Cuore Upgrade with Particle IDentification

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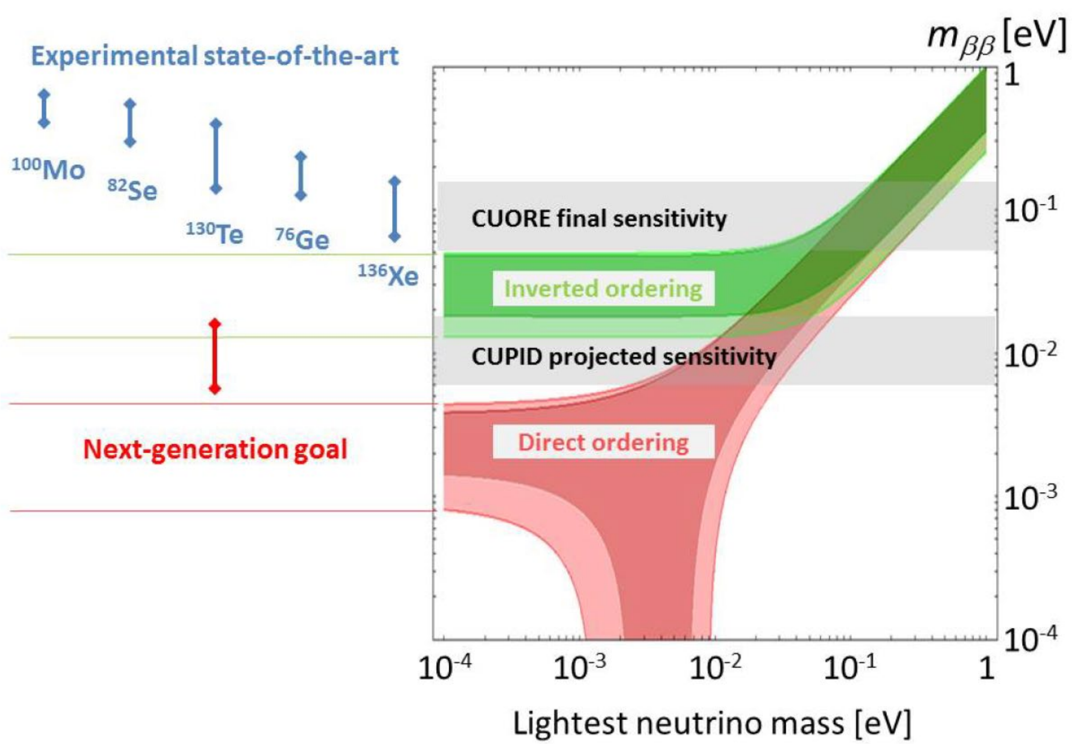
IBS-INFN joint meeting on underground physics, LNGS 30 May 2019

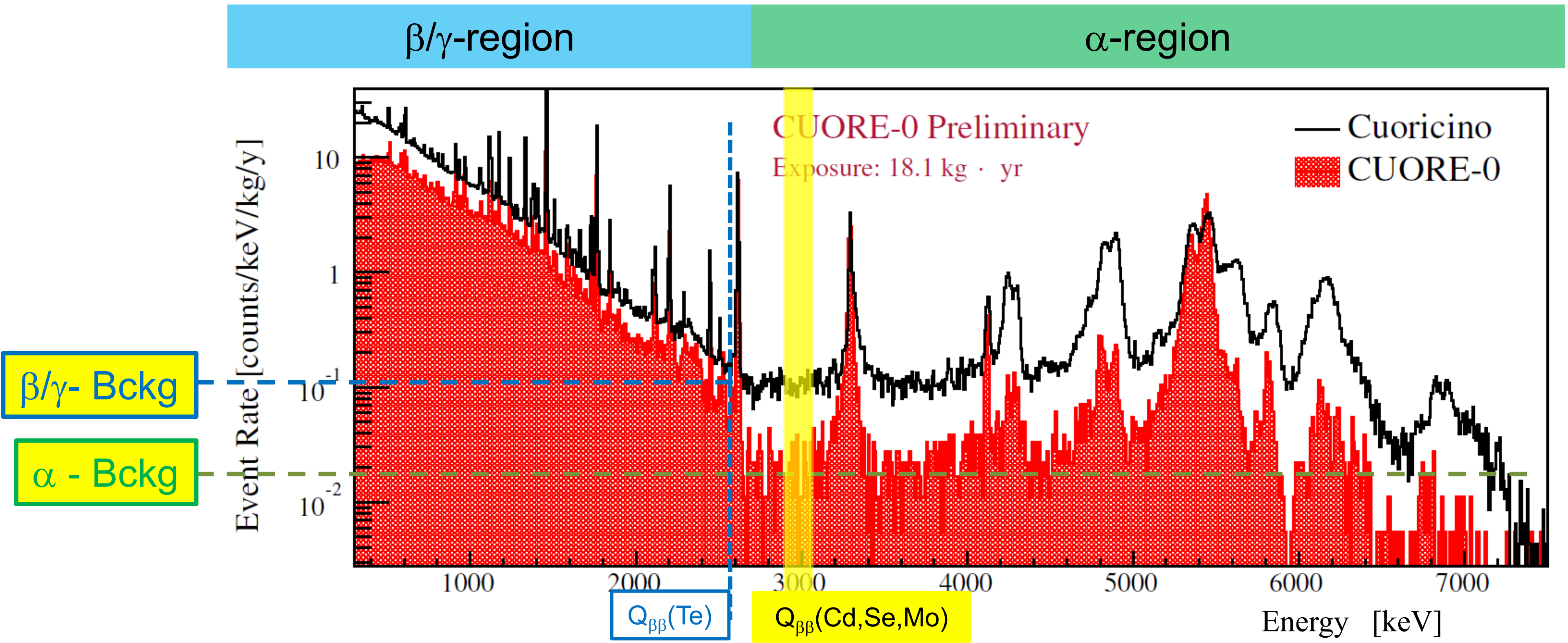
Scientific Objective

CUPID is a proposed bolometric 0ν-DBD program which aims at a sensitivity to the effective Majorana neutrino mass of the order of 10 meV. This level of sensitivity corresponds to the a lifetime of $\sim 10^{27}$ years, depending on the isotope.
This primary objective poses a set of technical challenges:

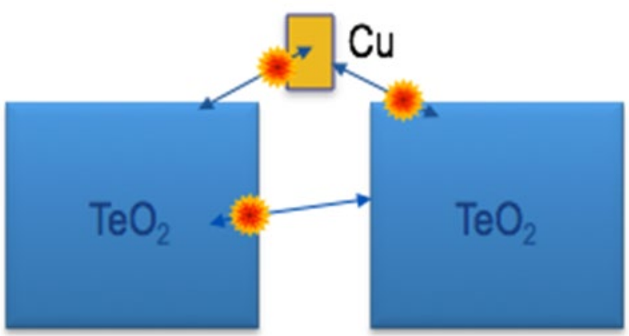
- *the sensitive detector mass must be in the range of several hundred kg to a ton of the isotope*
- *the background must be close to zero at the ton x year exposure scale.*



α-background: the bottleneck for DBD with bolometers



α-induced background reduced by a factor 6 with respect to CUORICINO, but still dominant for CUORE



Fully sensitive up to the surface, no α vs β/γ discrimination in the TeO_2 heat channel

Dominant Background :
energy-degraded αs from surfaces

CUPID

CUORE ***U***pgrade with ***P***article ***ID***entification represents a new world-wide interest group (133 Signers) aiming at constructing a future ton-scale bolometric neutrinoless double beta decay experiment, based on the experience, expertise and lessons learned in CUORE.
The CUPID goal is the use of the ***unique*** CUORE infrastructure @ LNGS, once CUORE completes operation

This requires major upgrades focused on the detector technology :

- ***New detector technologies (α-background or surface event ID)***
- ***Isotopic enrichment***

As well as stricter material selection, and possibly new shielding concepts with respect to the state of the art deployed in CUORE.

