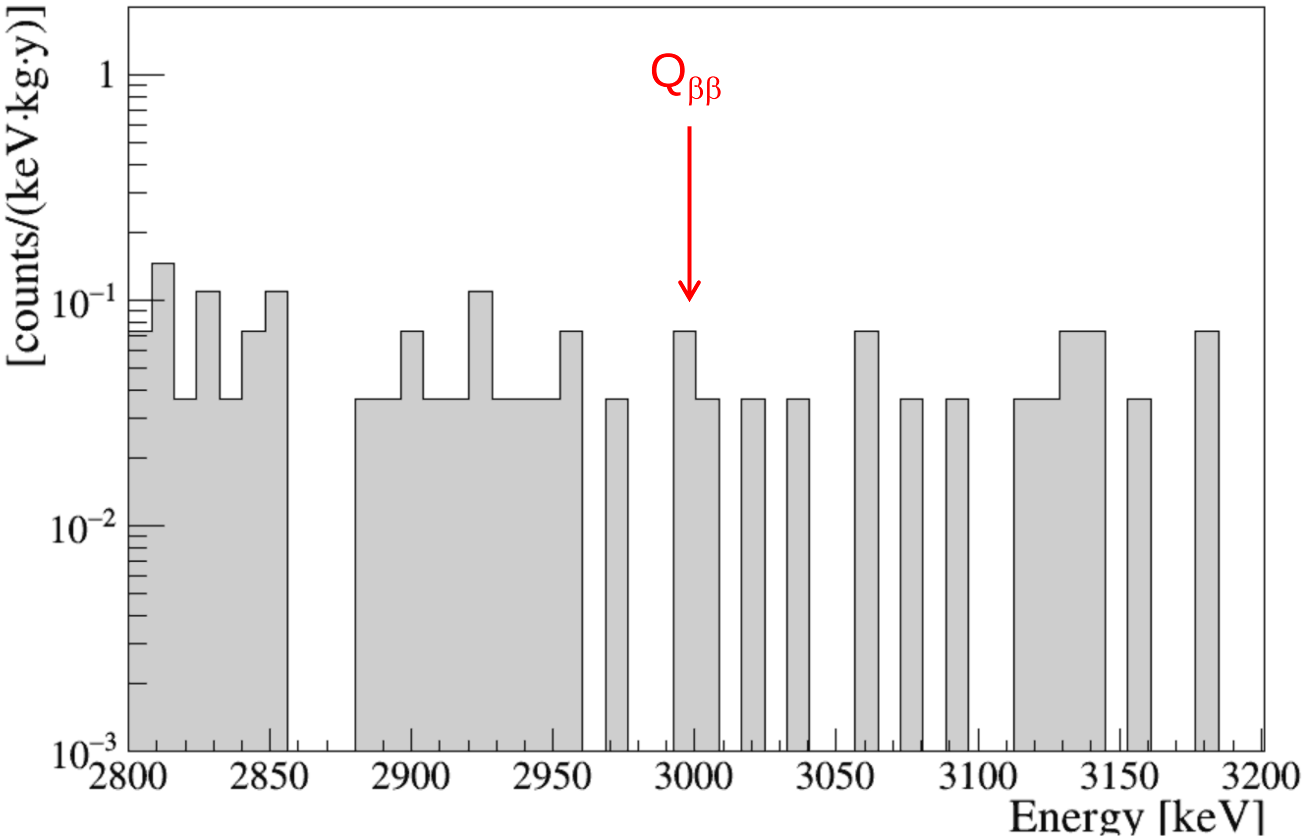


The mean baseline energy resolution of the detector is 3.8 keV. This indicates that the actual energy resolution is dominated by the low crystalline structure of the crystals (position effects).

