CUPID-0

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CUPID-0 is the first 0νββ experiment using the <u>scintillating bolometers technique</u>

Particle Identification thanks to the simultaneous read-out of the heat and light signals

CUPID-0 searches for the 0νββ of ^{82}Se using 26 ZnSe scintillating crystals (24 95% enriched in ^{82}Se + 2 natural) and very thin Ge slabs as light detectors, operated as bolometers themselves

- 10.5 kg of ZnSe (3.8×10^{25} nuclei)
- Detectors arranged in 5 towers, ~30 cm tall;
- Operated underground at LNGS (Italy) in the very same cryostat that hosted CUORE-0.

CUPID-0: a brief, recent history

Summer 2016
Construction

Early 2017
Commissioning

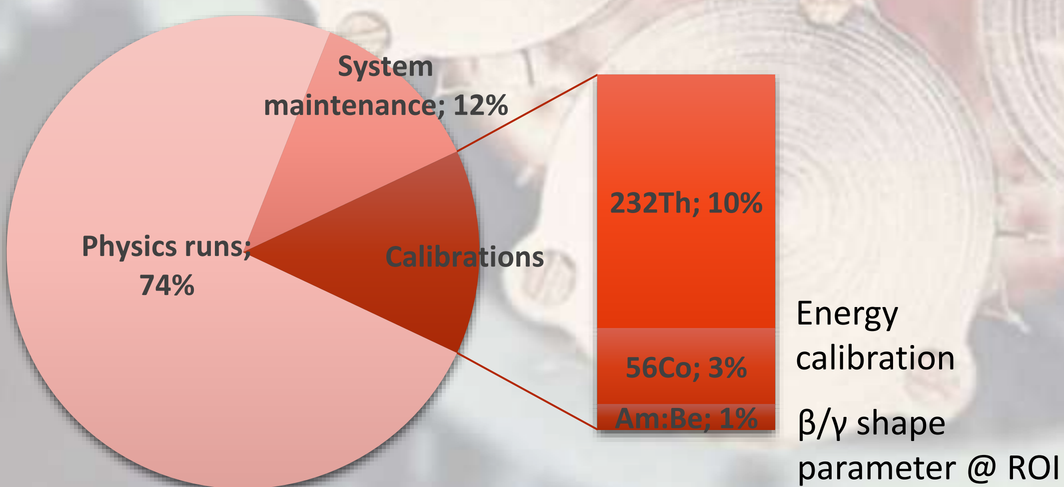
CUPID-0
Phase-II

Dec 2016 — Cooldown

Dec 2018 — End of Phase-I

Phase-I full statistics

~ 1.5 years → 9.95 kg × yr of ZnSe



- Jan 2019:
Detector upgrade
- Feb 2019:
Muon Veto installation
- Mar 2019:
Cool down
- Spring 2019:
Commissioning
- June 2019:
Start of Data Taking

CUPID-0 phase-I: results

- Lowest background ever achieved for cryogenic calorimeters
- Most stringent limit on ^{82}Se 0νββ decay to fundamental state of ^{82}Kr

Phys. Rev. Lett. 120, 232502
Published 5 June 2018

Phys. Rev. Lett. 123, 032501
Published 15 July 2019

- Most stringent limit on ^{82}Se 0νββ decay to excited states of ^{82}Kr

Eur. Phys. J. C 78 (2018) no.11, 888
Published 11 January 2018

- Solid model of the background sources

Eur. Phys. J. C (2019) no.79, 583
Published 11 July 2019

Phys. Rev. Lett.
Accepted 20 November 2019

Phys. Rev. D 100, 092002
Published 6 November 2019

- Study the ^{82}Se 2νββ with unprecedented precision:
  - half-life
  - evidence of the mechanism driving the process (HSD vs SSD)
  - search for Lorentz violations in the 2νββ spectrum

+ other technical publications

CUPID-0: what behind this result

1. The shoulders of the giants

A lot of know-how acquired through the R&D and construction phases of Cuoricino, CUORE-0, and CUORE detectors (e.g.. sensor to-absorber coupling, cleaning protocols, electronics, DAQ, analysis framework…)

2. The steps of the giants

Dedicated R&D to:

- Extend this know-how in particular to Light Detectors;
- Perfect a growth procedure for large Zn^{82}Se crystals.

Core of the LUCIFER project (ERC Grant Agreement no. 247115)

3. The head of the giants

Analysis of the factors having impact on:

- Detector feasibility (too many components, too complex assembly procedures, …);
- Detector performances (vibrations, contamination, …);
- Detector live-time (traps cleaning, 1k-pot adjustment, He refills, …);
- …

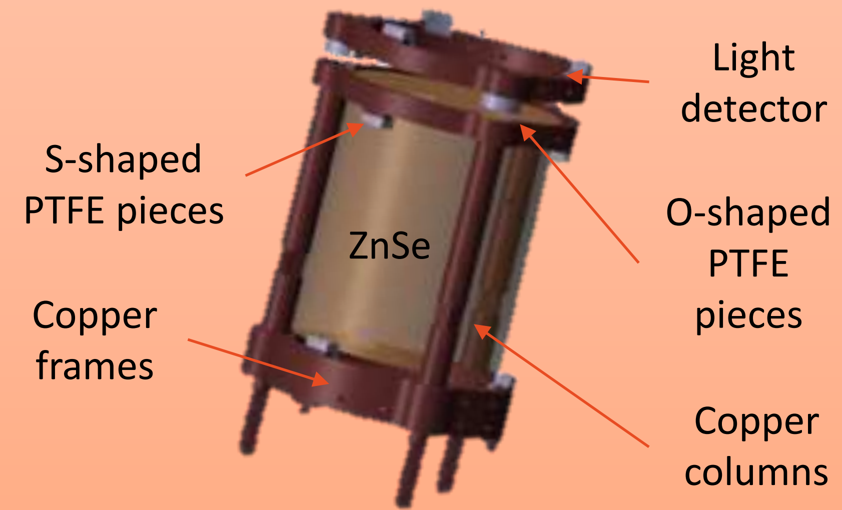
Introduction of disruptive solutions with respect to the tradition

CUPID-0: detector structure

Detector design

- Same design for ZnSe and LDs frames
- Single copper frame used to hold a ZnSe and its LD
- Length of each triplet of columns (and light reflector) tuned on the height of its crystal

→ Different sizes to optimize crystal yield



ZnSe crystal surrounded by plastic light reflector

The amount of copper in the detector structure and ancillary parts is ONLY 22% of the overall detector mass

CUPID-0: before construction

All the auxiliary operations to the detector construction/ final handling of detector components done inside a Radon free clean room (^{222}Rn concentration <20 mBq/m^3)