Background reduction

In order to achieve the scientific goals a significant improvement of the current CUORE background figure is mandatory.

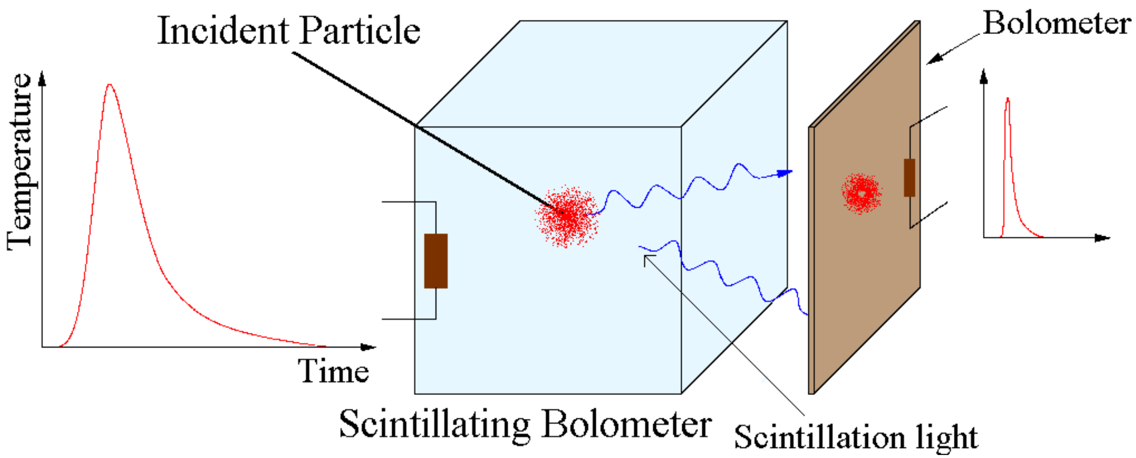
CUORE 10 C/(keV ton y) $\xrightarrow{\text{100 reduction}}$ CUPID 0.1 C/(keV ton y)

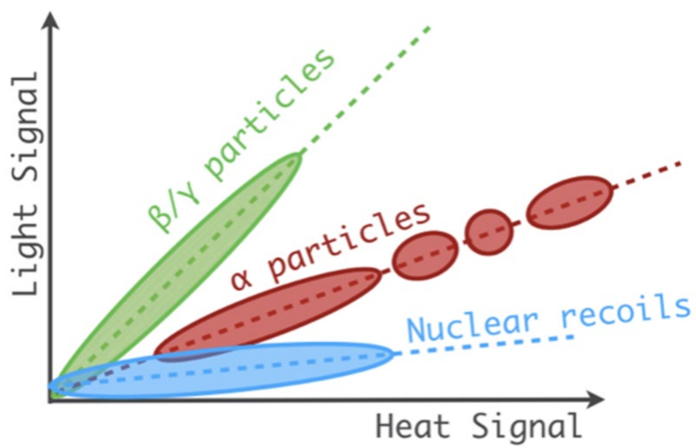
The dominant component of the background in CUORE is due to **energy-degraded alpha particles** emitted from the surfaces of the materials surrounding the detector or of the detector itself. Active background suppression promises the required levels, either with TeO_2 as sensitive material, or with other isotopes.

It is important to stress that improvement in the detector technology, even if mandatory, may not be not sufficient. Background coming from residual environmental radioactivity and that induced by sporadic muon interactions in the current CUORE configuration could produce backgrounds .

Scintillating Bolometers: rudiments of operation

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





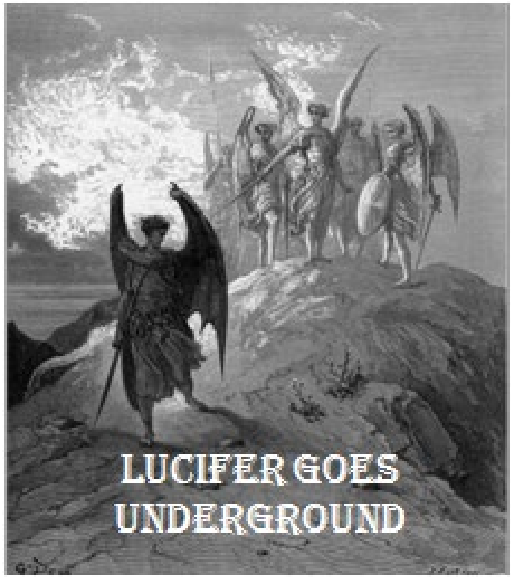
A Bolometric Light Detector is a fully active a particle detector