Total background- 3.44 kg y

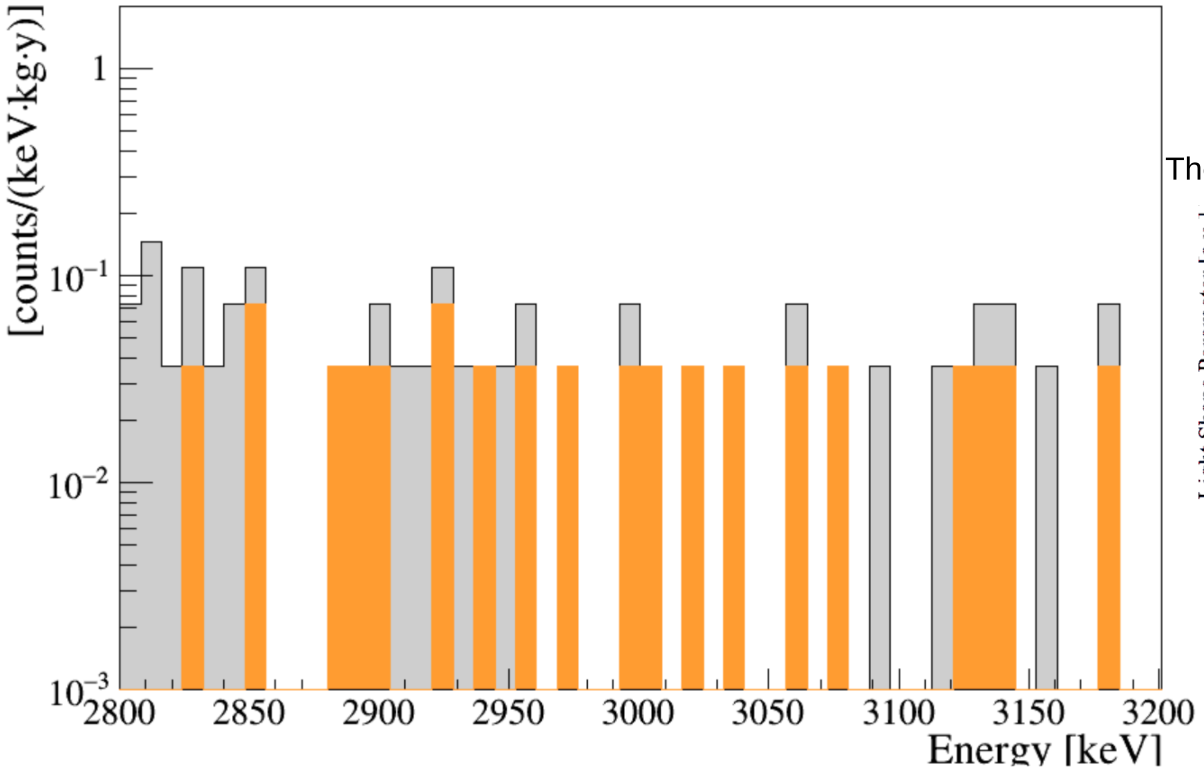


Background in the RoI

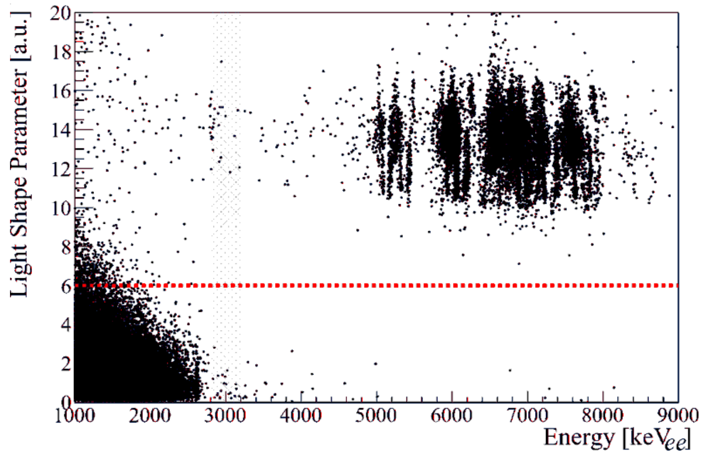


We have chosen a symmetric window (± 200 keV) across $Q_{\beta\beta}$

Background in the RoI (2): PSA

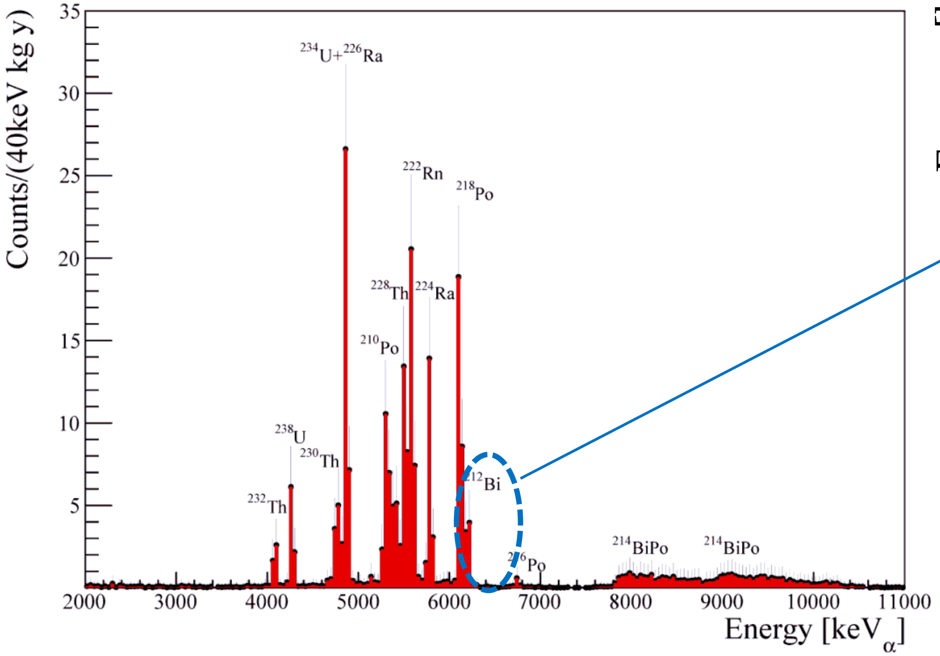


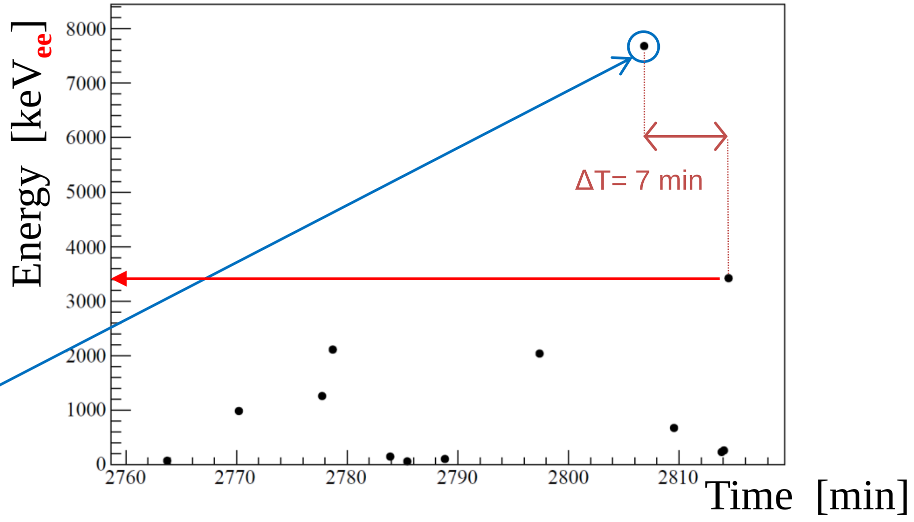