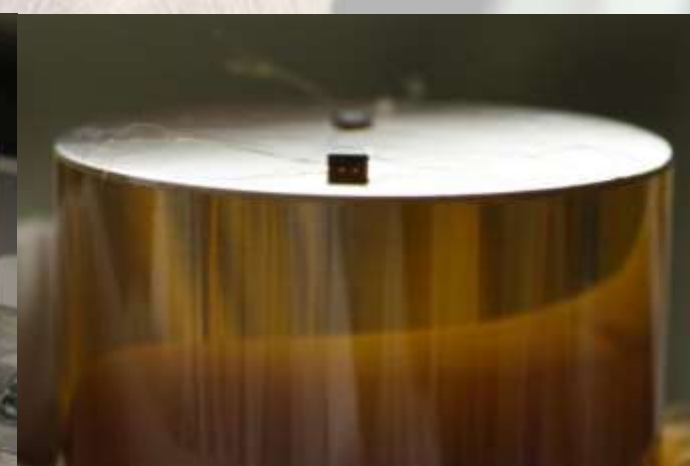
- NTDs and heaters (already equipped with 50 um thick, 2.5 cm long gold wires, 2/3 per side) final cleaning
- Crystals shaping and polishing
- Copper frames equipping with copper pins as electrical feed-through

CUPID-0: NTD-to-absorber gluing

- Bi-component epoxy glue deposit in dots (0.07 mm in diameter) on the sensor surface thanks to a spring-loaded matrix of tips moved by a x-axes robot

- Crystal/LD lowered toward the sensor surface and kept at 0.05 mm distance until the glue is cured

From mixing to crystal deposition < 3 min



CUPID-0: LDs pre-assembly

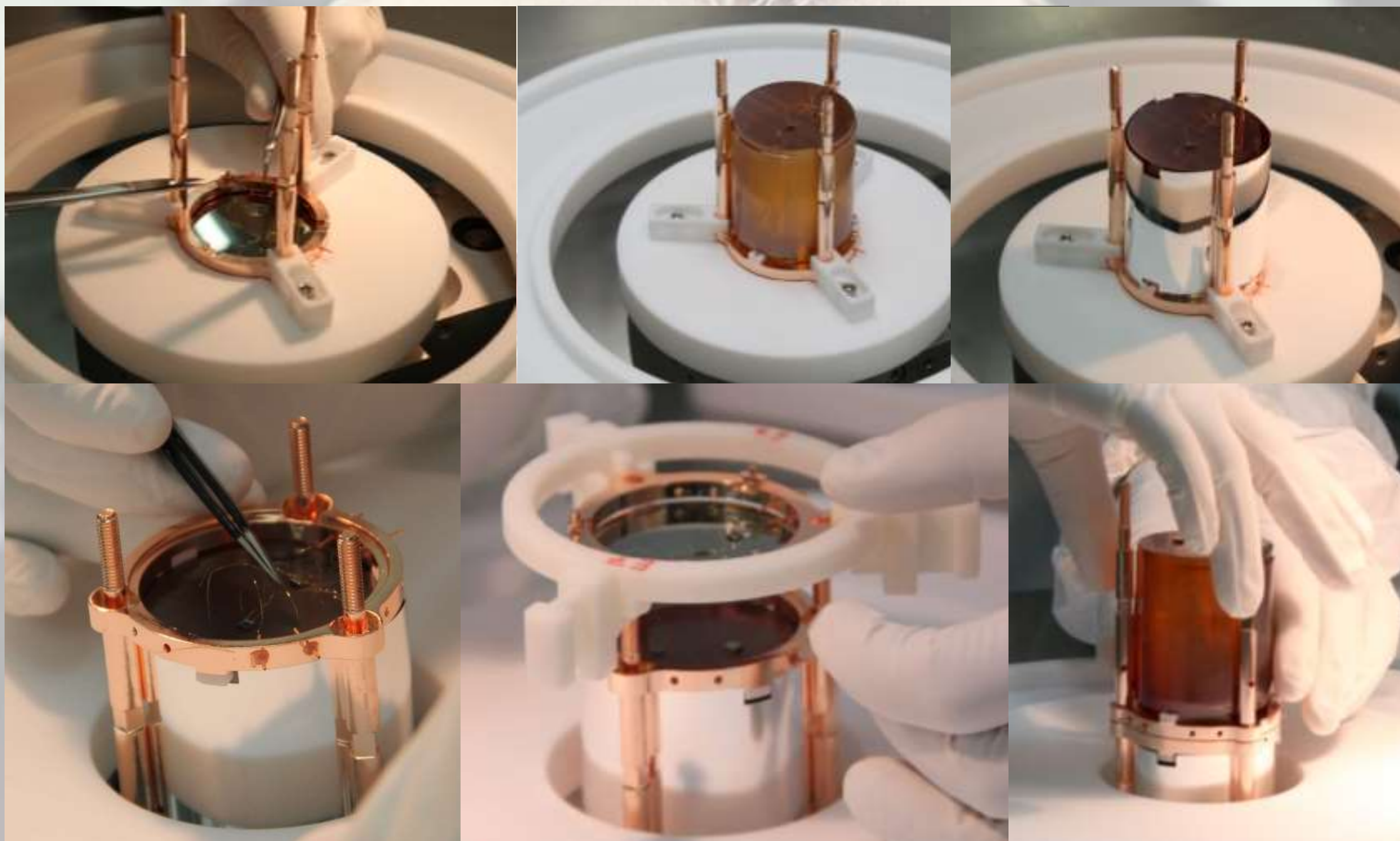
- Each Ge wafer equipped with its NTD is mounted in a single copper frame using three PTFE O-shape pieces.