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/

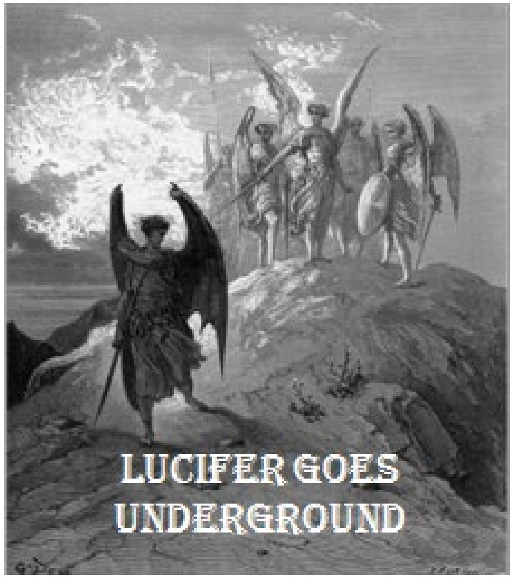
demonstrator

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

Lucifer

LUCIFER Low-background Underground Cryogenics Installation For Elusive Rates



European Research Council

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

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

material: ZnSe , $ZnMoO_4$, $CdWO_4$

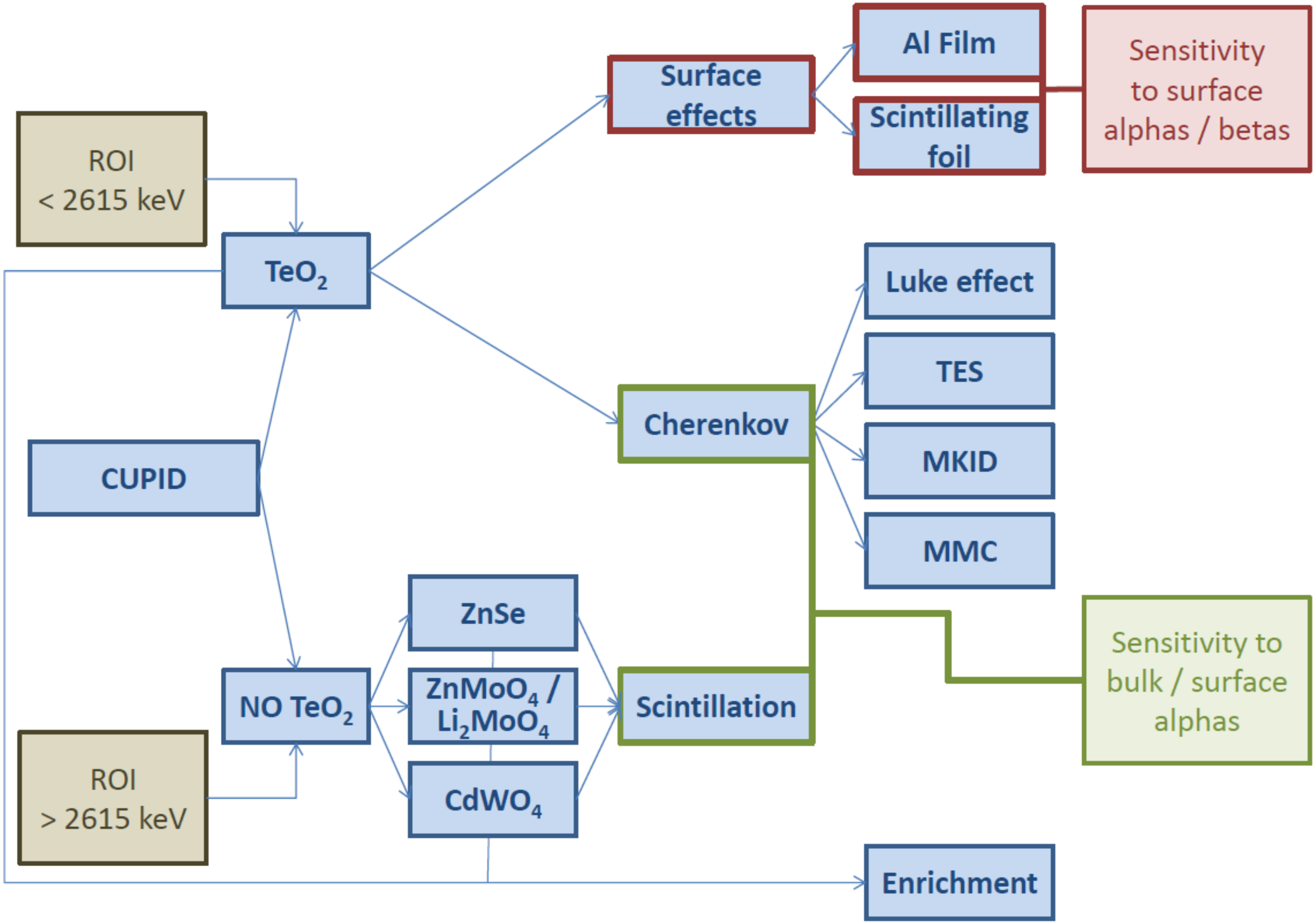
technique: scintillating bolmeter

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

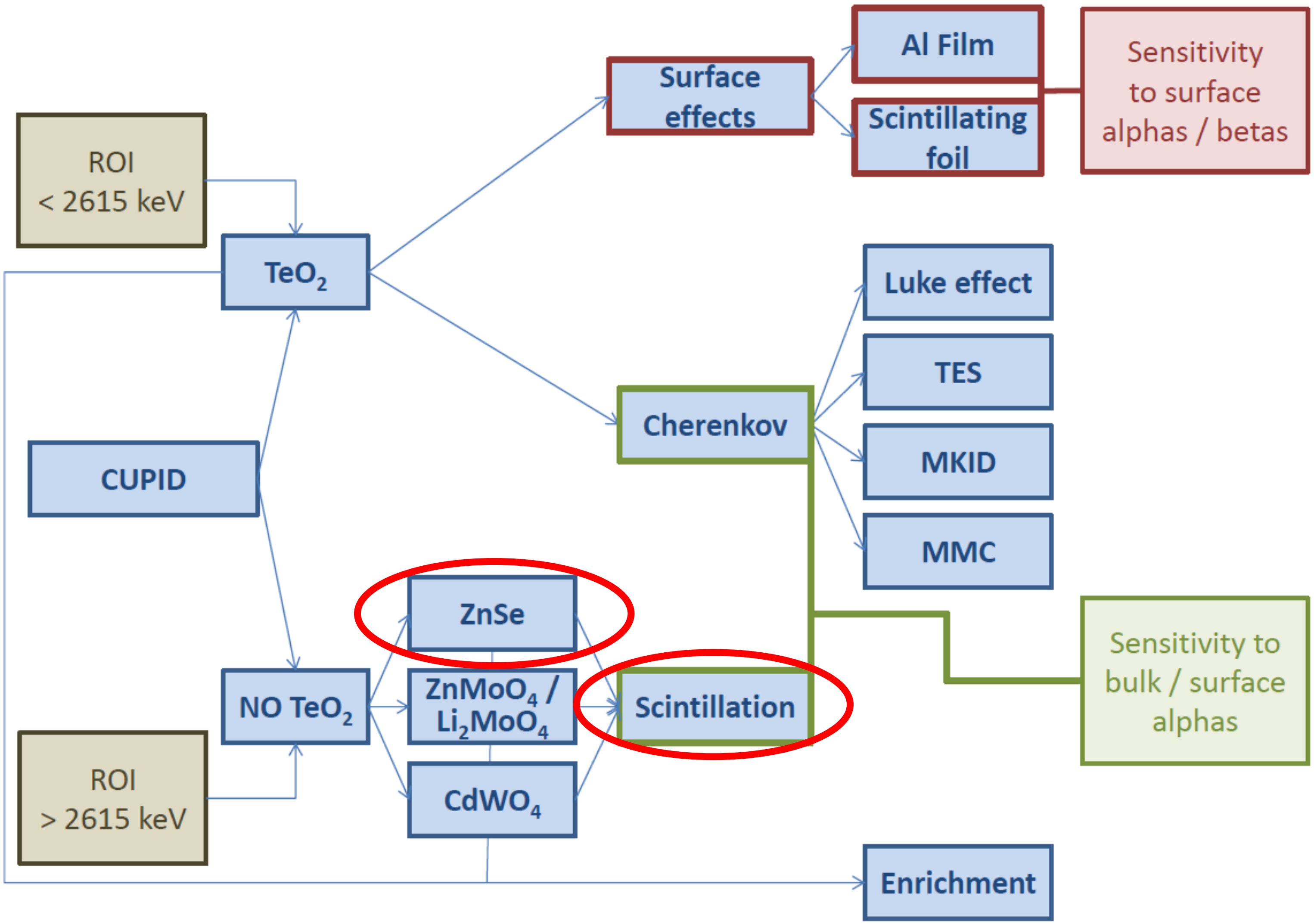
Cuore **U**pgrade with **P**article **ID**entification

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



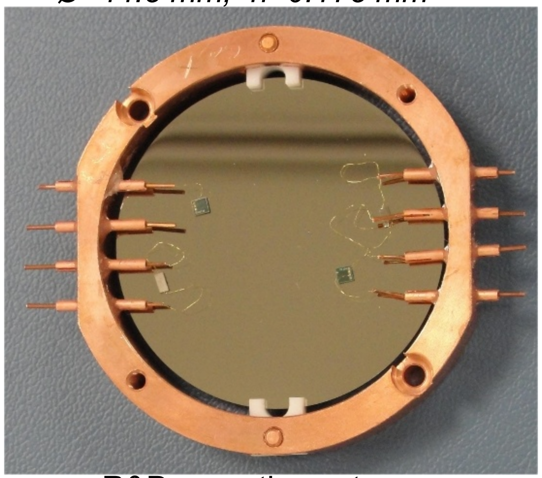
Bolometric Light Detectors

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.

