CUPID-0

cryogenic calorimeter with particle identification for double beta decay search

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CUPID

Cuore Upgrade with Particle IDentification

1. arXiv:1504.03612 [pdf, other]
   R&D towards CUPID (CUORE Upgrade with Particle IDentification)
   The CUPID Interest Group
   Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex)

2. arXiv:1504.03599 [pdf, ps, other]
   CUPID: CUORE (Cryogenic Underground Observatory for Rare Events) Upgrade with Particle IDentification
   The CUPID Interest Group
   Subjects: **Instrumentation and Detectors (physics.ins-det)**; High Energy Physics - Experiment (hep-ex); Nuclear Experiment (nucl-ex)

In the middle of 2015 INFN decided to support CUPID activity to develop:

- **CUPID-0: a scintillating bolometer (ZnSe) experiment as small scale demonstrator**
- **Some R&D to optimize cryogenic light detector performances**
- **Collaboration with other research groups were established and under definition**

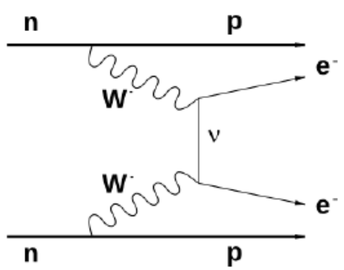
ββ Decay Searches

WHAT WE ARE LOOKING FOR

2νββ: $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$

- allowed in the SM and already observed with $T_{1/2} > 10^{18}$ y

0νββ: $(A,Z) \rightarrow (A,Z+2) + 2e^-$



- not allowed in the SM
- expected with $T_{1/2} > 10^{25}$ y

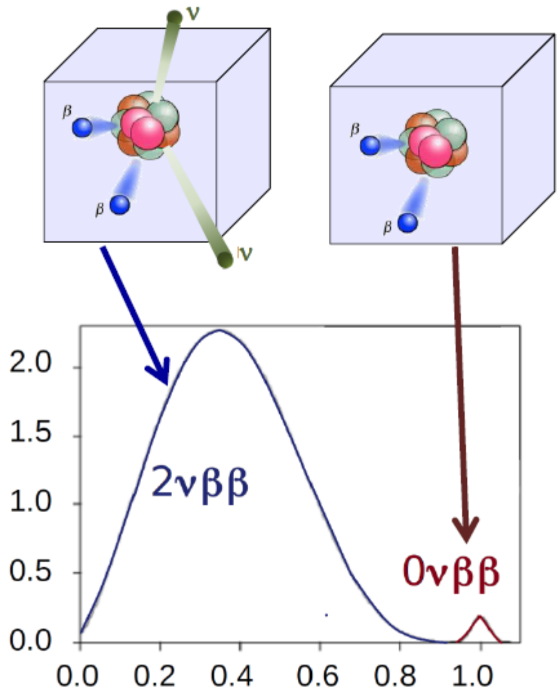
If observed:

- lepton number violation
- neutrinos are Majorana particles
- measures effective electron neutrino mass

$$m_{\beta\beta} \equiv |e^{i\alpha_1}|U_{ei}^2|m_1 + e^{i\alpha_2}|U_{e2}^2|m_2 + |U_{e3}^2|m_3|$$

EXPERIMENTAL SIGNATURE

Approach:
SOURCE = DETECTOR



Main signature:
Peak at Q-value over 2νββ tail enlarged only by detector resolution

EXPERIMENTAL SENSITIVITY

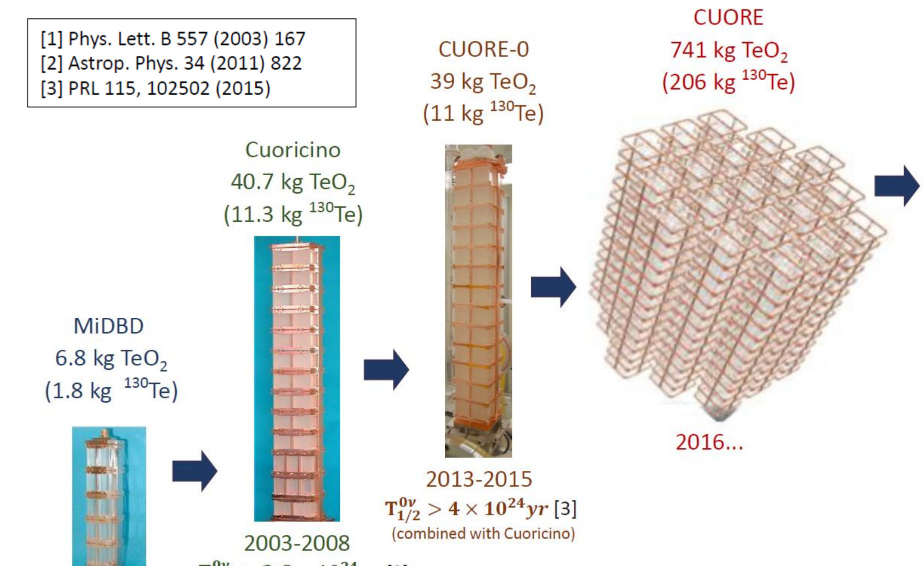
Lifetime corresponding to the minimum detectable number of events over background at a given C.L.:

$$S^{0\nu} \propto \epsilon\, i.a. \sqrt{\frac{MT}{b\Delta E}} \qquad b \neq 0$$

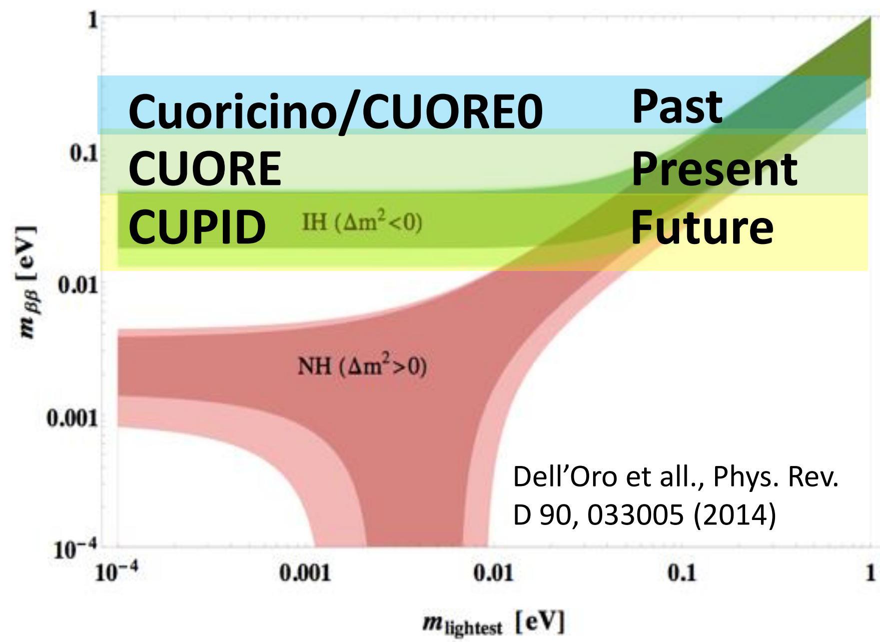
$$S^{0\nu} \propto \epsilon\, i.a. MT \qquad b = 0$$