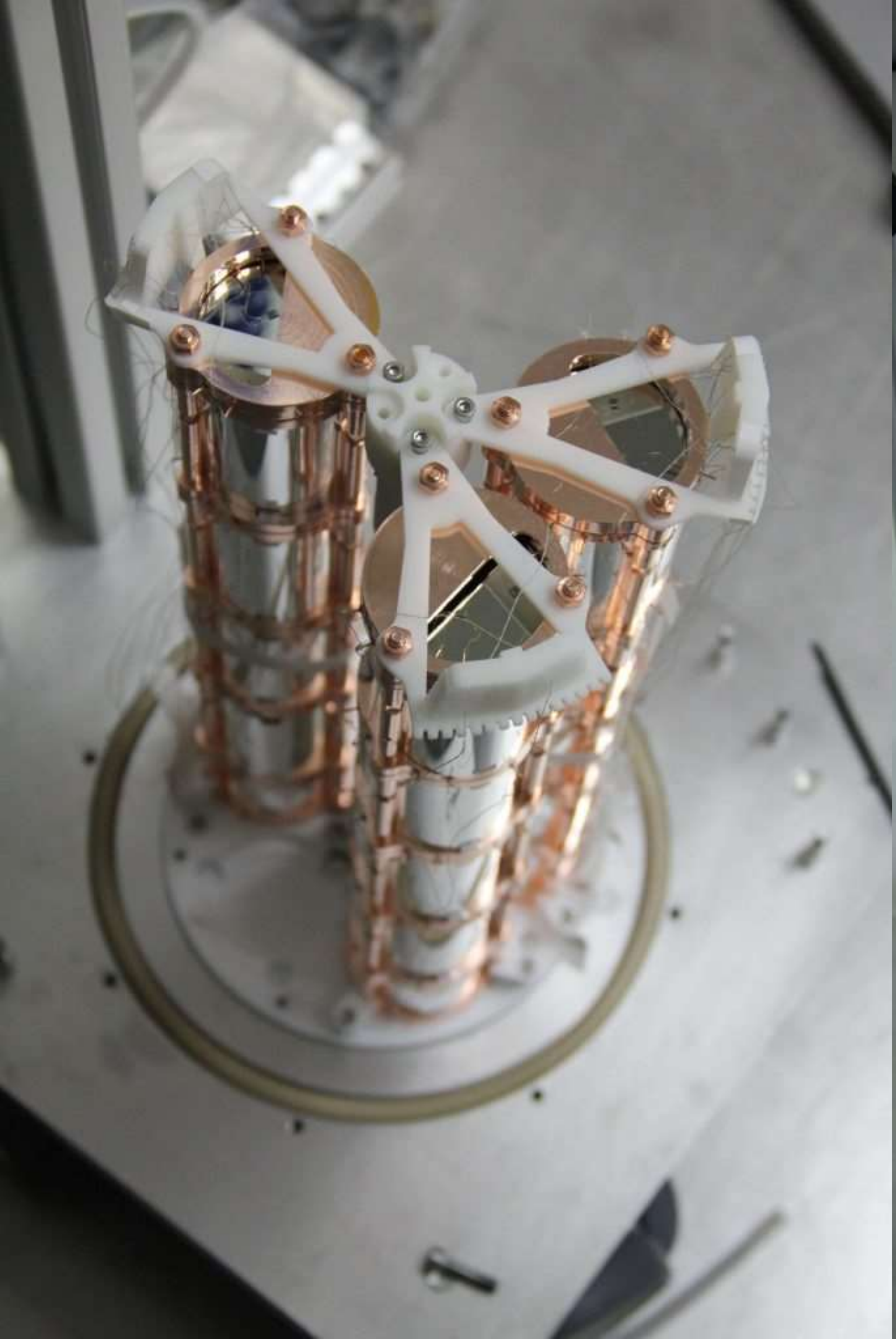
- Dedicated 3D printed tools were developed to keep the thin Ge disk in position even within a single frame

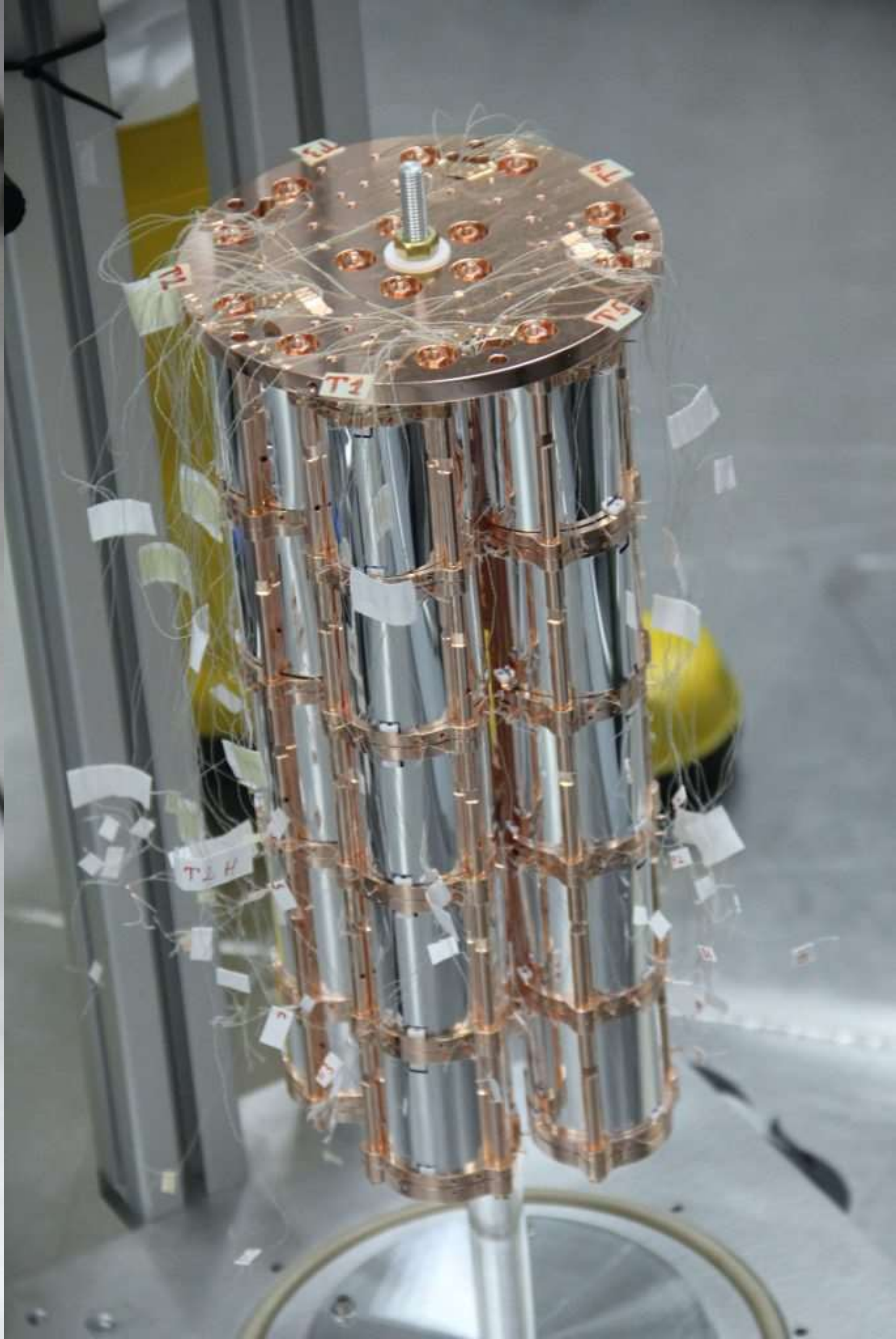
- In this way the LD can be handled as a complete stand alone detector and can be completed with the gluing of the heater and the connection of the chips gold wires to the copper pin fitting.