The alpha are recognized thanks to the Light shape



Internal background rejection

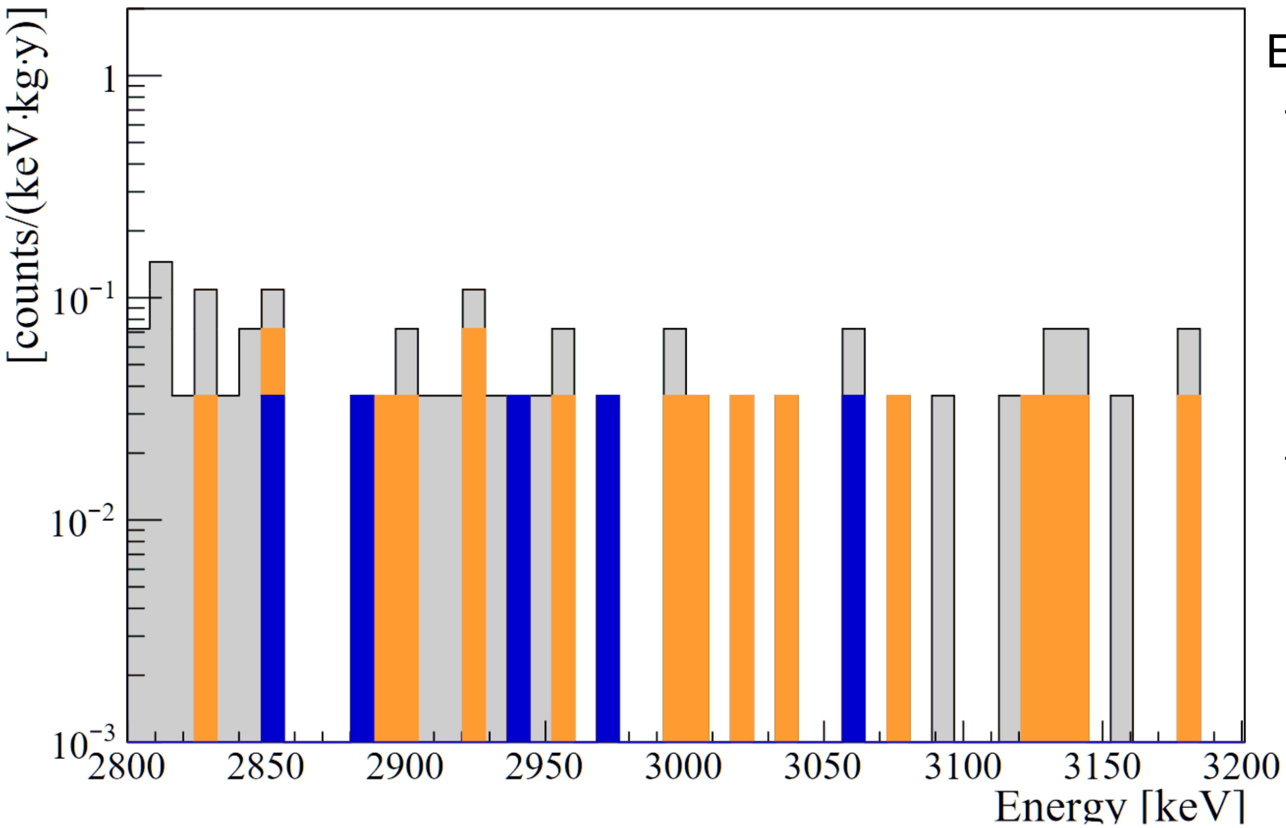
A not negligible background is induced by internal contamination belonging to the ^{232}Th chain, through the decay of ^{208}Tl with Q-Value of 5 MeV. The decay is preceded ($T_{1/2} \cong 3$ min) by the α-decay of ^{212}Bi, Q-value 6.2 MeV.