M: Total active mass in kg
ϵ: Detector efficiency
$i.a.$: Isotopic abundance
b: Background in c/keV/kg/y
ΔE: Detector resolution @ ROI in keV
T: Exposure time in y

Bolometric ββ Decay Experiments (I)



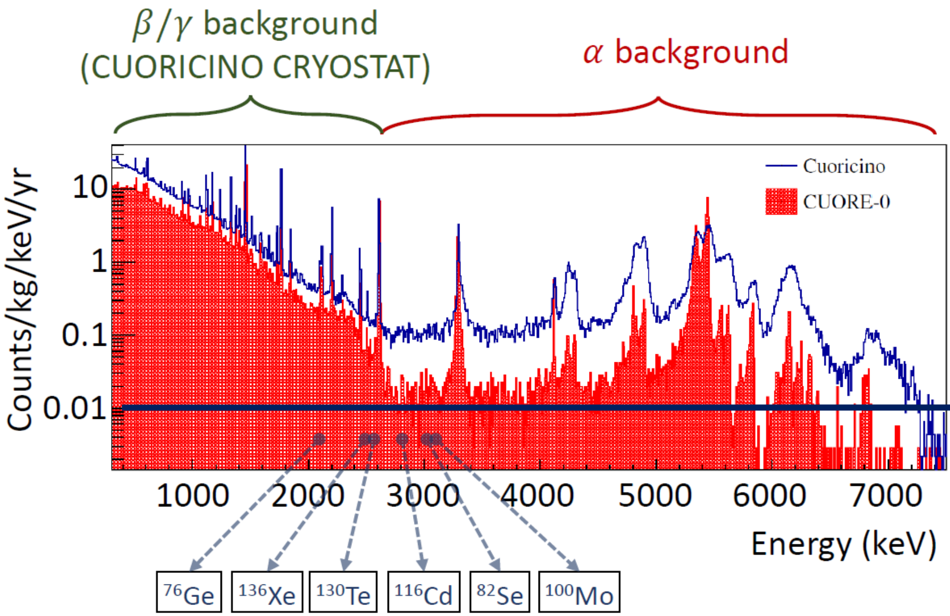
$$T^{0\nu}_{1/2} \propto 1/{m_{\beta\beta}}^2$$



To improve the sensitivity it is necessary to reduce the experimental background.

- Estimated background for **CUORE ≈ 10^{-2} counts/(keV kg year)**
- Designed background for **CUPID ≈ 10^{-4} counts/(keV kg year)**

Bolometric ββ Decay Experiments (II)