CUPID-0: assembly sequence






T1
T5
T2 H

CUPID-0 approach: example 1

One shot detectors
No redundancy, no possibility to repair in case of failure after the towers were assembled

Most critical item: wires (gold, 50 µm thick, 25 mm long)

NTDs had gold pads only on the lateral surfaces → gold wires must be attached before connecting the sensor to the crystal, and then handled during all the construction steps

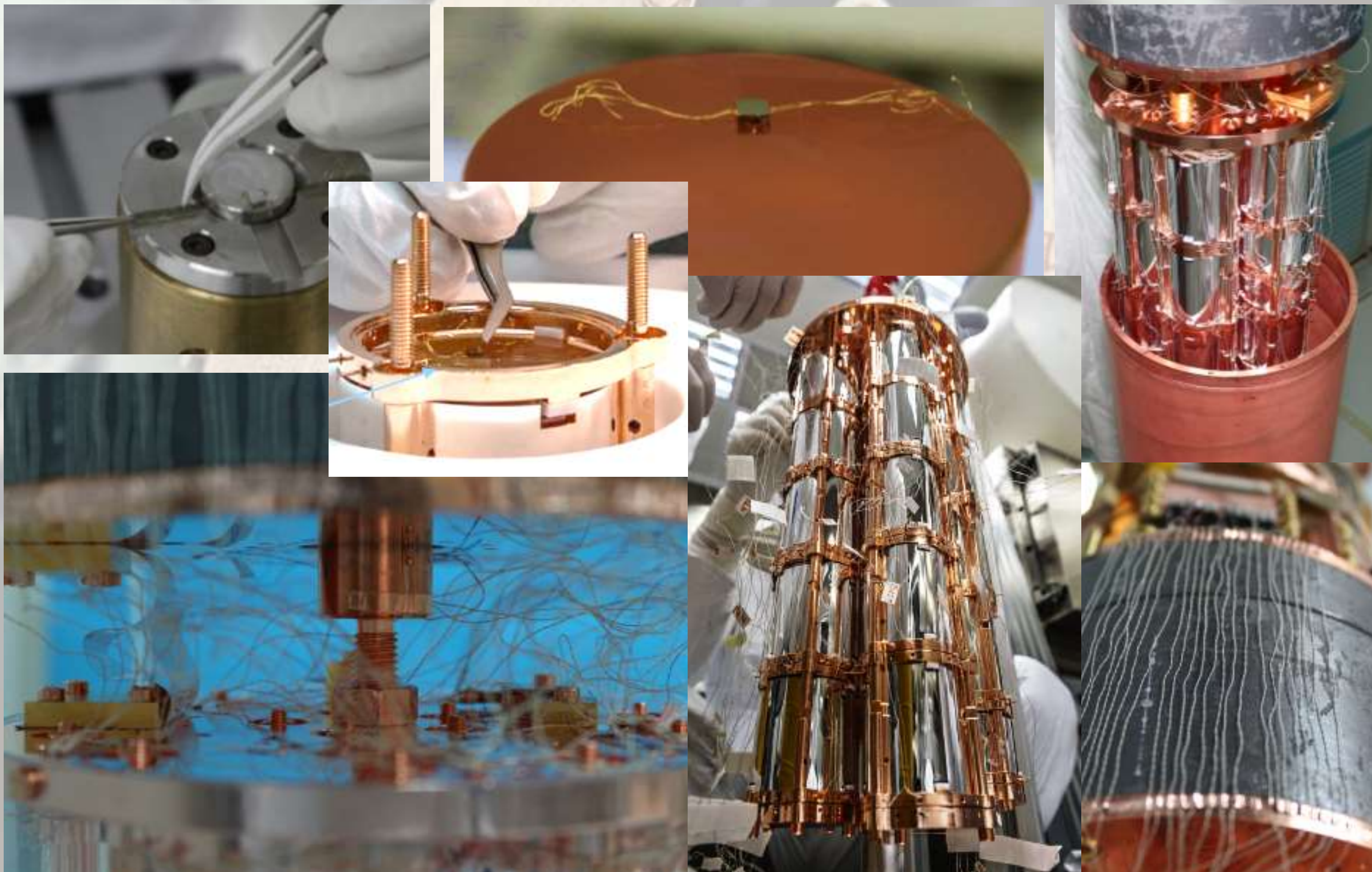
- Wires have not to interfere during the sensor gluing process
- Wires have to be connected to the feed-through towards the cryostat wiring

Wires manipulated by hand

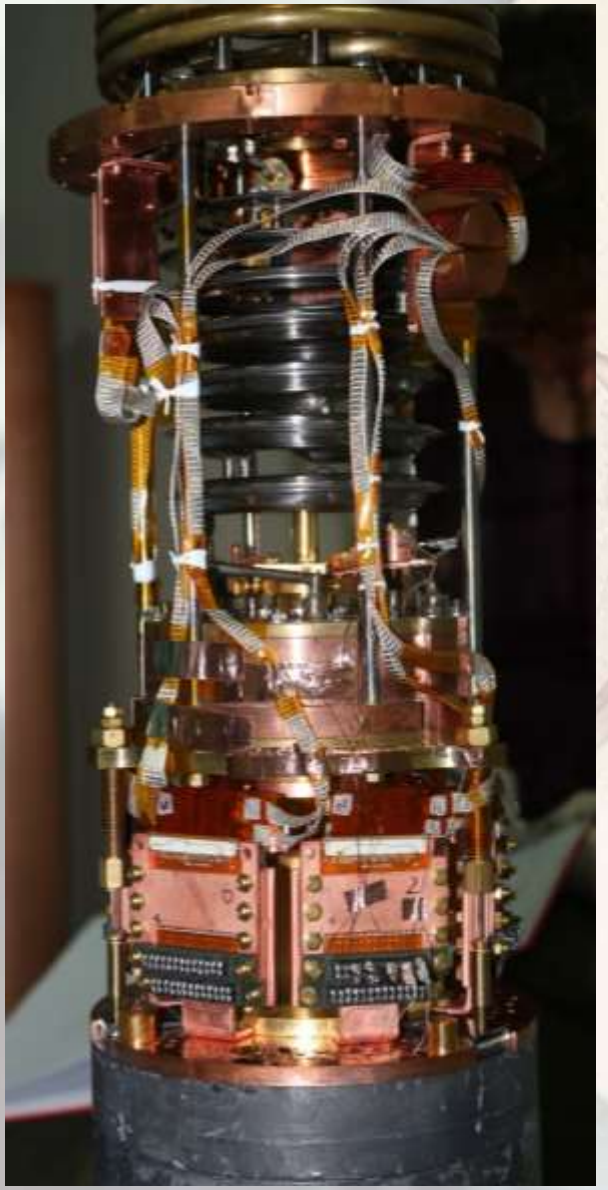
→
- assembly procedure as easy as possible
- NO glove boxes

Same applies to the wires going from the detector to the cryostat MC.

CUPID-0: wires!