Alpha **D**elayed **C**oincidence

Background in the RoI (3)



Efficiencies

Trigger **99.44 %**

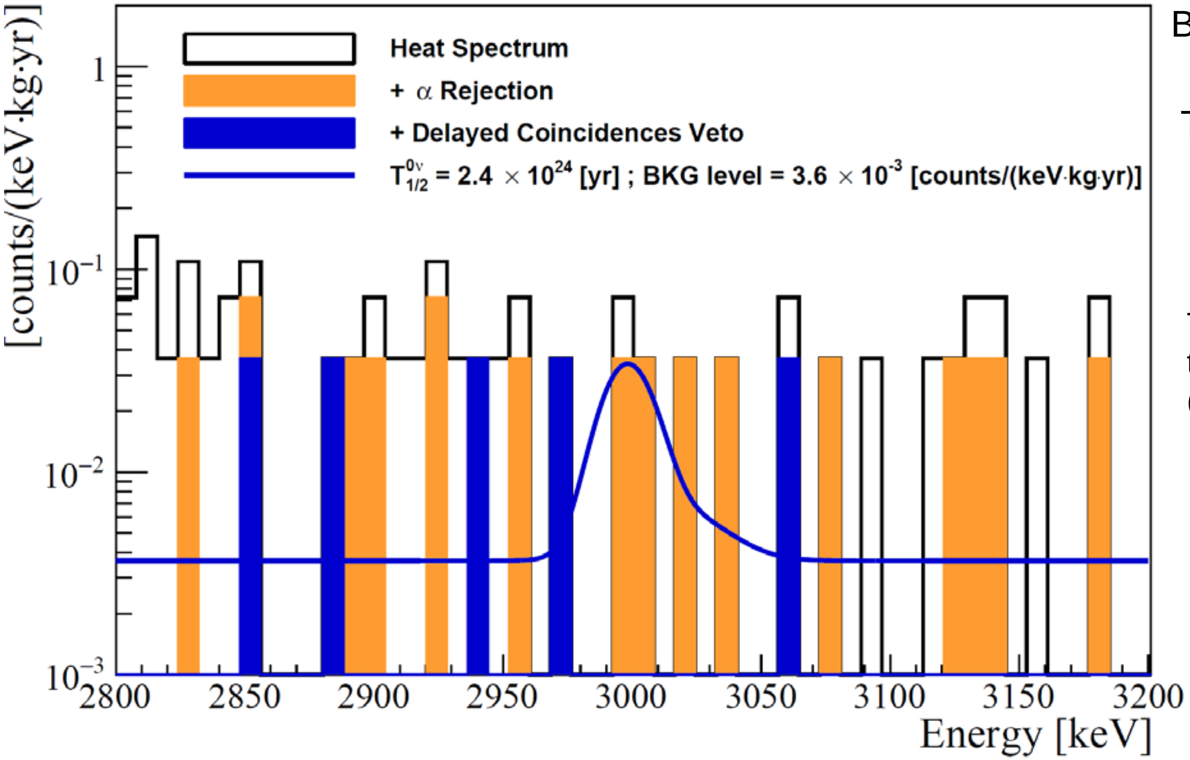
Heat Shape+alpha DC **93±2 %**

Light Shape **100 %**

ββ-containment **81 %**

TOTAL efficiency **75 ± 2 %**

ββ-0ν Results



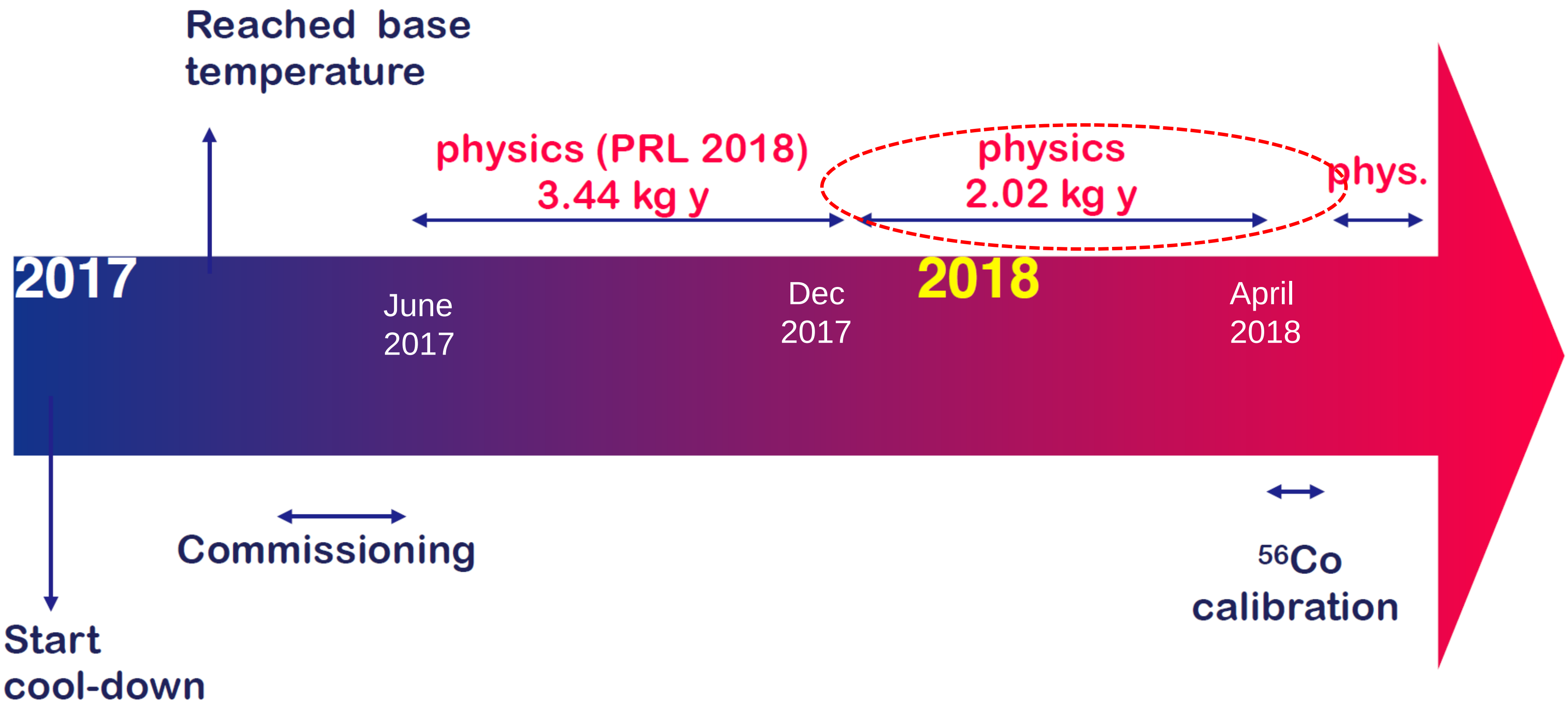
Background Level: 3.6×10^{-3} counts/(keV kg y)