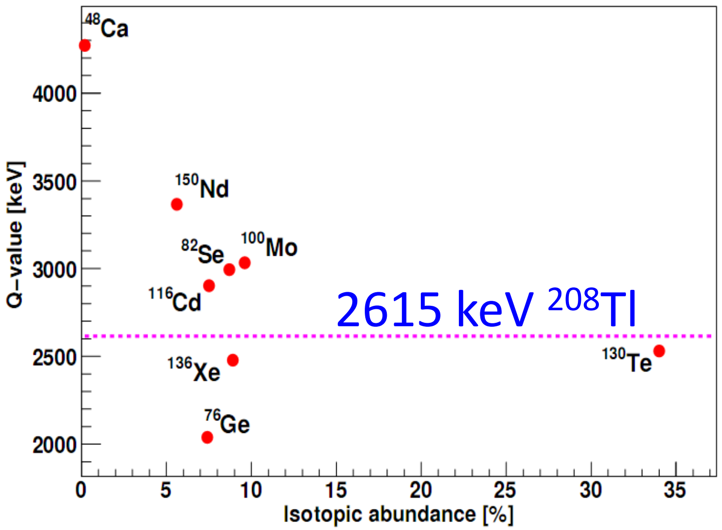
To reduce experimental background

α/β discrimination is needed

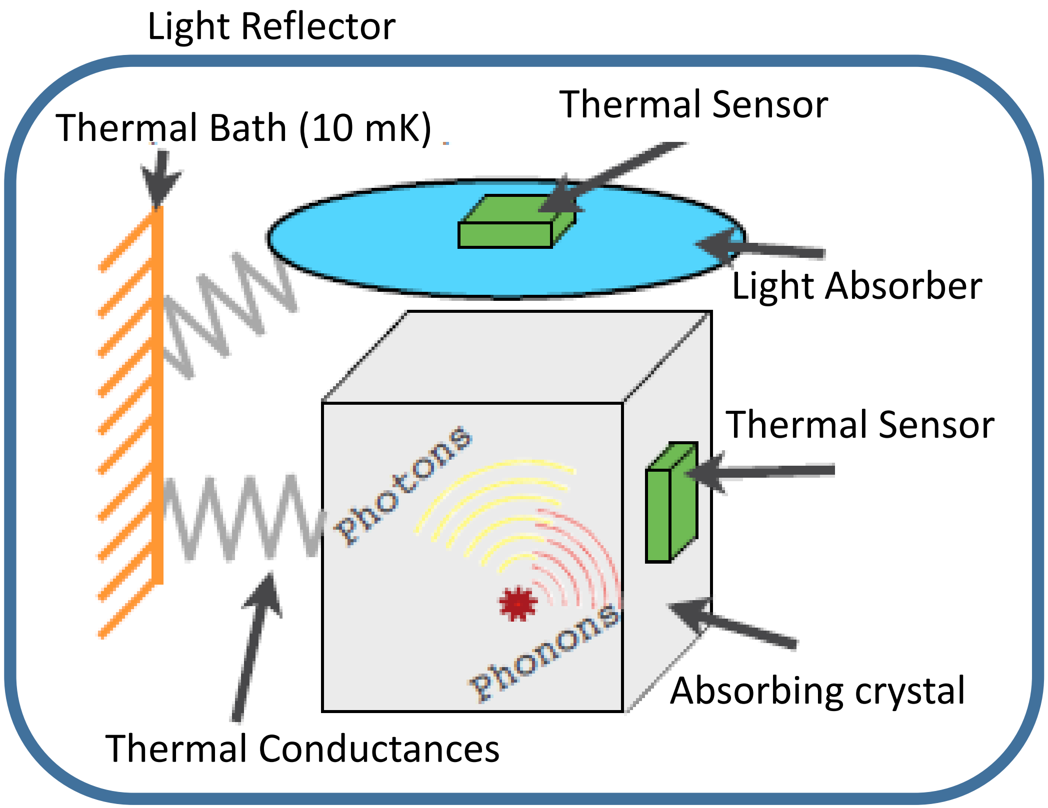
Energy-degraded alpha background

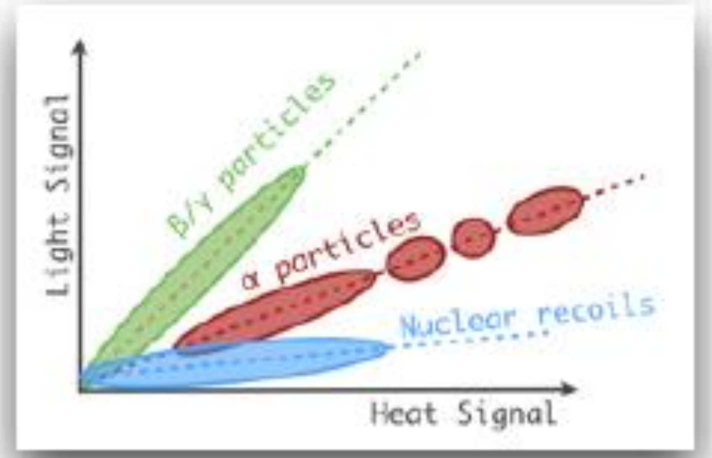
A careful selection of the ββ isotopes

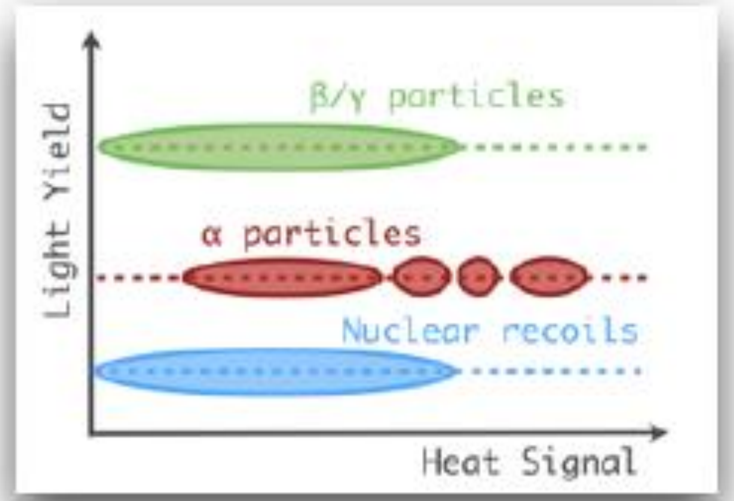
Help in reducing β/γ background
But isotope enrichment is needed



Scintillating Bolometers







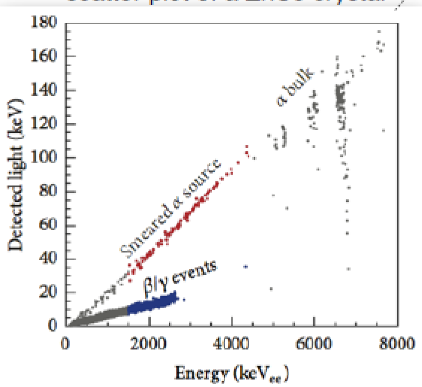
Simultaneous read-out of Photons and Phonons

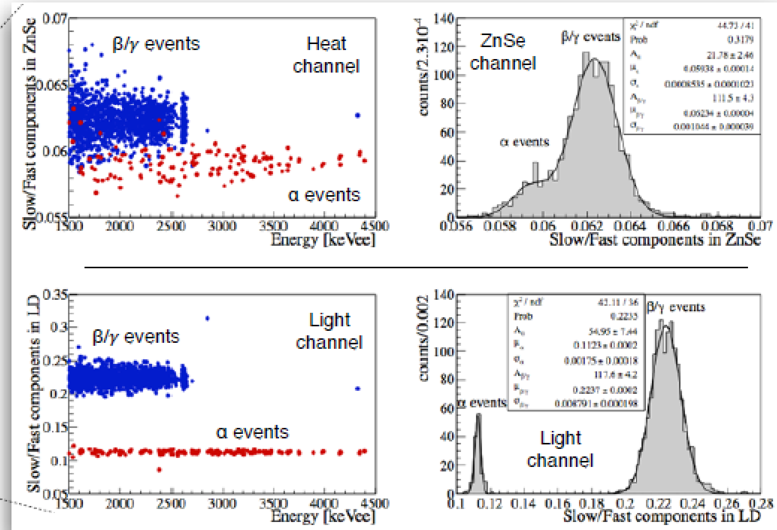
High energy resolution: **as bolometer**
High discrimination capability: **as scintillator**

ZnSe Scintillating Bolometers

Particle identification using Pulse Shape Parameters (decay time)

Calibration Light VS Heat scatter plot of a ZnSe crystal





For CUPID-0 experiment

^{82}Se enriched @URENCO(96%)

Enriched powder activity (HP-Ge)	
Isotope	Upper limit 90% CL (μBq/kg)
^{232}Th	<61
^{238}U	<110
^{235}U	<74

Discrimination potential @ ROI:

$$DP(E) = \frac{|\mu_\alpha(E) - \mu_{\beta\gamma}(E)|}{\sqrt{\sigma_\alpha^2(E) + \sigma_{\beta\gamma}^2(E)}}$$

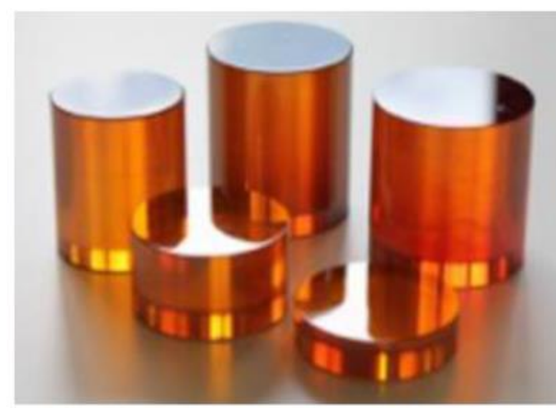
Heat channel
DP@ROI = 2

Light channel
DP@ROI = 11

Full rejection of α events shapeHEAT+shapeLIGHT+light

Zn^{82}Se grew @ISMA (Ukraine)

Final enrichment 95% in ^{82}Se



ZnSe crystals show:

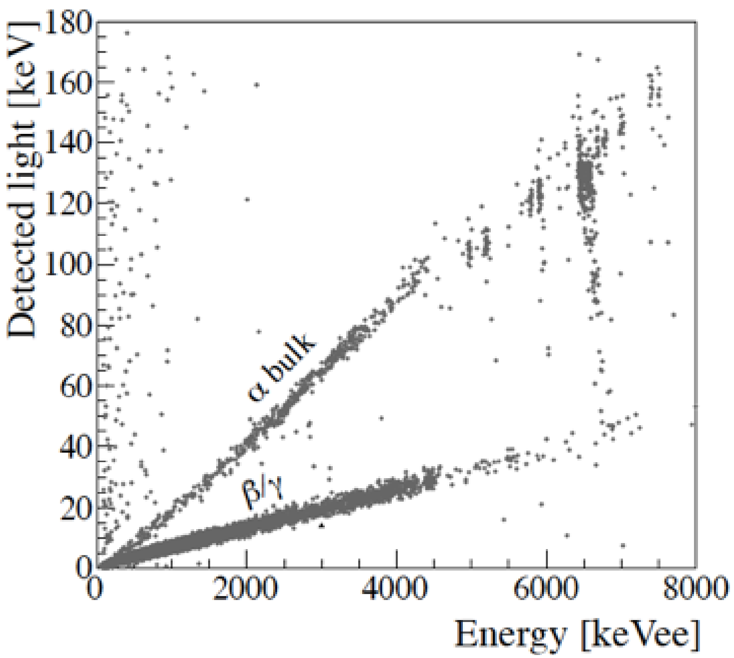
- Excellent light/heat discrimination - **α scintillates more then β**
- Excellent pulse shape discrimination - **especially on light signal**

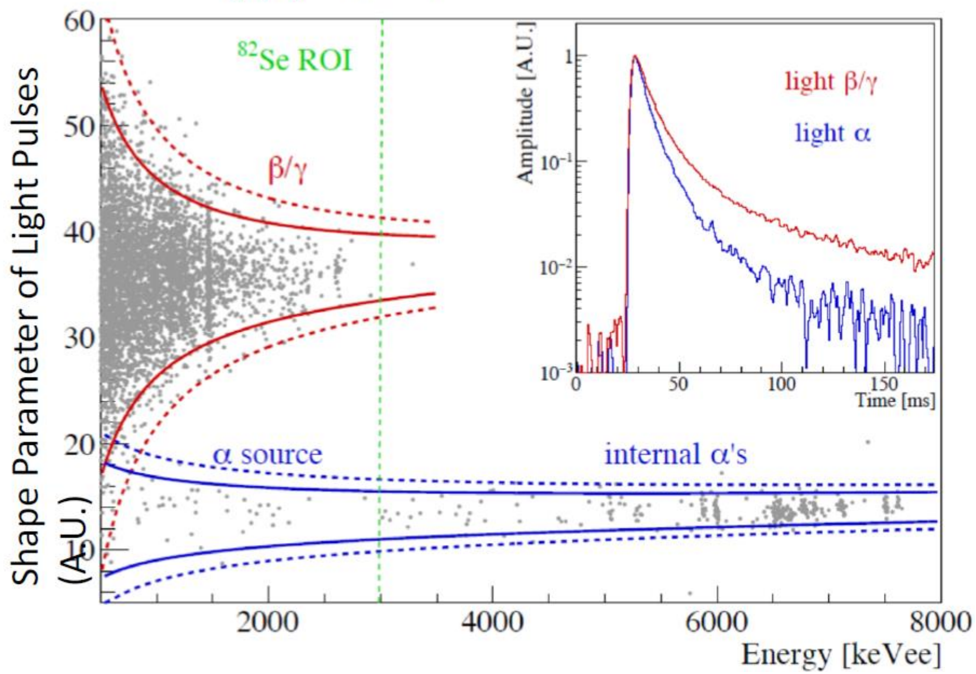
$Zn^{82}Se$ Crystal Characterization

A cryogenic measurement with **3 $Zn^{82}Se$ crystals** was performed in 2016

$Zn^{82}Se$ bolometers work properly
$Zn^{82}Se$ crystals show similar performances
Ge light detectors work very well

To discriminate α respect to β/γ:
- Cuts on light **signal amplitudes**
- Cuts on light **signal shapes**





Excellent discrimination potential was measured for $Zn^{82}Se$ bolometers as for ZnSe

$Zn^{82}Se$ Crystal Background

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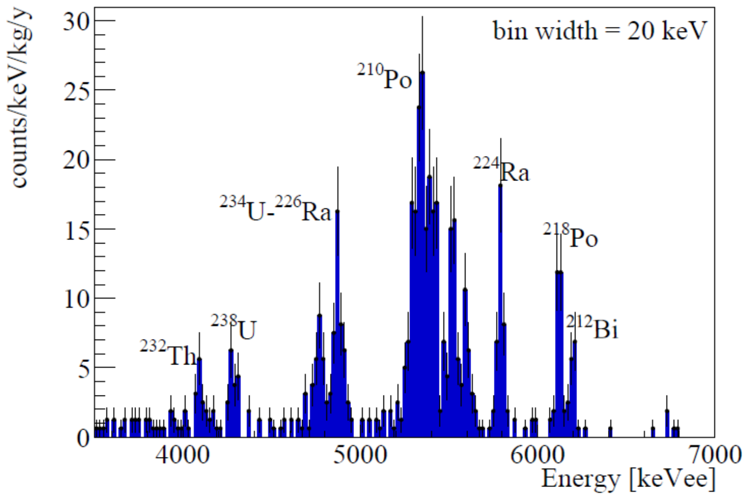


	$Zn^{82}Se$-1 [μBq/kg]	$Zn^{82}Se$-2 [μBq/kg]	$Zn^{82}Se$-3 [μBq/kg]	Array [μBq/kg]
^{232}**Th**	13 ± 4	13 ± 4	<5	7 ± 2
^{228}**Th**	32 ± 7	30 ± 6	22 ± 4	26 ± 2
^{224}Ra	29 ± 6	26 ± 5	23 ± 5	27 ± 3
^{212}Bi	31 ± 6	31 ± 6	23 ± 5	29 ± 3
^{238}**U**	17 ± 4	20 ± 5	<10	10 ± 2
^{234}**U**+^{226}**Ra**	42 ± 7	30 ± 6	23 ± 5	33 ± 4
^{230}**Th**	18 ± 5	19 ± 5	17 ± 4	18 ± 3
^{218}Po	20 ± 5	24 ± 5	21 ± 5	21 ± 2
^{210}**Pb**	100 ± 11	250 ± 17	100 ± 12	150 ± 8