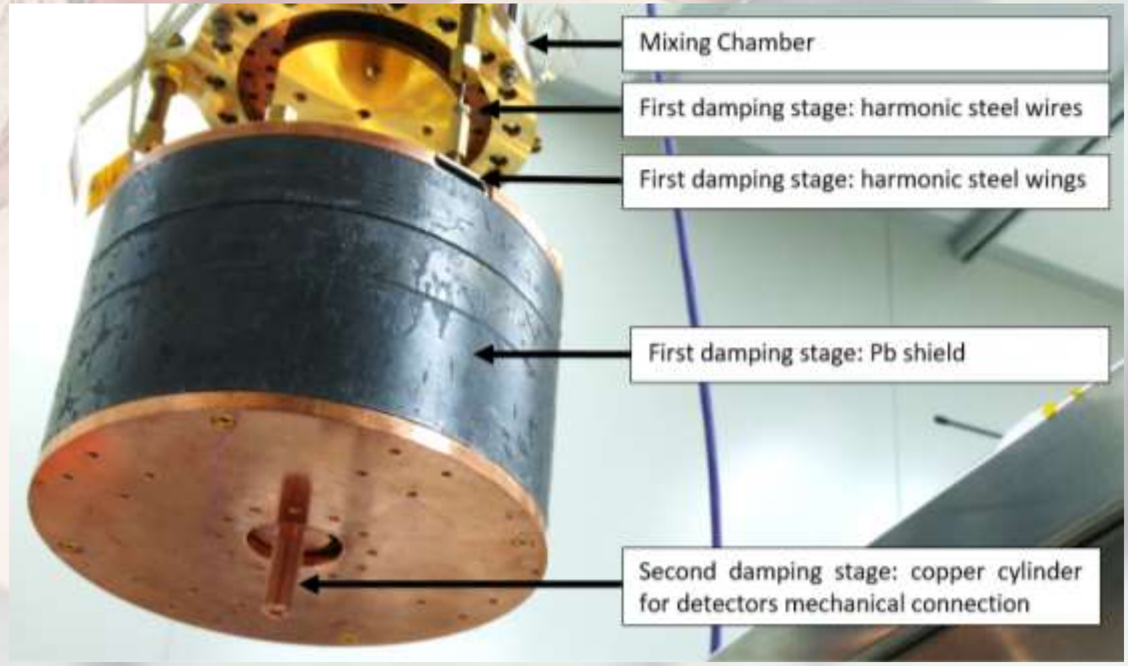


CUPID-0 approach: example 2



Reducing source of vibrations!

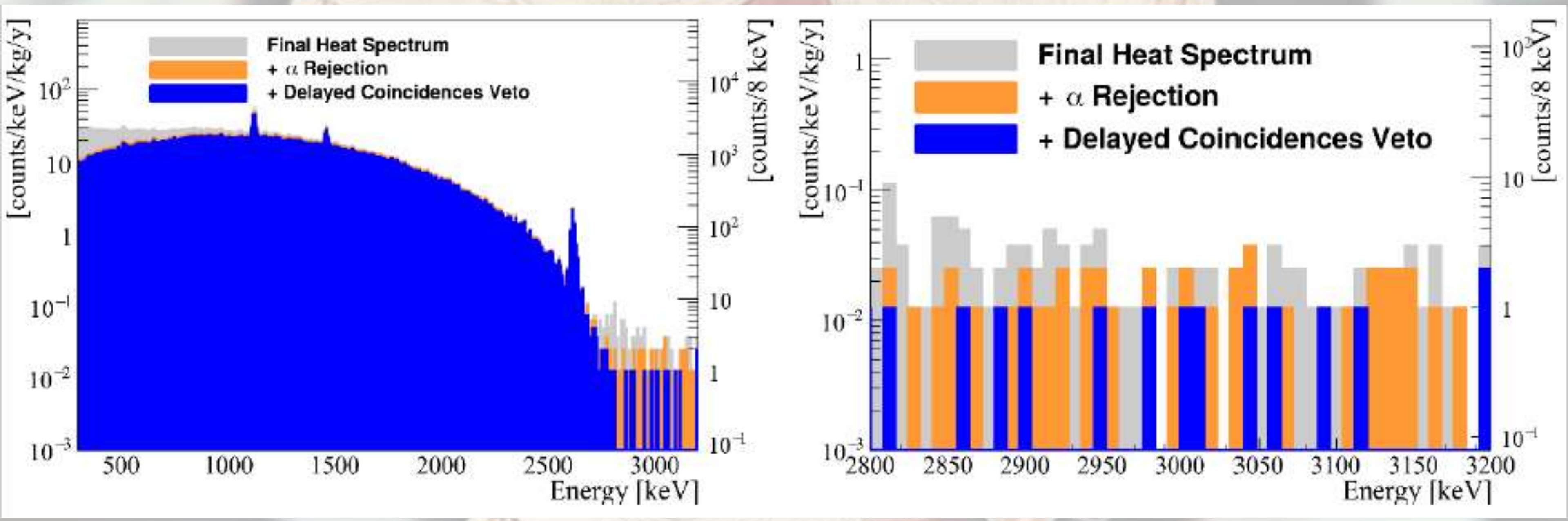
- New cryostat wiring (from Mixing Chamber to 300K) compact but as less “rigid” as possible
- A new mechanical double stage anti-vibrational decoupling system, decoupling the detector from the Mixing Chamber



CUPID-0: results on 0νββ

From Phase-I

- Total exposure: 9.95 kg × yr of $Zn^{82}Se$ (3.88 × 10^{25} emitters × yr of ^{82}Se)
- Final efficiency: (70 ± 1)%
- FWHM energy resolution in the ROI: (20.05 ± 0.34) keV