$T_{1/2}(^{82}Se \longrightarrow {}^{82}Kr) >$ **2.4×10^{24}** y (90%C.I.)

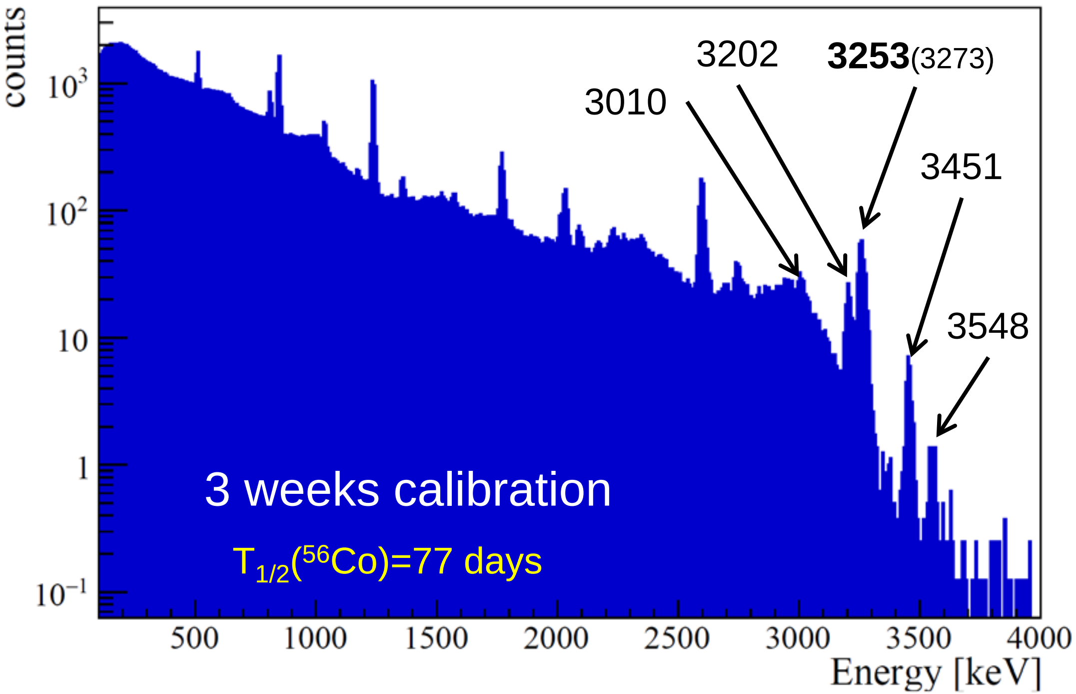
This results overcomes by 1 order of magnitude the results of Nemo recently republished (https://arxiv.org/abs/1806.05553)