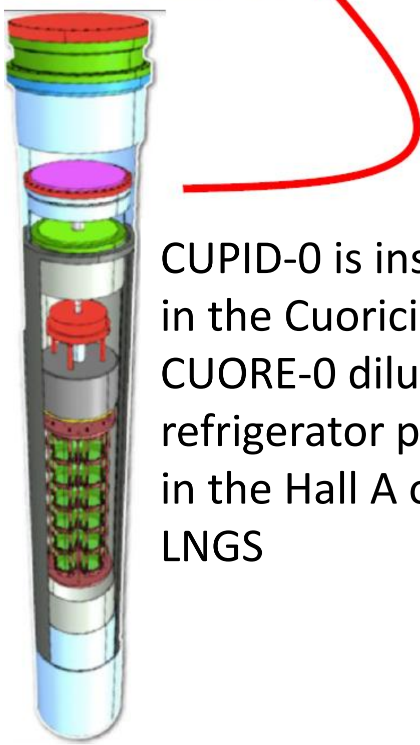
Background test measurement: **530 h live time**

Considerations on α background spectrum:

- **U and Th chains** practically @ equilibrium
- Energies of α peaks indicate **internal contamination**
- **^{210}Po seems to be on surfaces** (5.3/5.4 MeV peaks)
- Contribution outside the peaks seems not critical

All $Zn^{82}Se$ crystals show comparable contamination

CUPID-0 Experiment



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

$Q_{\beta\beta}(^{82}Se)$ = 2996 keV

Light detectors high purity Ge wafers with antireflecting coating

Thermal sensors made with NTD thermistors

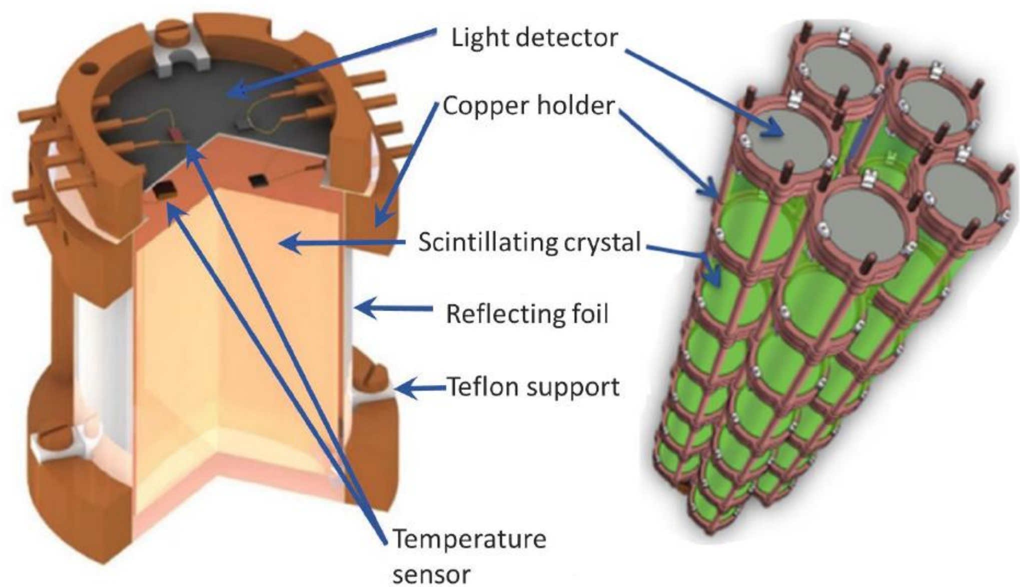
Detector assembled in 5 towers in Cuoricino/CUORE-0 cryostat

Total active **mass of the detector ~10.5 kg**

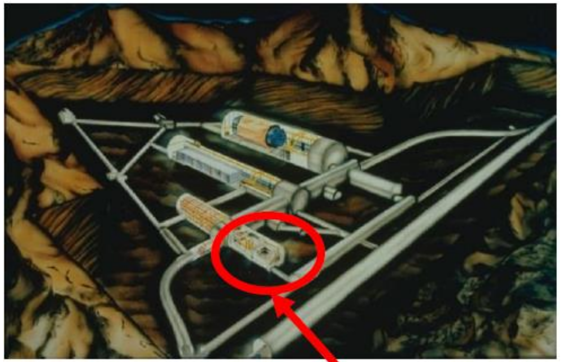
Expected background @ ROI 10^{-3} count/(keV kg year)

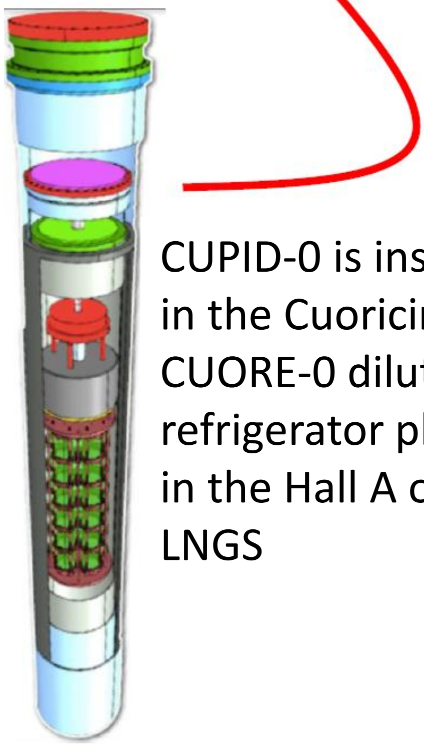
Expected FWHM energy resolution @ ROI 20 keV