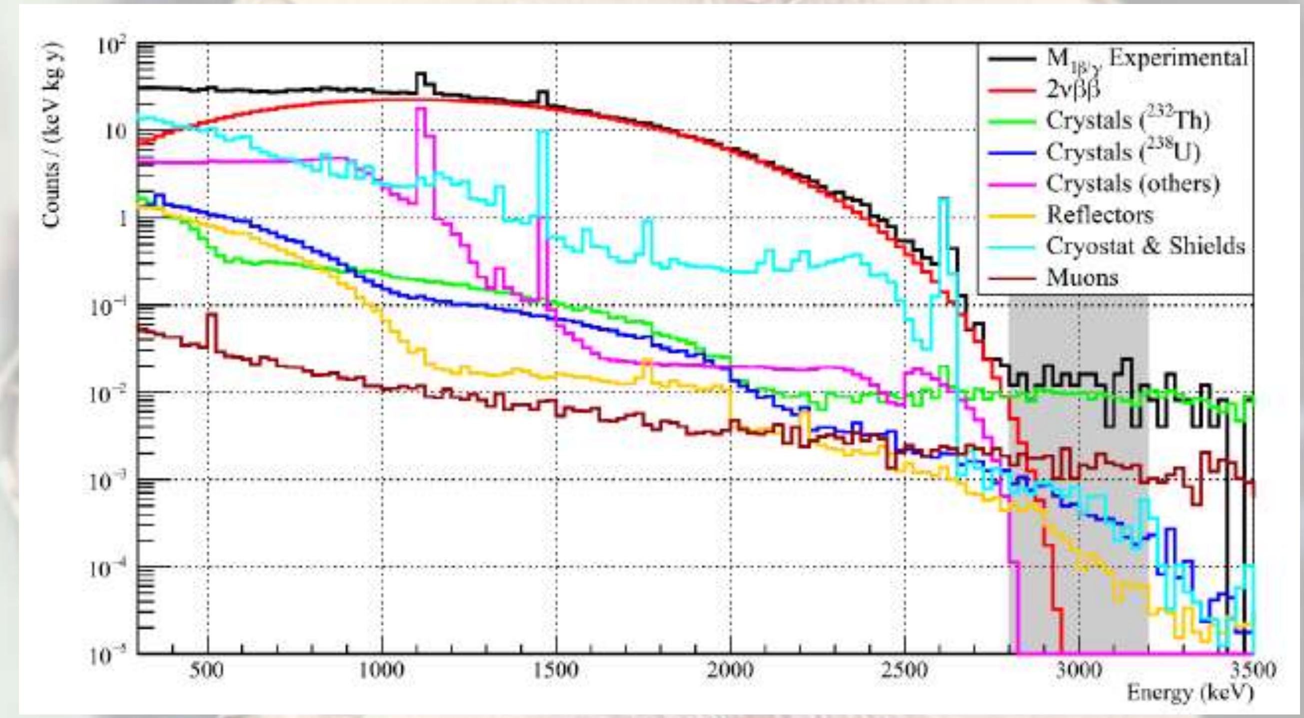


Bkg index in the ROI:
$(3.5^{+1.0}_{-0.9}) \times 10^{-3}$ cts/(kev × kg × yr)

Best half-life limit on ^{82}Se 0νββ:
$T^{0\nu}_{1/2} > 3.5 \times 10^{24}$ yr (90% CI)

CUPID-0: bkg model

Reconstruction of the bkg sources contributing to the M1β/γ spectrum



2νββ is a dominant contribution

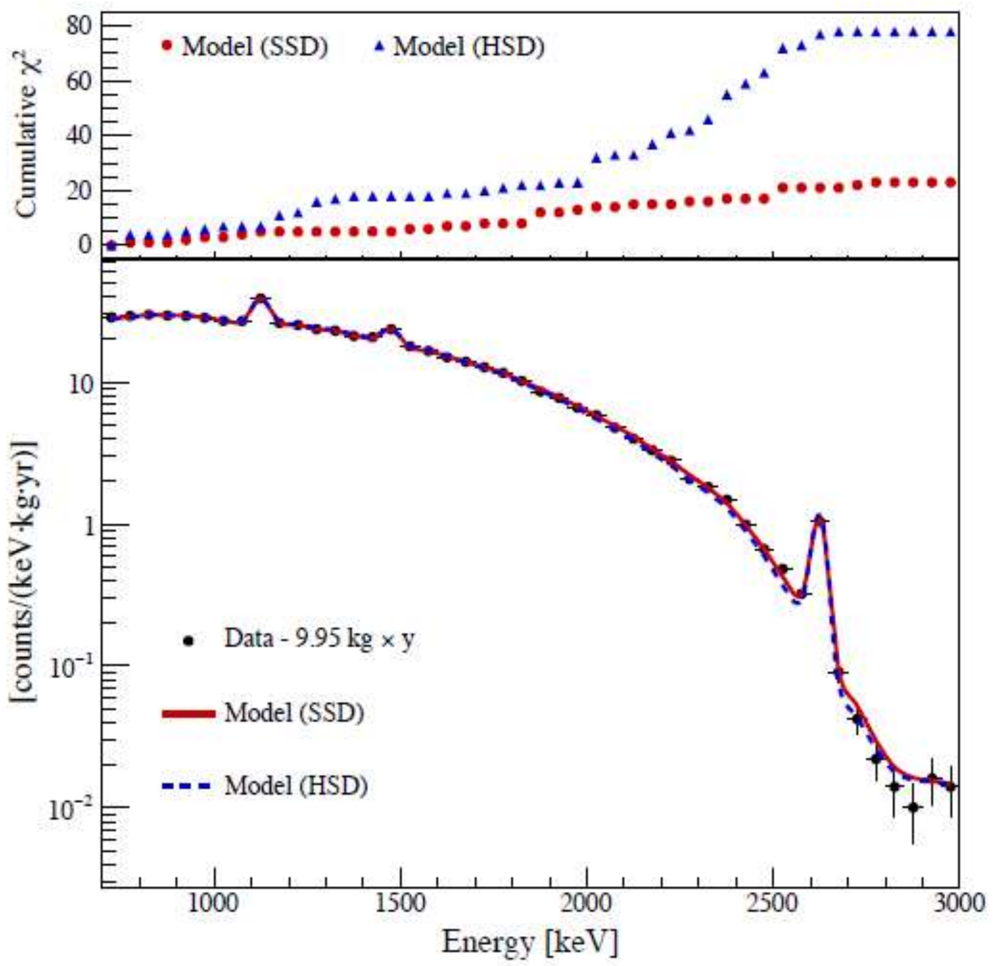
Detailed study

In the ROI

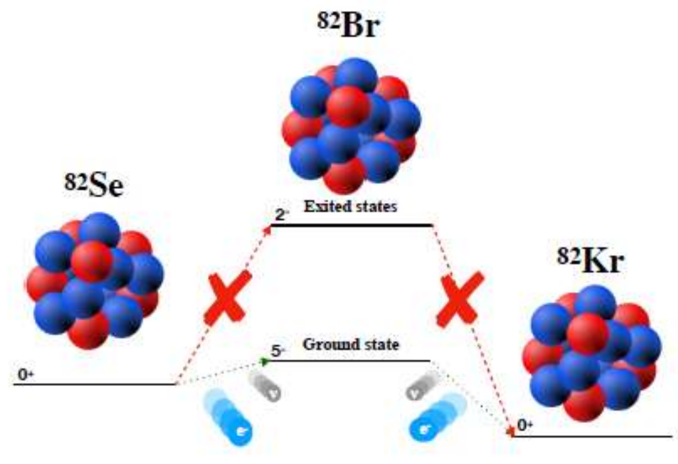
- ~44% muons
- ~33% contaminations in ZnSe crystals
- ~17% cryostat
- ~6% reflecting foil and holders

CUPID-0: results on 2νββ

Half-life limit on ^{82}Se 2νββ:
$T_{1/2}^{2\nu}$ = [8.60 ± 0.03 (stat.)$^{+0.17}_{-0.10}$ (syst.)] x 10^{19} yr



Evidence of Single State Dominance in the 2νββ of ^{82}Se



$$t_X = \frac{|N_{exp} - N_X|}{\sqrt{\sigma^2_{exp} + \sigma^2_X}}$$

Spectrum	Counts	t
Experimental	14830 ± 122	
Model (SSD)	14972 ± 57	1.1 σ
Model (HSD)	14095 ± 56	5.5 σ

HSD excluded

CUPID-0 phase II: the detector

From bkg model:

- ~44% muons
- ~33% contaminations in ZnSe crystals
- ~17% cryostat
- ~6% reflecting foil and holders