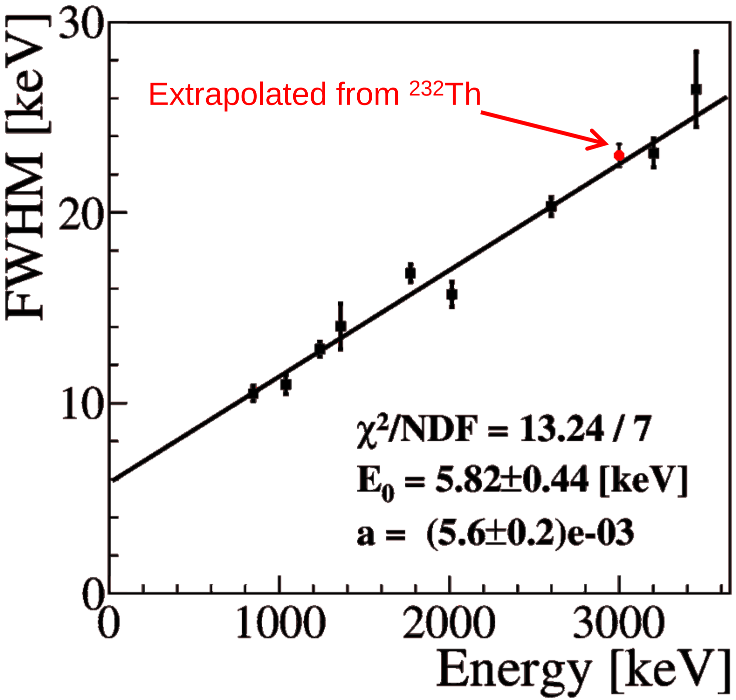
CUPID-0 Analysis paper: https://arxiv.org/abs/1806.02826 *submitted to EPJ-C*

CUPID-0 Timeline



Energy calibration @ $Q_{\beta\beta}$ - ^{56}Co

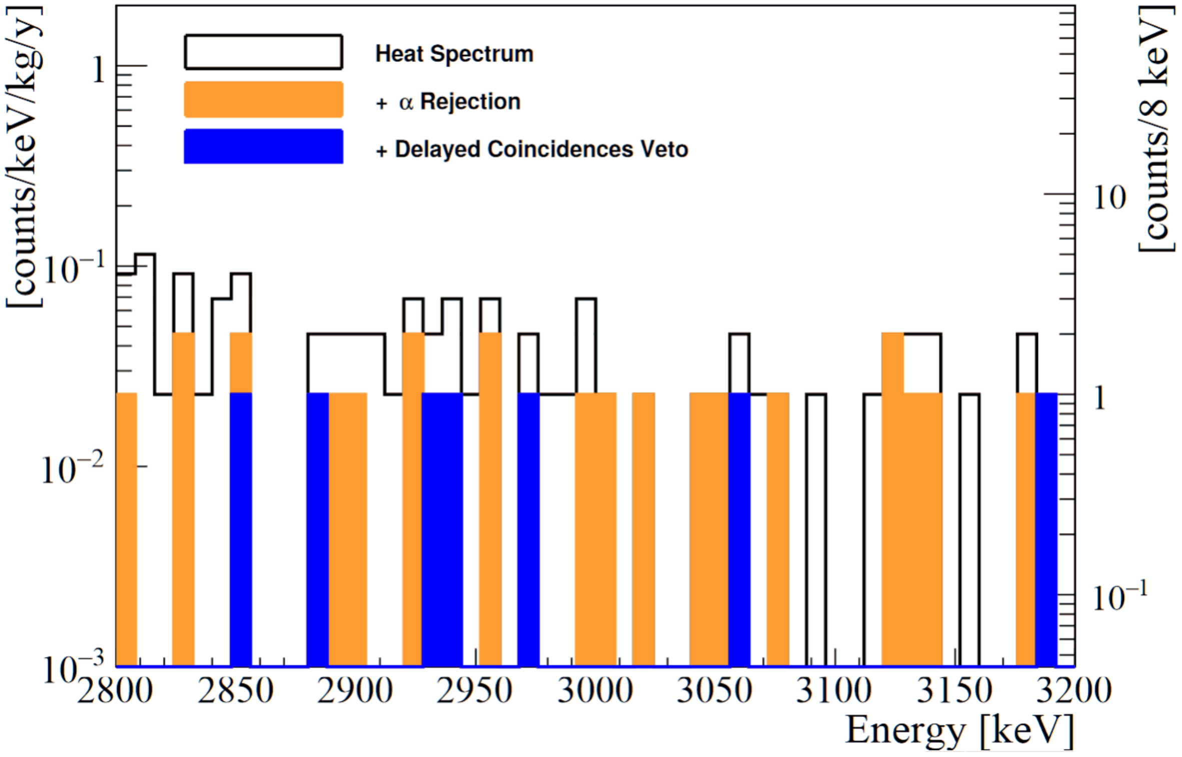




Energy resolution in ROI = (22.5 ± 1.2) keV FWHM, consistent with (23.0 ± 0.6) keV extracted from ^{232}Th calibration, used or PRL analysis. Residuals @ $Q_{\beta\beta}$< 3 keV

New dataset (till April 2018)