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



CUPID-0 Experiment





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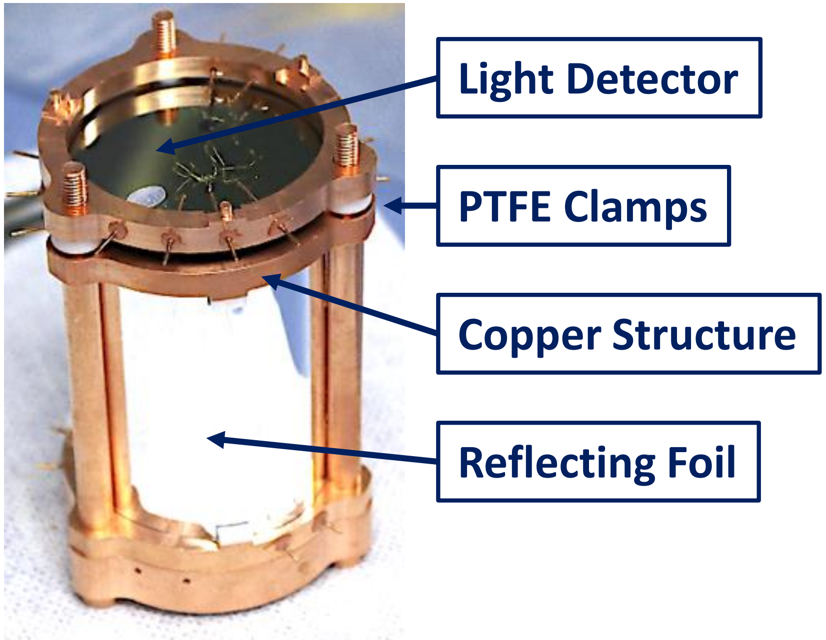
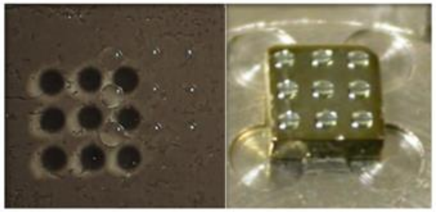
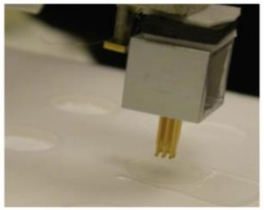
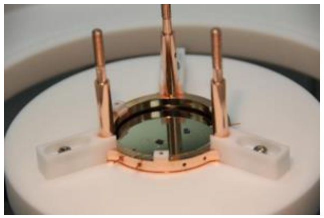


CUPID-0 Assembly



Gluing





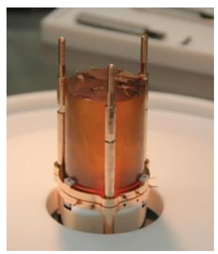
1st LD installation

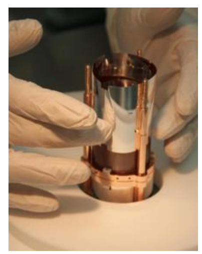
During last part of 2016

Step

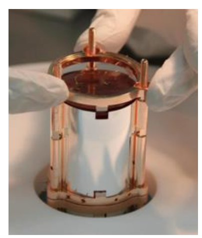
by

Step

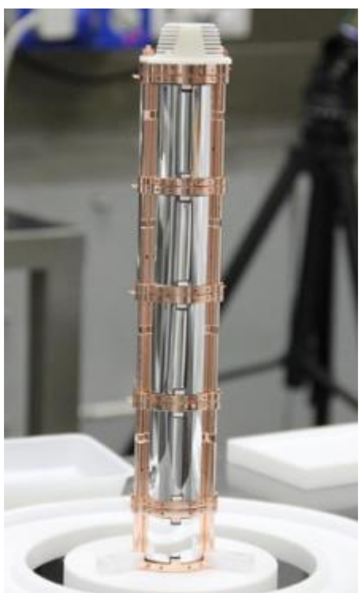




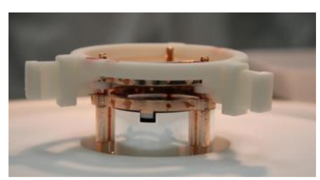
Reflecting foil installation



ZnSe crystal fixed

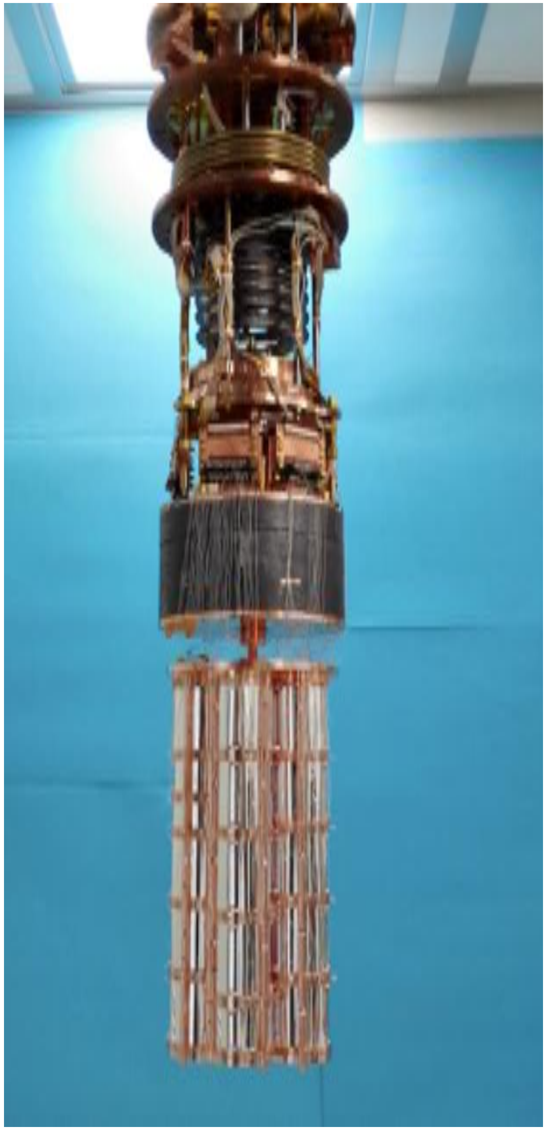


Tower Completed



2nd LD installation

CUPID-0 Installation



CUPID-0 detector is installed in **the former Cuoricino/CUORE0 dilution refrigerator** inside Hall A of LNGS Underground Labs

Some upgrades were done on cryogenic system:

- **New double pendulum system** to reduce vibrational noise
- Upgrade of the **radon abatement system to reduce ^{214}Bi**
- **New cryostat wiring** to measure up to 120 detectors

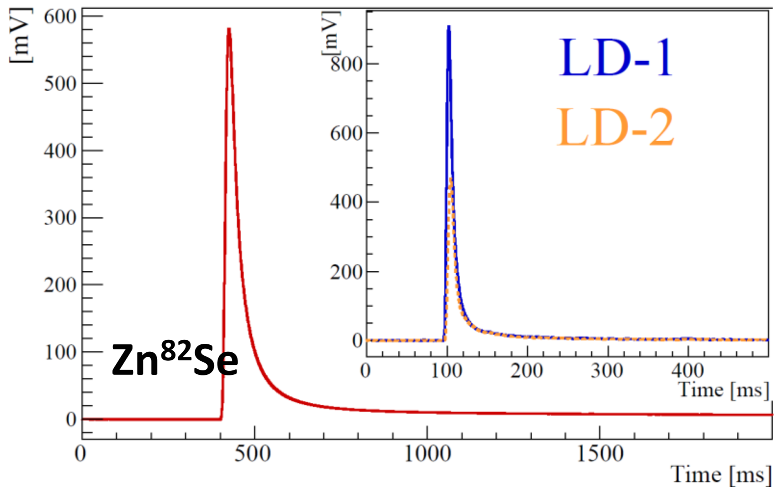
However we cannot change the thermal shields!!!