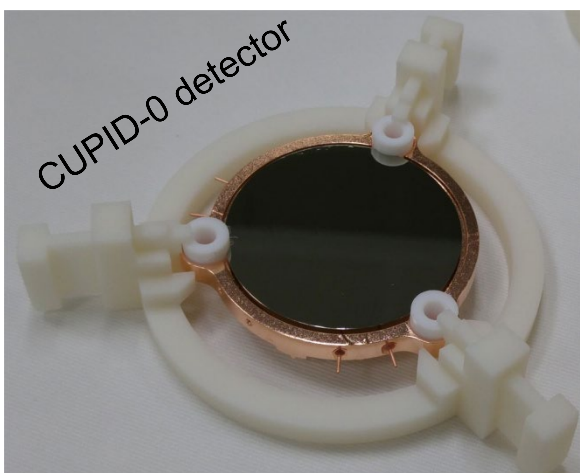
The light detector is a Ge thin wafer equipped with a <u>small</u> thermistor

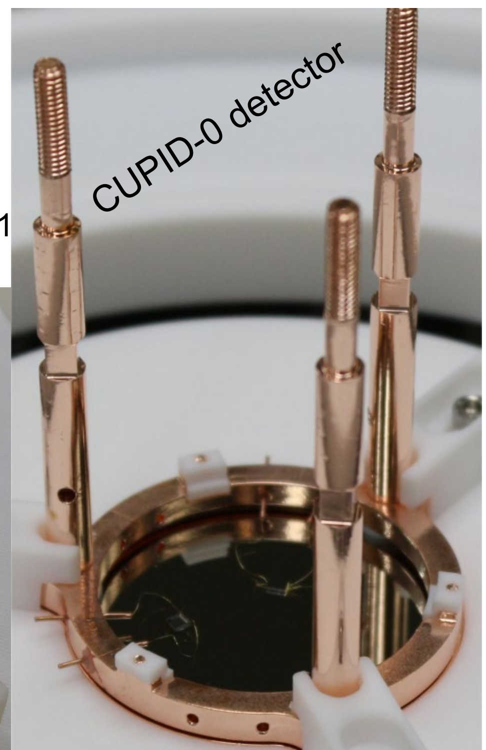
These devices are calibrated through an Ionizing ^{55}Fe sources

Ø=44.5 mm, h=0.175 mm

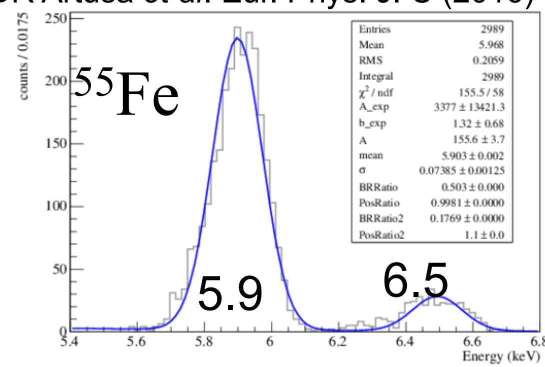


R&D mounting setup
JW Beeman *et al*. JINST 8(2013) P07021





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

$< \sigma >= 43$ eV ~ 15 γ

NTD-BLD, Baseline for CUPID

Within CUPID-0 we developed improved LD that fully match the requirements for the 1-ton detector, both in terms of energy resolution than in time response

Nuclear Inst. and Methods in Physics Research, A 935 (2019) 150–155

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Cryogenic light detectors with enhanced performance for rare event physics

M. Barucci [a], J.W. Beeman [b], V. Caracciolo [c], L. Pagnanini [d,e], L. Pattavina [f,c,1], G. Pessina [e], S. Pirro [c,*], C. Rusconi [g,c], K. Schäffner [f,c]

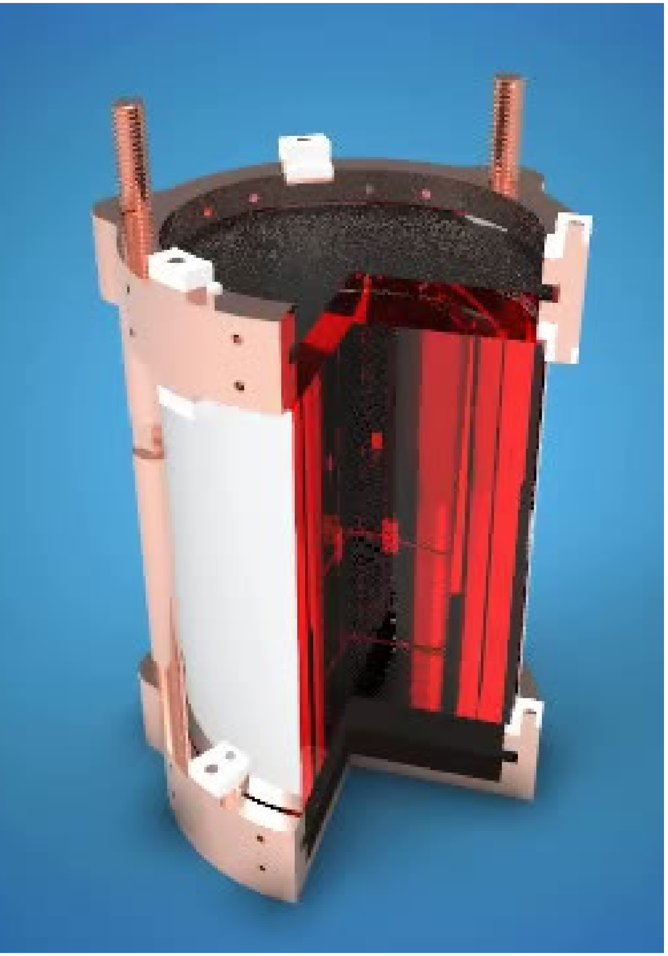
R_{work} [MΩ]	Response [μV/keV]	Baseline RMS [eV]	τ_r [ms]	τ_d [ms]
0.87	1.36	43	1.77	5.06
1.47	3.86	20	0.83	1.63