Exposure: 3.44 + 2.02 = 5.46 kg x y of ^{82}Se

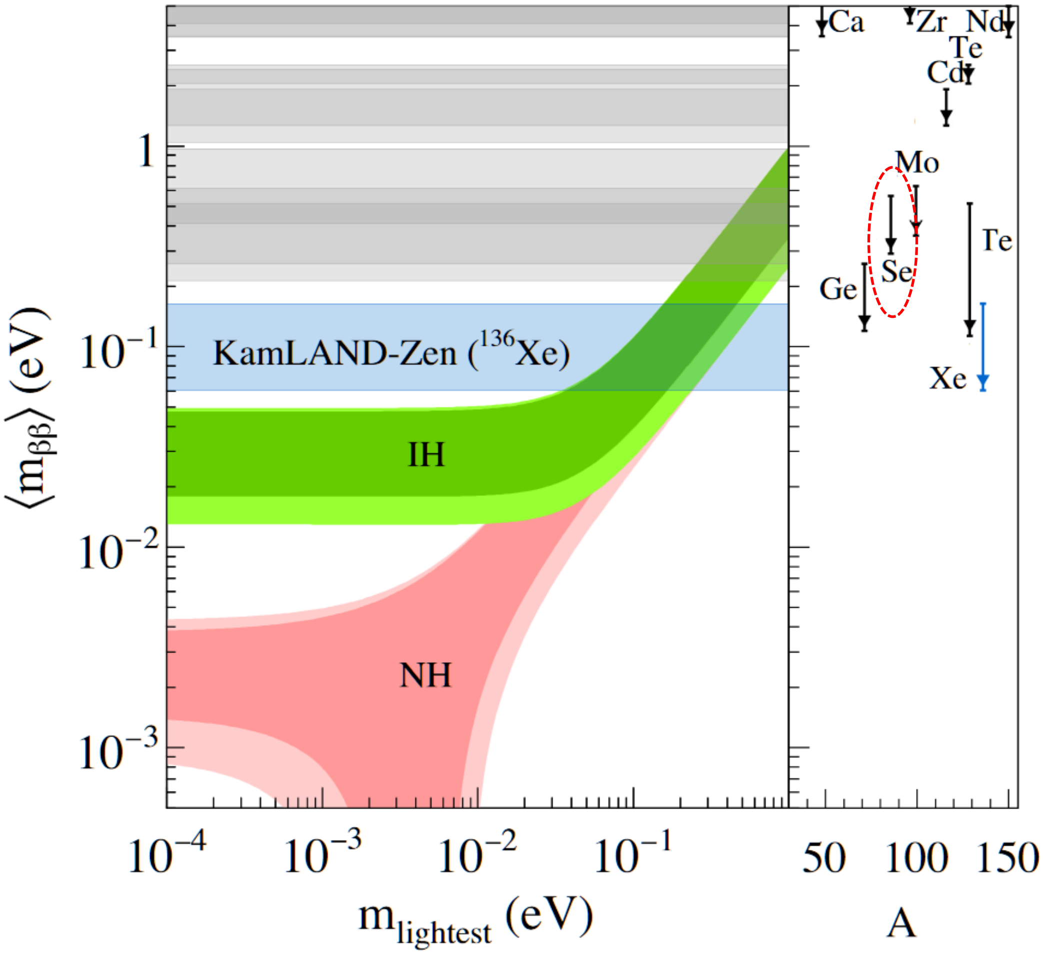


BI: $3.2^{+1.3}_{-1.1}$ x10^{-3} counts/(keV kg y)

$T^{0\nu}_{1/2} >$ **4.0x10^{24}** y (90%C.I.)

$m_{\beta\beta}$ < (292 -596) meV

CUPID-0

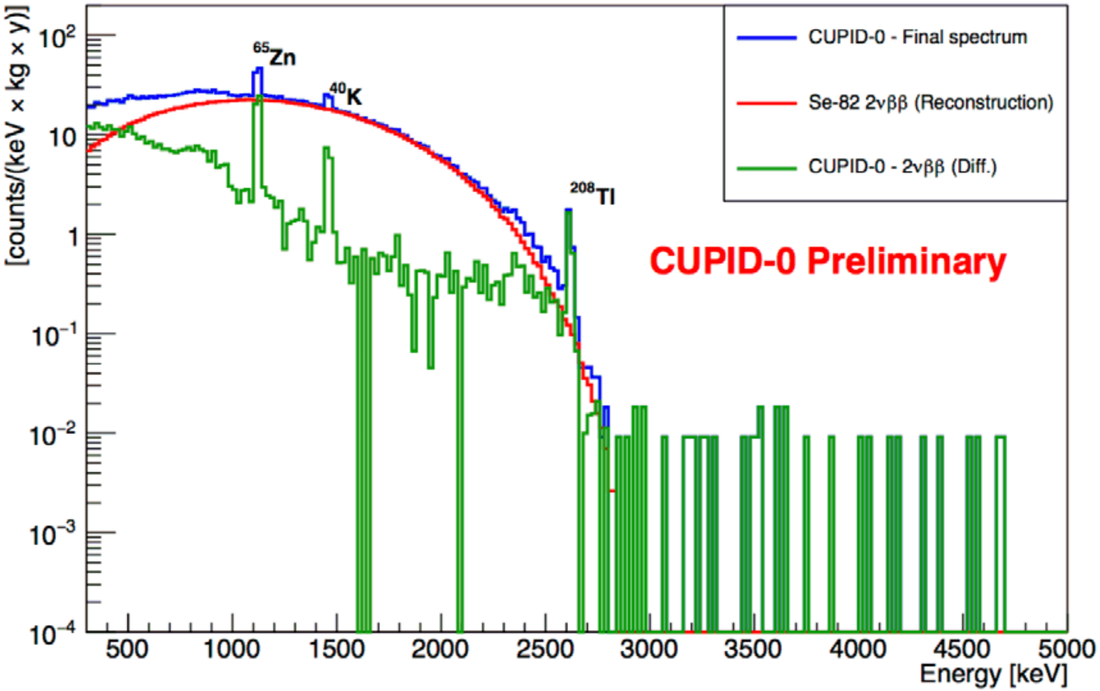


From J. Engel, J Menéndez, Rep. on Prog. in Physics 80, 046301 (2017) arXiv:1610.06548 updated accordingly to