Modification to CUPID-0 setup in early 2019 to investigate these components

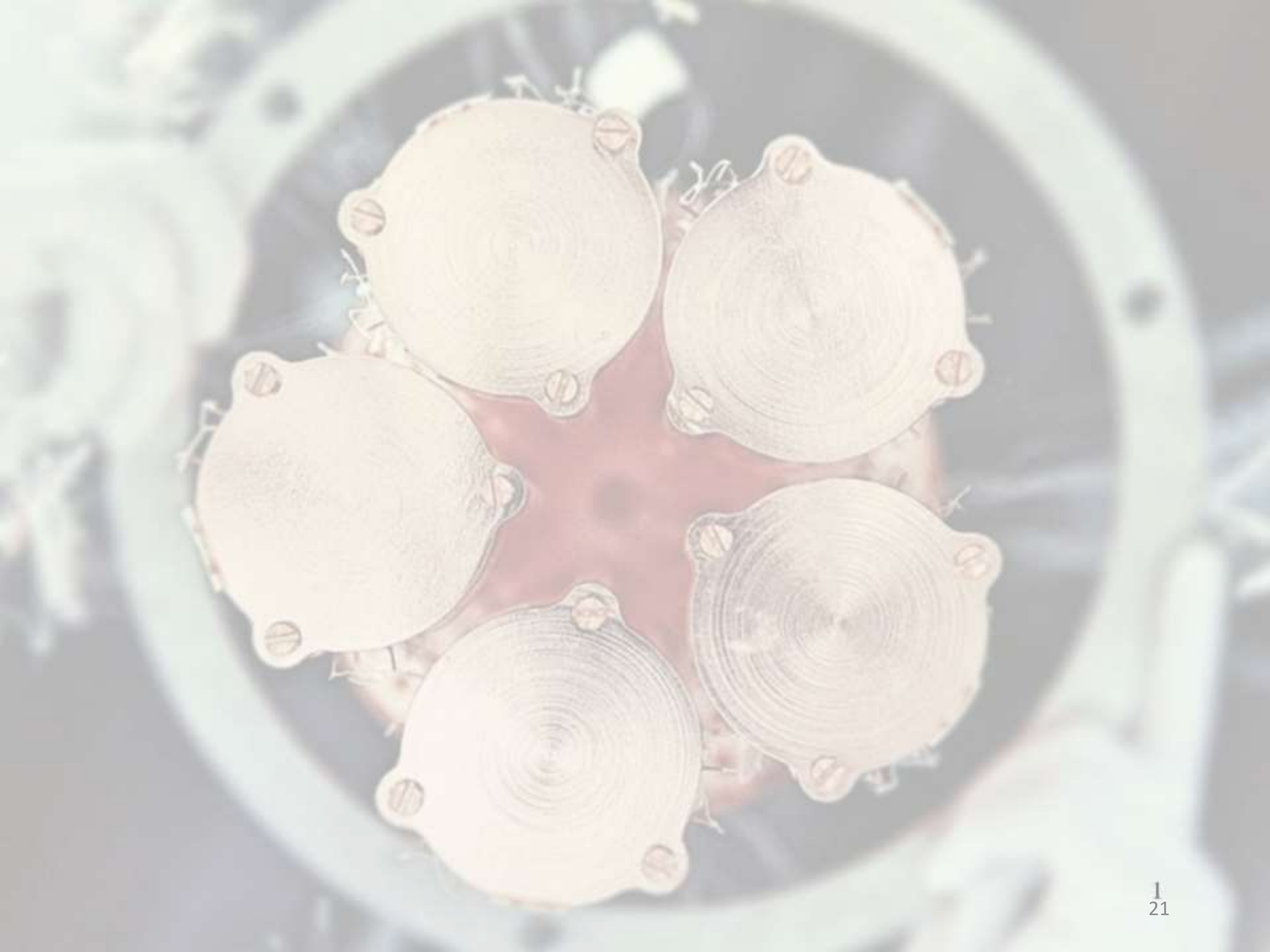
- Removal of the reflecting foil (→ coincidence among detectors)
- Installation of additional internal Cu shielding (at 10 and 50 mK)
- Installation of a muon veto surrounding the cryostat

CUPID-0 phase II: the muon veto

- Made with double layers plastic scintillators surrounding the lateral and top sides of the cryostat structure
- 36 photomultipliers to detect the light generated in the scintillating material
- Veto signal embedded within the DAQ in only one channel: it has an analogic-digital 6 bits pattern that allows identifying which side of the veto or which combination of them has triggered.

Conclusion

- CUPID-0 is the first 0νββ experiment based on the scintillating bolometers
- In its Phase-I CUPID-o reached an exposure of 9.95 kg × yr of ZnSe
- Wide span of physics results despite the small exposure, proving the potential of the technique
- Phase-II ongoing, stay tuned for more results!