CUPID-0- mean

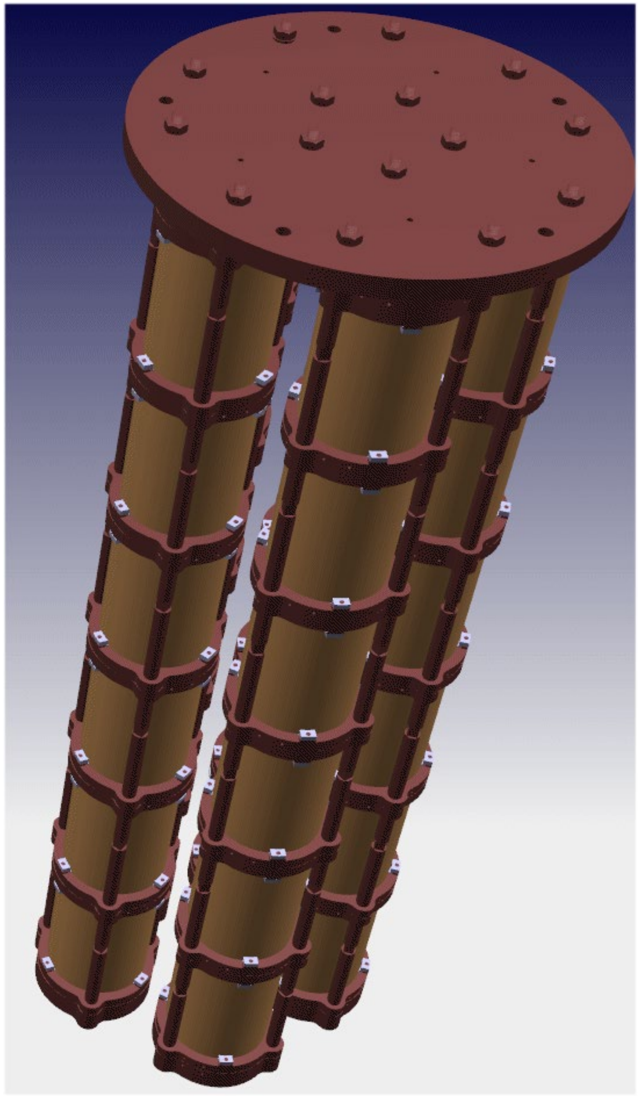
New detector technology

CUPID-0 Mechanical structure

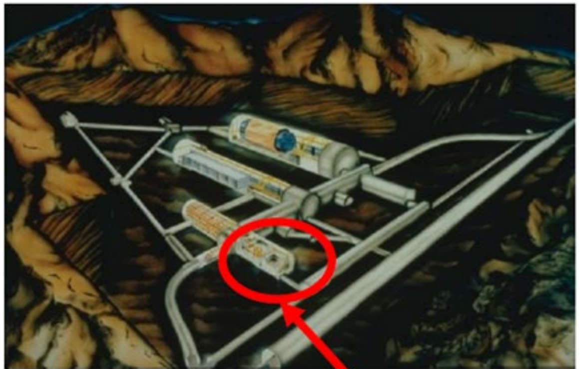
The mechanical configuration of the CUPID-0 tower was designed by the LNGS Mechanical workshop and 3D printing service. *Driving Idea: minimize frame mass, type of pieces, use only certified (large slab) copper*



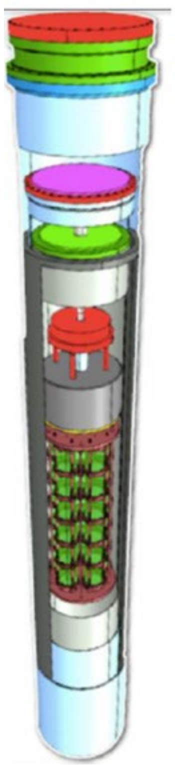
ZnSe 78 %
Cu 22%
PTFE 0.1%



CUPID-0: 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

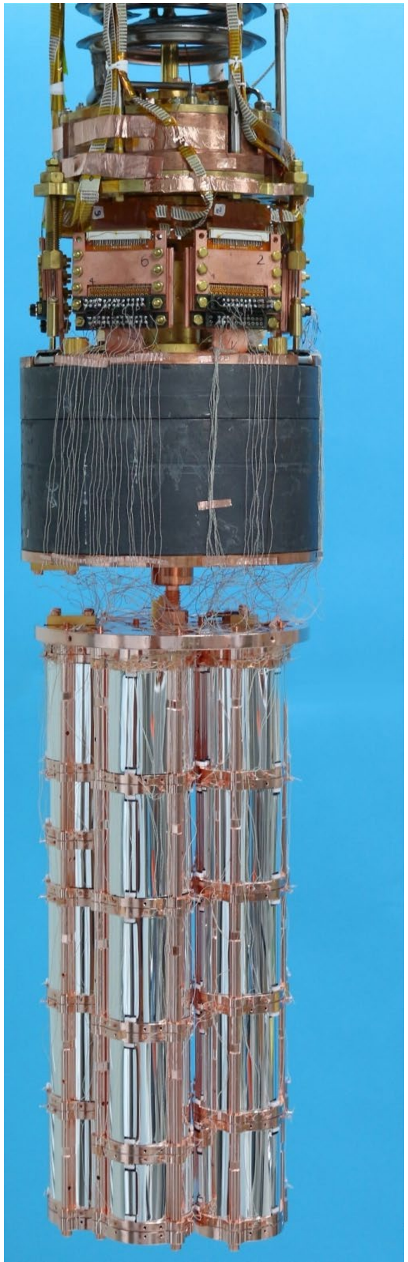
Some upgrades were done on the cryogenic system:

- **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

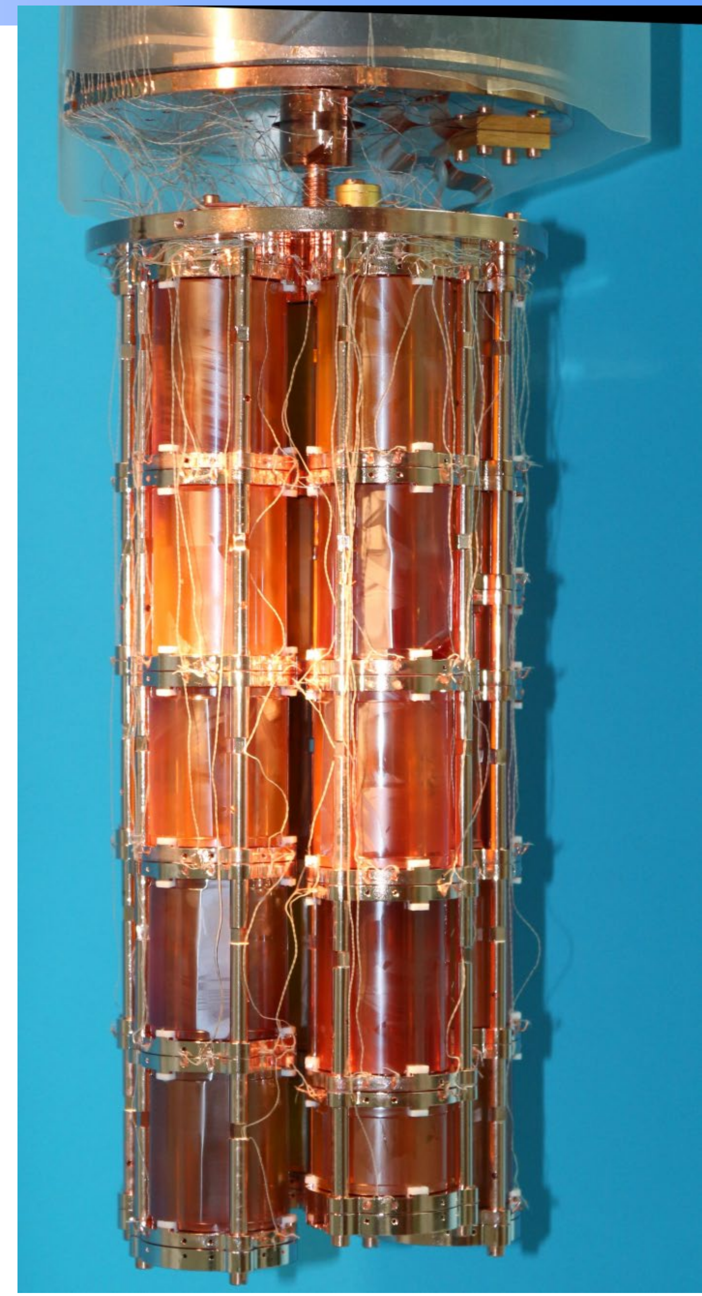
https://www.lngs.infn.it/en/cupid

CUPID-0

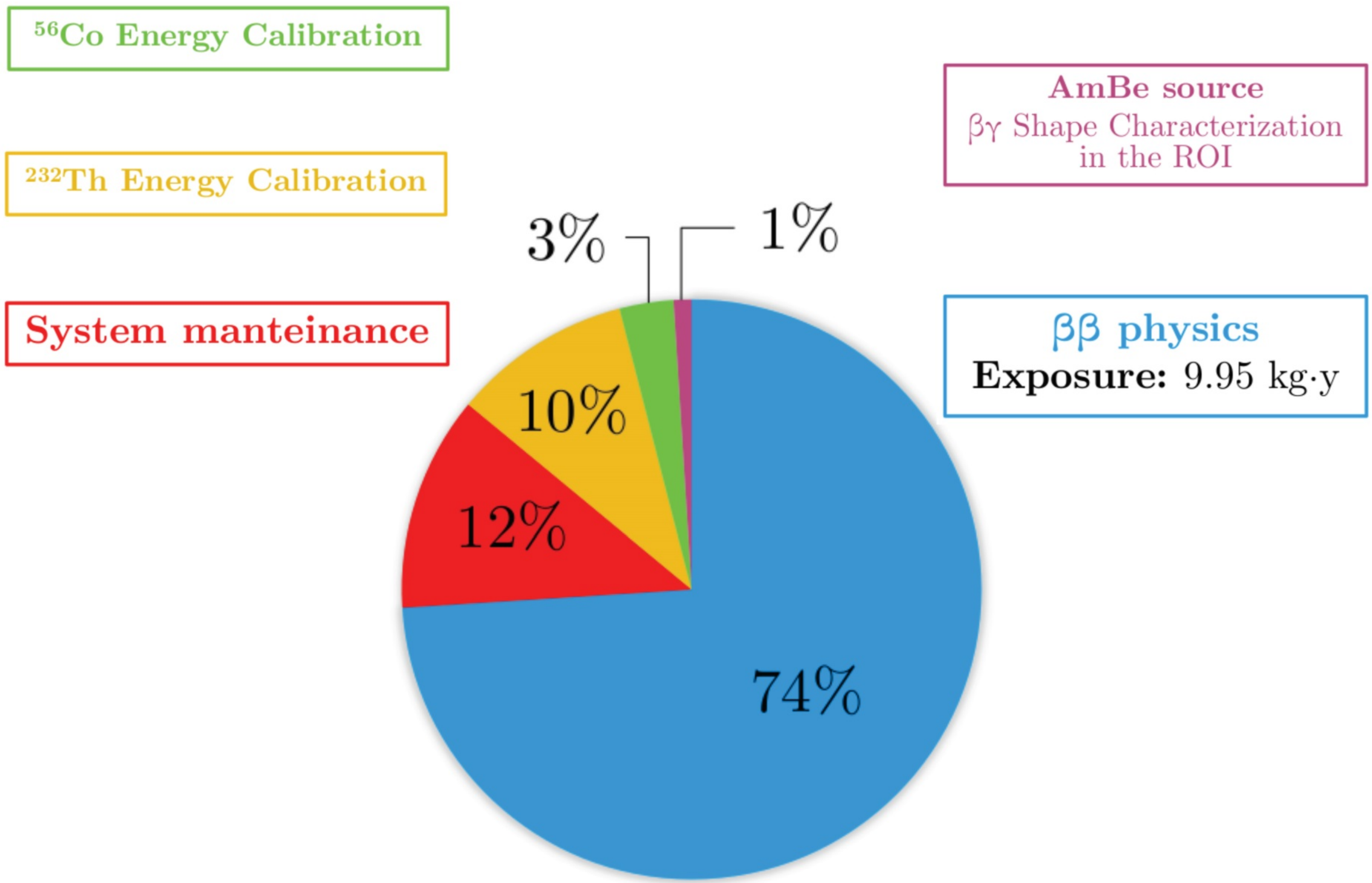
CUPID-0 – Phase II



Phase II



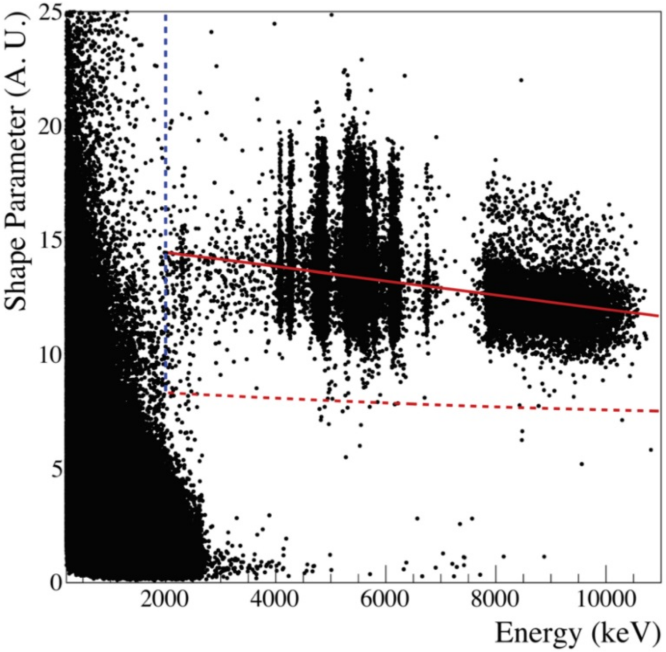
CUPID-0 - Live Time

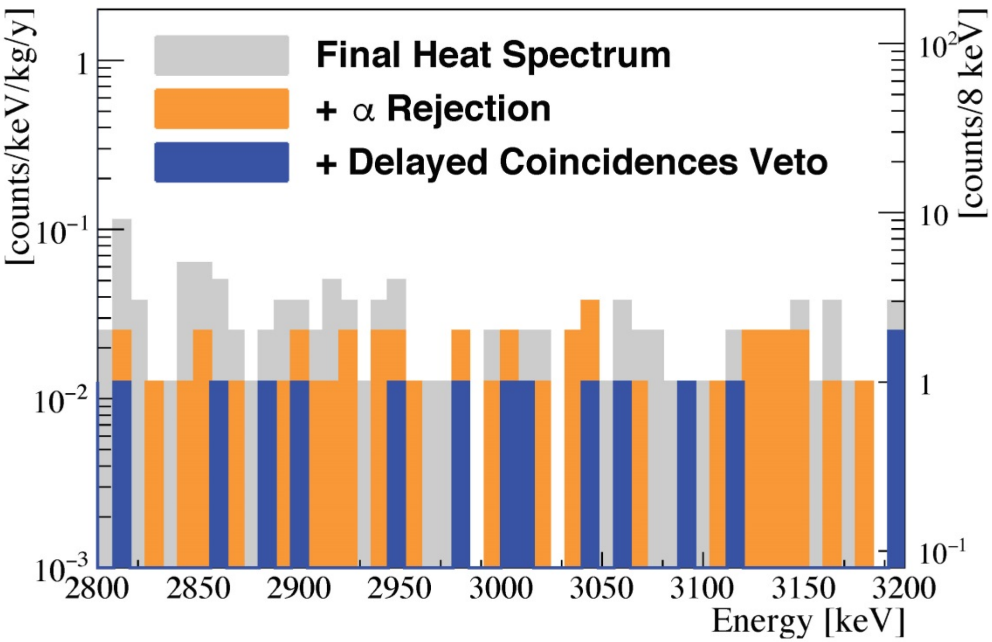


This Live Time demonstrates that bolometers are now definitively mature under all the aspects