^{76}Ge : ***Phys. Rev. Lett. 120 (2018) 132503***
^{130}Te : ***Phys. Rev. Lett. 120 (2018) 132501***
^{82}Se : previous slide

Excited States, 2ν

Yesterday we submitted the paper on *Search of the neutrino-less double beta decay of ^{82}Se into the excited states of ^{82}Kr with CUPID-0* https://arxiv.org/abs/1807.00665



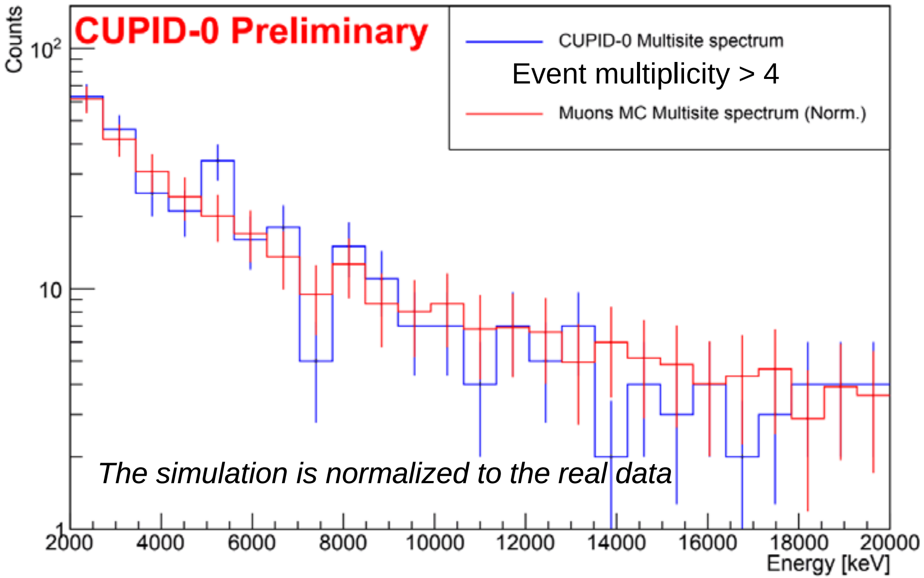
The number of 2ν collected so far is $\approx 2\cdot 10^5$

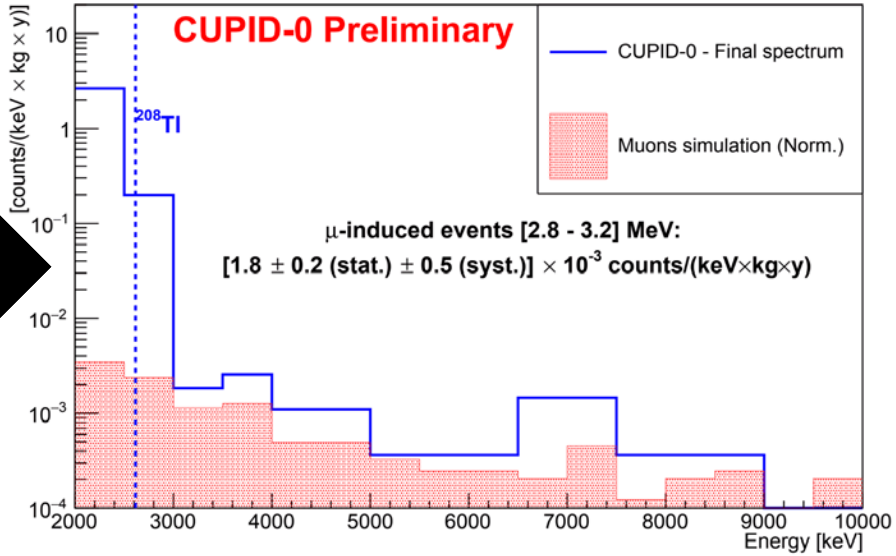
We are still fixing the background model

The main difficulty is the "absence" of peaks (^{232}Th and ^{238}U to perform a very precise background model

Muon induced background - Preliminary

CUPID-0 is not equipped with a μ-veto: most of its induced background can be discriminated through anticoincidence. Nevertheless the residual (single) interaction represents the largest background of CUPID-0 in the RoI. This contribution can be evaluated through MC simulation normalized on the high energy – high multiplicity background data





Half of the background in the RoI could be due to μ

Conclusions

- CUPID-0 demonstrator is working extremely good and with an unprecedented LT
- The BI is extremely small and is only limited by the "old" facility
- in 10 months of operation we increased the previous 0ν limit of ^{82}Se by a factor **15**
- We are evaluating the possibility to mount an additional internal Cu-shield and a μ-veto to further decrease the background
- The goal is to approach 10^{25} y by the end of the next year.
- We are evaluating the possibility to add a enriched Li_2MoO4 tower just below CUPID-0 by the middle of next year

But, more important, CUPID-0 & CUORE represent the definitive proof of principle of **CUPID**