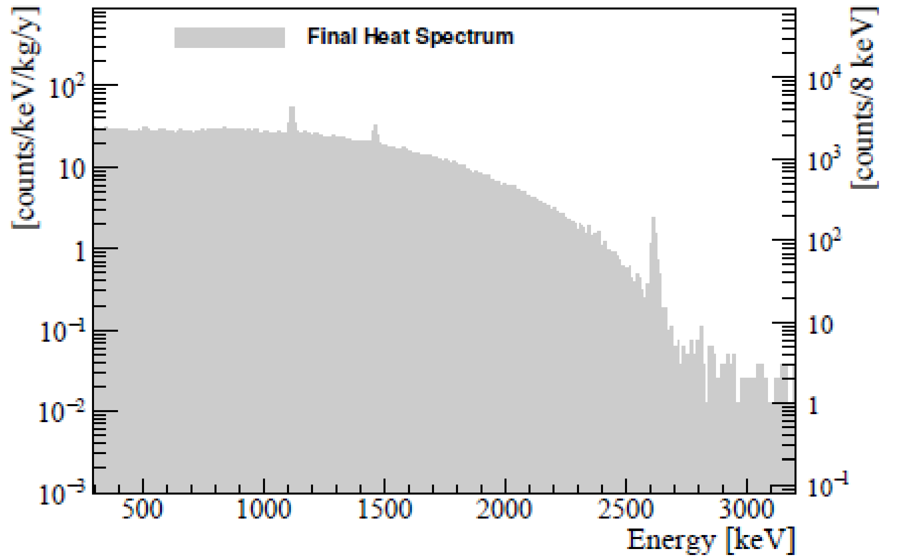


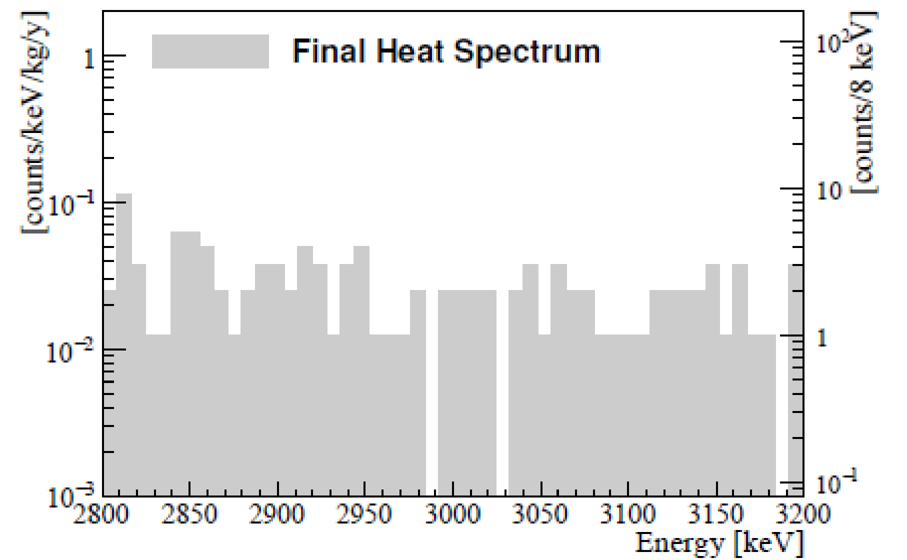
Data selection (1)

1. Rejection of non physics event (earthquake, electronic noise…)
2. Selection of the number of triggering crystals (1 for 0νββ)

Bkg in ROI (2800-3200 keV):

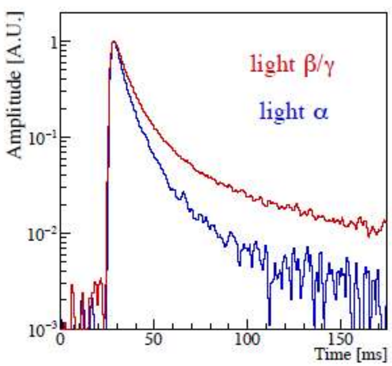
3.2×10^{-2} counts/(keV × kg × yr)

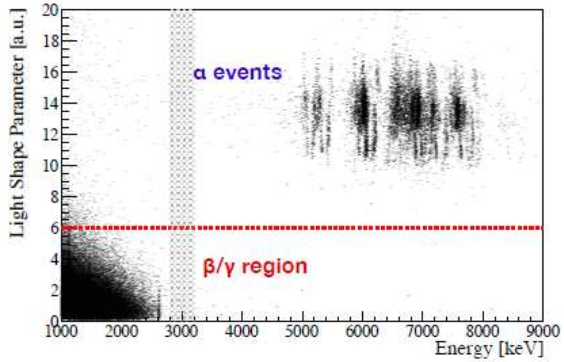


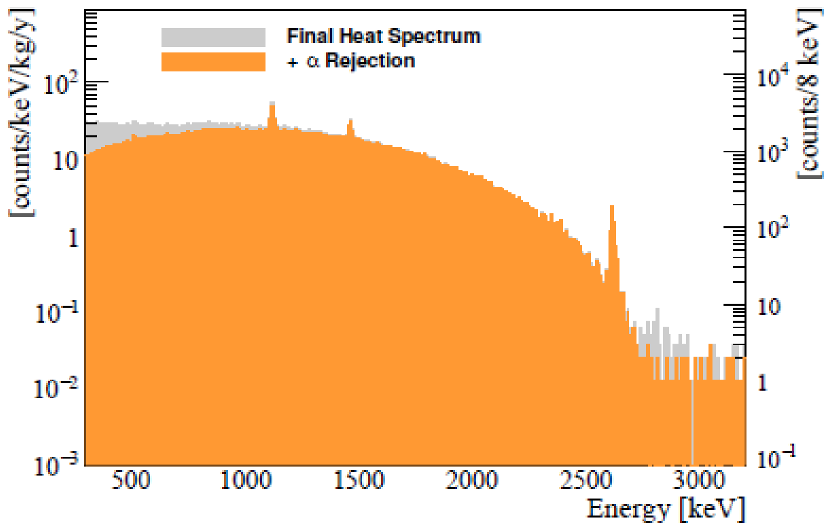


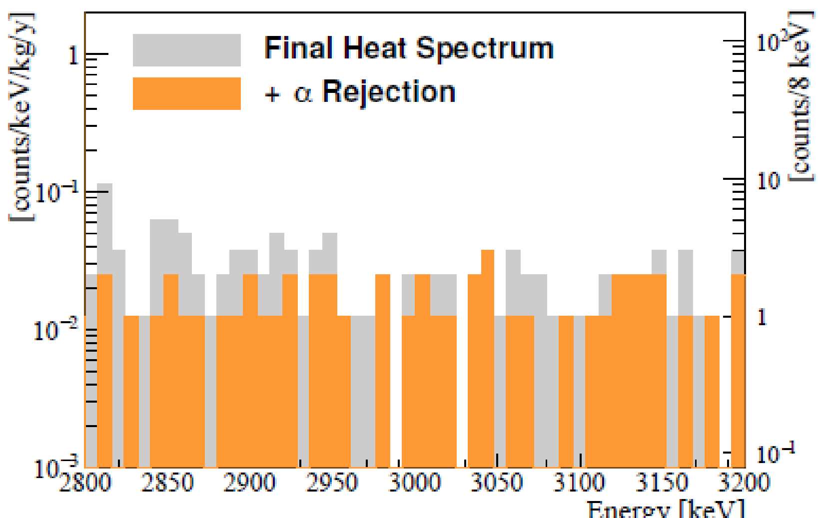
Data selection (2)

3. Add info from LDs







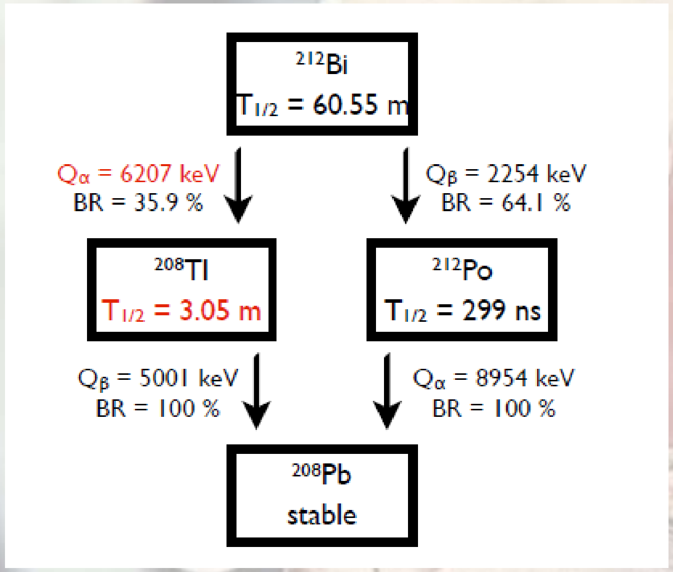


Bkg in ROI (2800-3200 keV):

1.3 x 10^{-2} counts/(keV × kg × yr)

Particle ID → bkg suppression x 3

Data selection (3)



Bkg in ROI (2800-3200 keV):

3.5×10^{-3} counts/(keV × kg × yr)