CUPID-0 – Results

- Final Exposure (Physics Runs): **9.95 kg × y (22 Zn^{82}Se)**
- Resolution at $Q_{\beta\beta}$: **(20.05 ± 0.34) keV**
- $T_{1/2}$ ($0\nu\beta\beta$ ^{82}Se) > **3.5 × 10^{24} y (90% C.I. Limit)**
  5.0 × 10^{24} y (Median Sensitivity)
- $m_{\beta\beta}$ < **(311 - 638) eV**
- Background: **$3.5^{-0.9}_{+1.0}$ × 10^{-3} counts/(keV × kg × y)**





CUPID-0 – Background Model

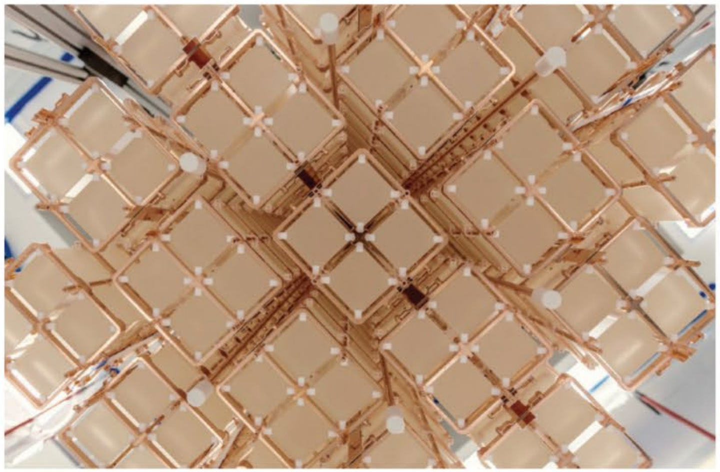
Background rate in the ROI (2.8 - 3.2 MeV) after the **delayed coincidences** cut.

Source	Rate (counts/(keV·kg·y))	Systematics
$2\nu\beta\beta$	$(6.0 \pm 0.3) \times 10^{-4}$	
Crystals bulk – ^{232}Th	$(3.4 \pm 0.6) \times 10^{-4}$	
Crystals surf – ^{232}Th	$(3.4 \pm 0.5) \times 10^{-4}$	$[2.2 - 4.7] \times 10^{-4}$
Crystals surf – ^{238}U	$(5.3 \pm 0.4) \times 10^{-4}$	$[5 - 7] \times 10^{-4}$
Reflectors – ^{232}Th	$< 7 \times 10^{-5}$	
Reflectors – ^{238}U	$(1.8 \pm 0.3) \times 10^{-4}$	$[1 - 3] \times 10^{-4}$
Cryostat & Shields – ^{232}Th	$(4.0 \pm 1.3) \times 10^{-4}$	$[0.7 - 11] \times 10^{-4}$
Cryostat & Shields – ^{238}U	$(2.2 \pm 0.4) \times 10^{-4}$	$[1.5 - 2.6] \times 10^{-4}$
Muons	$(1.53 \pm 0.13) \times 10^{-3}$	$[1.3 - 1.8] \times 10^{-3}$
Total	$(4.2 \pm 0.2) \times 10^{-3}$	$[4.1 - 4.8] \times 10^{-3}$

We can improve understanding of our background thanks to CUPID-0 Phase II

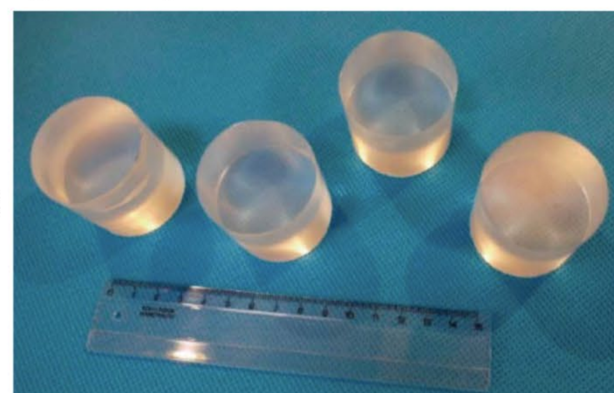
CUPID-Towards Li_2MoO_4

CUPID: CUORE Upgrade with Particle ID
Mission: To discover $0\nu\beta\beta$ if $m_{\beta\beta}$ > 10 meV ($T_{1/2}(^{100}Mo) > 1\times10^{27}$ yrs)



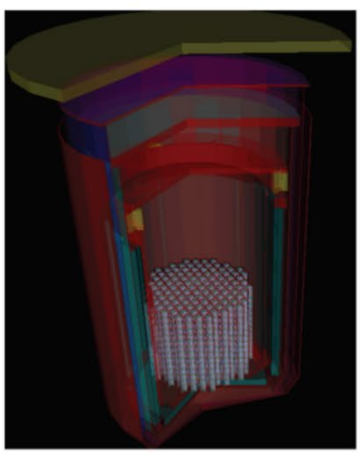
CUORE Achievements:
- Ton-scale bolometric detector is technically feasible.
- Analysis of 1000 bolometers demonstrated
- Reliable data-driven background model constructed.
- Infrastructure for next-generation experiment exists.

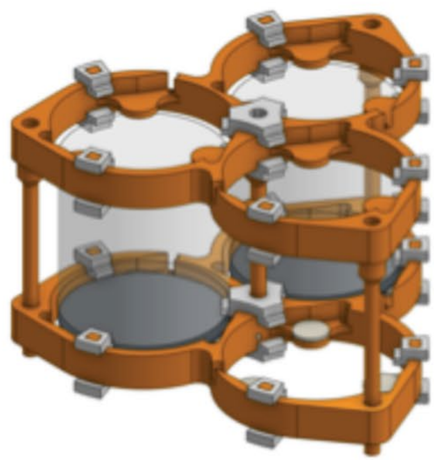
Scintillating Bolometer R&D by CUPID-0, LUMINEU, CUPID-Mo, etc.
- Demonstrated large-scale enriched crystal production capability
- Internal radio-purity targets met
- Demonstrated active background rejection
- Energy resolution ~5 keV demonstrated.
- Total background of $\sim10^{-1}$ cnts/ton-keV-yr achievable