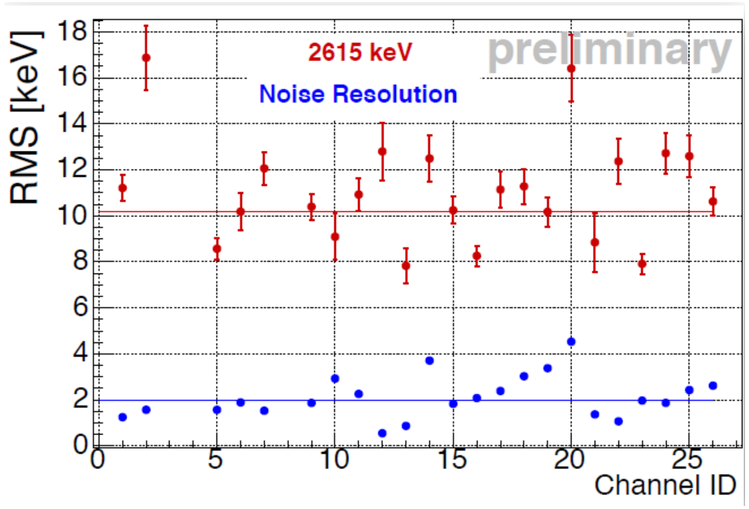
Beginning of 2017 detector commissioning phase start

- Optimization of detector performances
- Calibration of alpha and beta scales
- Analysis of the discrimination capabilities

End of March 2017 the commissioning phase was finalized and the experimental **data taking has started**

CUPID-0 Characterization





All ZnSe and light detectors work correctly

Excellent scintillating performances

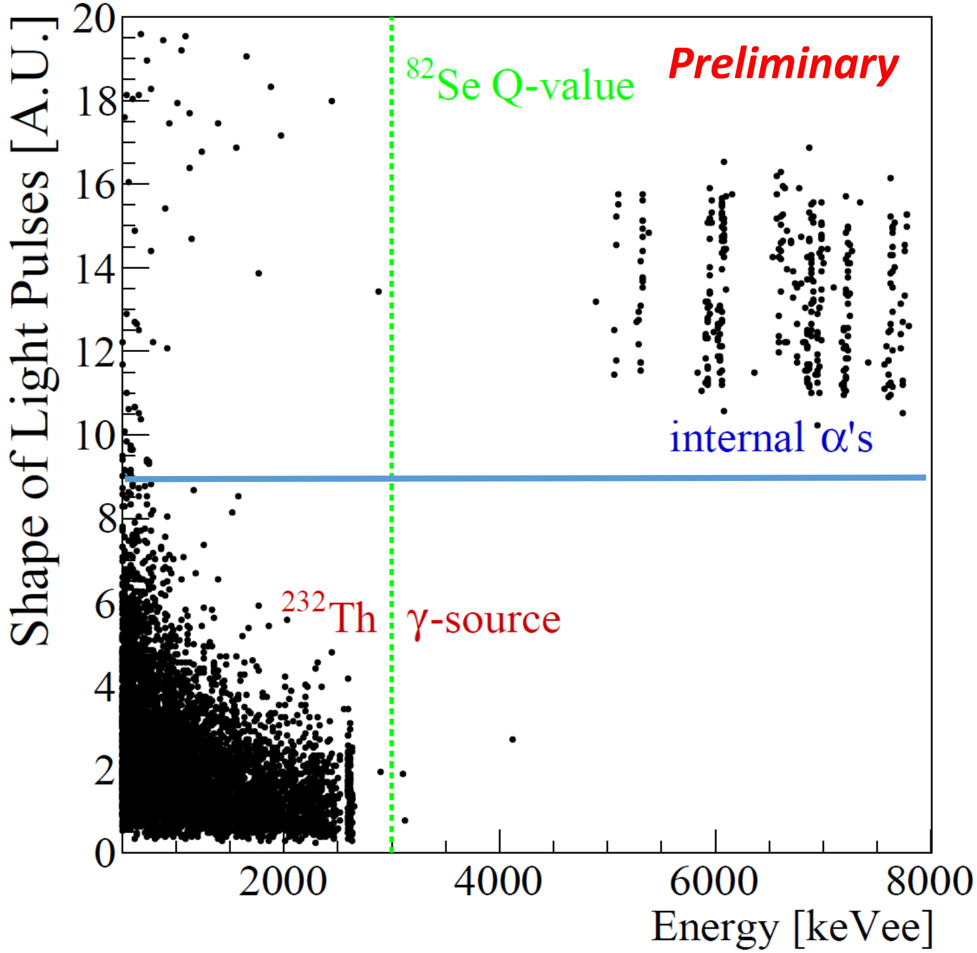
Very low noise for light and heat channels

But

Energy resolution **on heat channels** not optimal
Average **FWHM @ 2.6** MeV around **25 keV**
Main contribution comes **from crystal quality**

There are room for improvements

α/β Discrimination



Two methods can be applied:

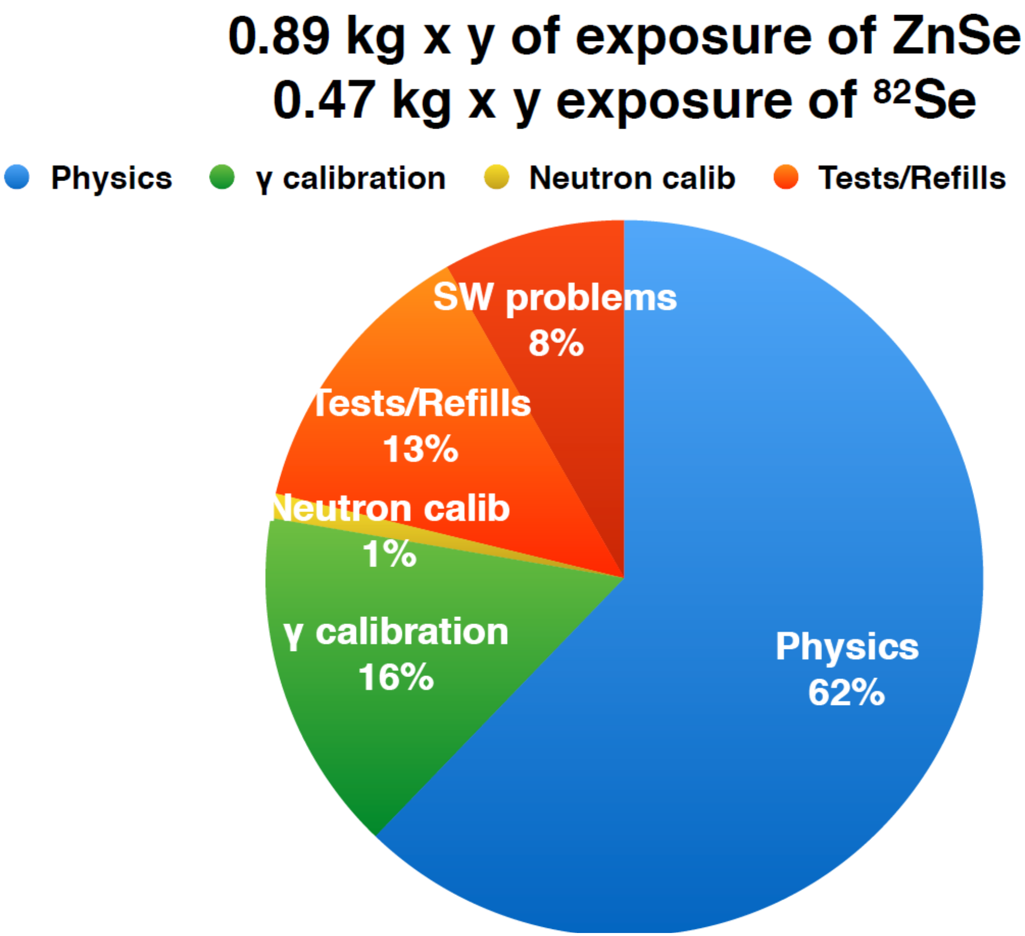
- Light signal shapes
- Light vs heat signal

α/β Discrimination Potential is high

Looking to light signal shape analysis no overlap between α and β signal characteristics was observed

Optimization of the DP is ongoing

CUPID-0 Data Taking

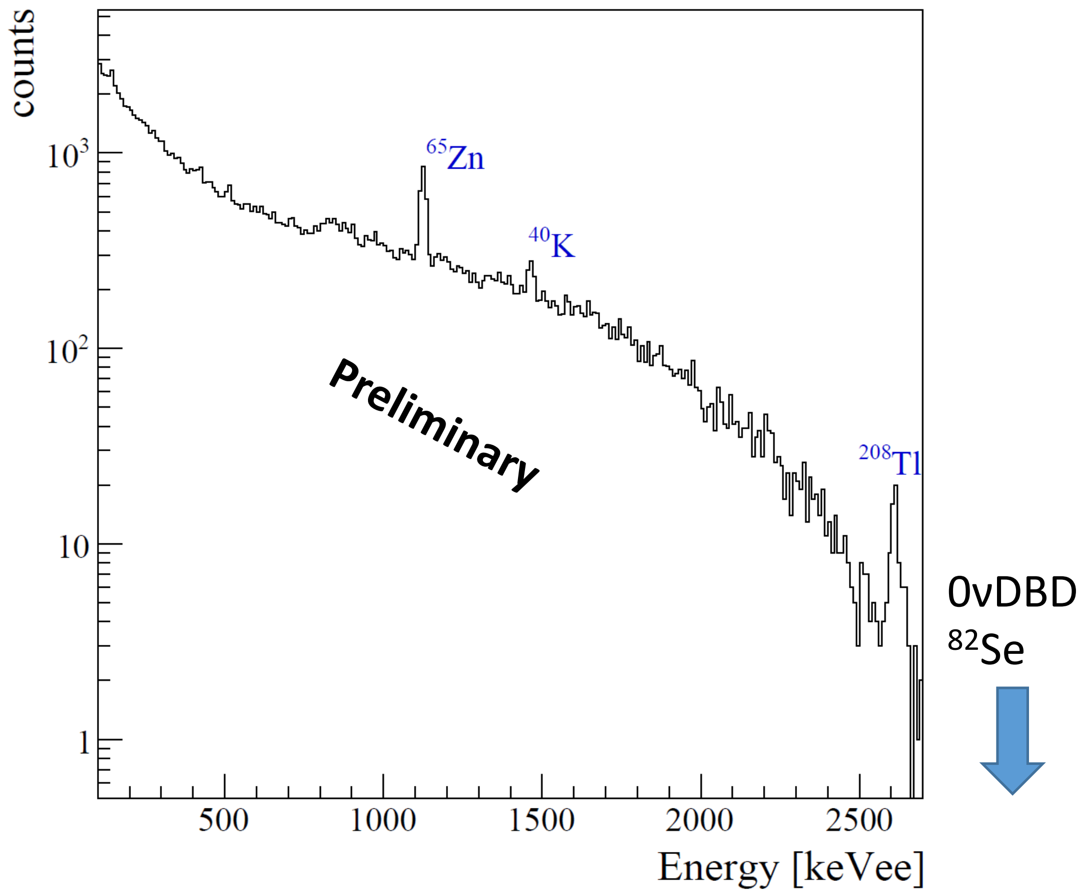


The first phase of CUPID-0 data taking is on going reasonably well

Some critical problems were solved

We plan to increase the Physics running time **to more then 70%** of the measurement time

CUPID-0 Background



Background energy spectrum
Relevant contributions come from:

- ^{65}Zn **activation of crystals**
- ^{40}K from **experimental setup**
- ^{208}Tl from the **dilution refrigerator**
- **2vDBD ^{82}Se**

Data analysis is ongoing

Data on background in the ROI will be presented soon

Sensitivity of CUPID-0

Based on **our MC simulation model of the CUPID-0 detector** and assuming:

- Energy resolution **= 30 keV FWHM**
- Discrimination potential **= 12**
- Measured contamination as **crystal internal background**

It is possible to evaluate the **expected background in the ROI** of ^{82}Se 0νββ decay

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Background at ^{82}Se $Q_{\beta\beta}$ (counts/keV/kg/y)	
after α discrimination	4×10^{-3}
coincidences rejection	2.3×10^{-3}
^{208}Tl – ^{212}Bi time delay rejection	1×10^{-3}
+ cryostat γ contamination	$< 1.5 \times 10^{-3}$

↓

$T_{1/2}$ (0νββ ^{82}Se) = 7 x 10^{24} years (90% cl) (x 1 year data taking, 0 background approx.)

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Conclusions

- **The installation and the commissioning** of CUPID-0 **are completed**
- All the bolometers are working properly
- Preliminary tests of $Zn^{82}Se$ detector tower **show good performances**
- Energy resolution is limited by **the quality of the $Zn^{82}Se$ crystals**
- Very **high discrimination potential for α background** rejection is shown
- Data taking is ongoing
- First **background** and **0νDBD ^{82}Se** result will be presented soon