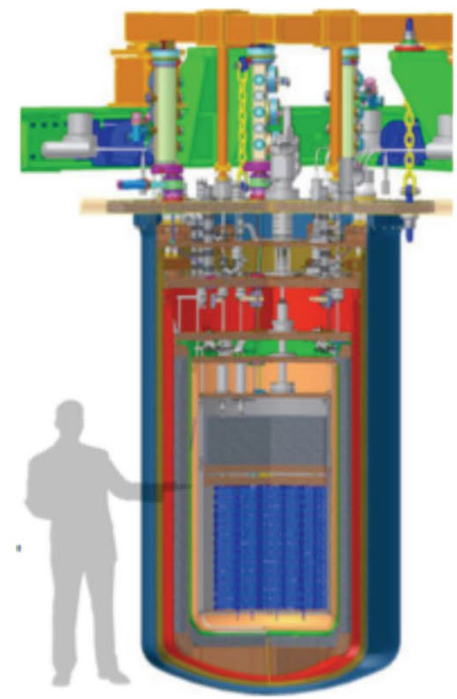


CUPID-Proposed structure

- Re-use ***CUORE cryogenic infrastructure*** at LNGS
- $Li_2{}^{100}MoO_4$ scintillating crystals
- ~1500 crystals for ***270 kg of ^{100}Mo***
- Active background rejection using light and heat signals
- Options for ***multiple isotopes*** possible.
- TDR and ***construction readiness in 2021***

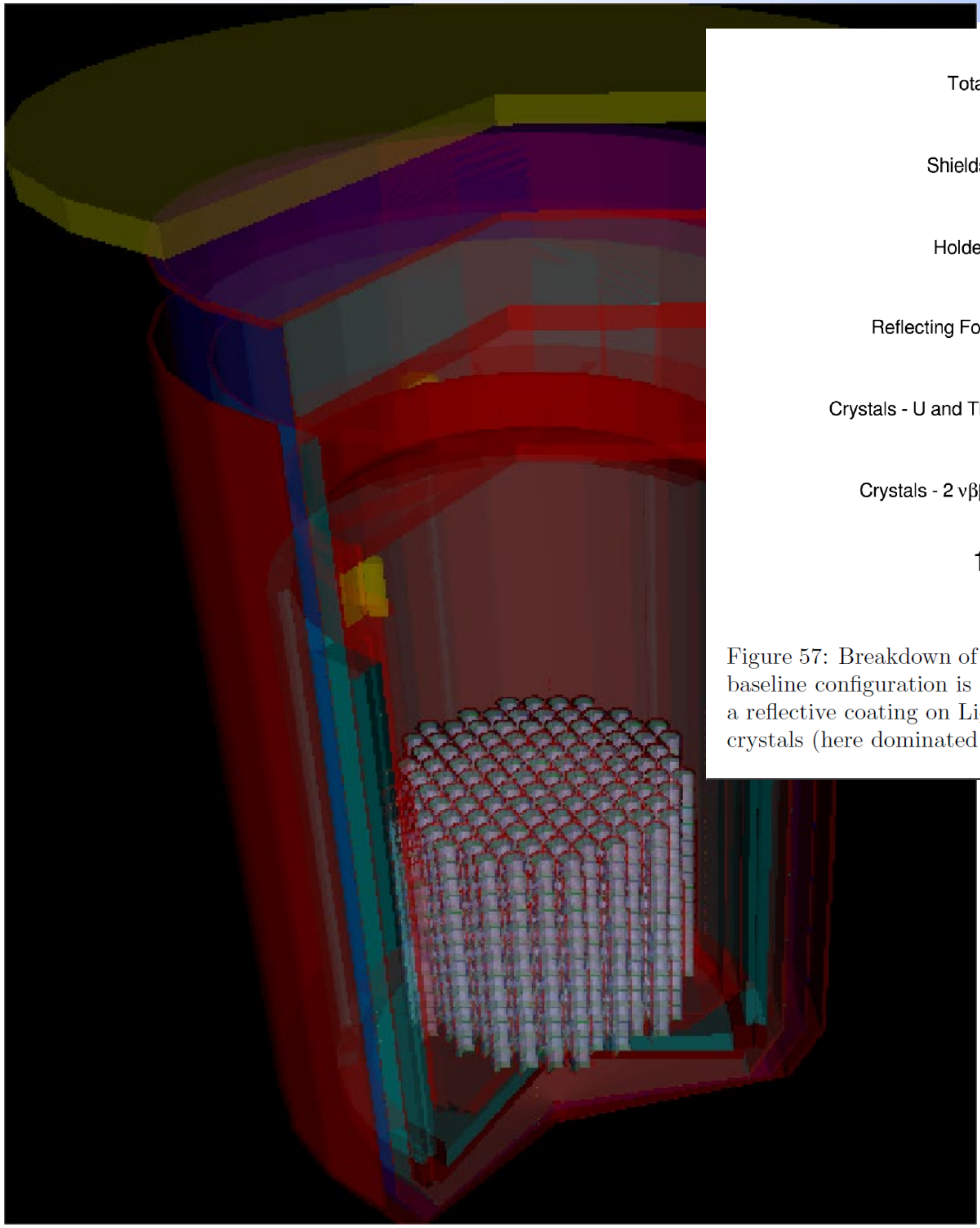






Conservative, Mature, Data Driven Baseline Design

CUPID- Background model in the RoI



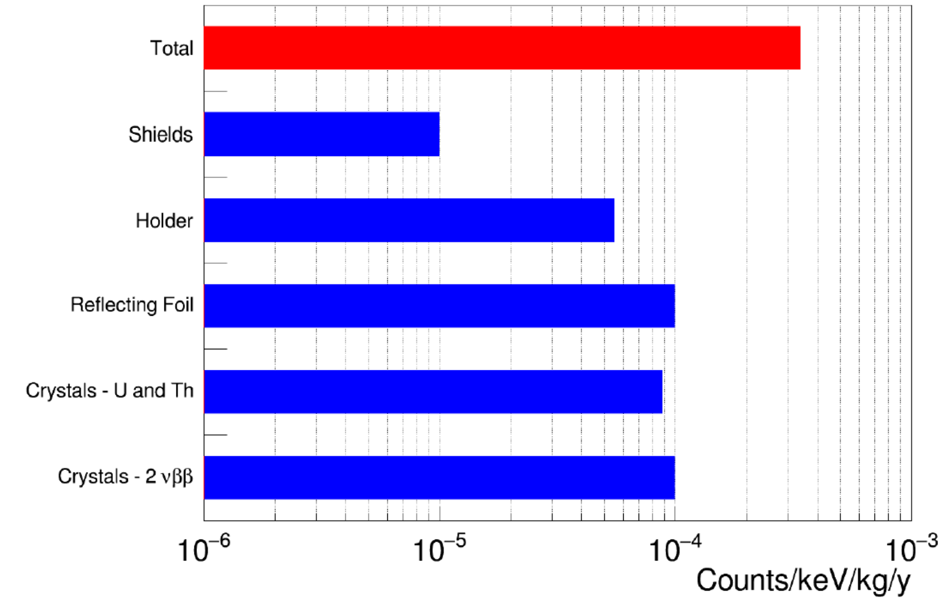


Figure 57: Breakdown of the CUPID β/γ counting rate predicted by the BM in the ^{100}Mo ROI. Here the baseline configuration is considered. As discussed in the text, the substitution of the reflective foil with a reflective coating on Li_2MoO_4 crystals would dramatically reduce both the U and Th contributions of crystals (here dominated by surface contaminants) and that of the reflector itself.