# CUPID-0: a double-readout cryogenic detector for DBD

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on behalf of the CUPID-0 collaboration

VIENNA CONFERENCE ON INSTRUMENTATION

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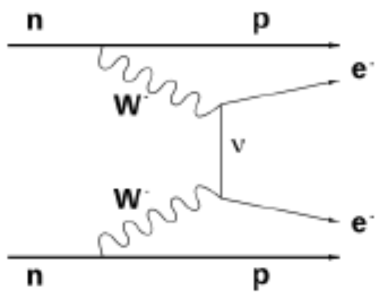
# Experimental search for 0νββ

## 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:

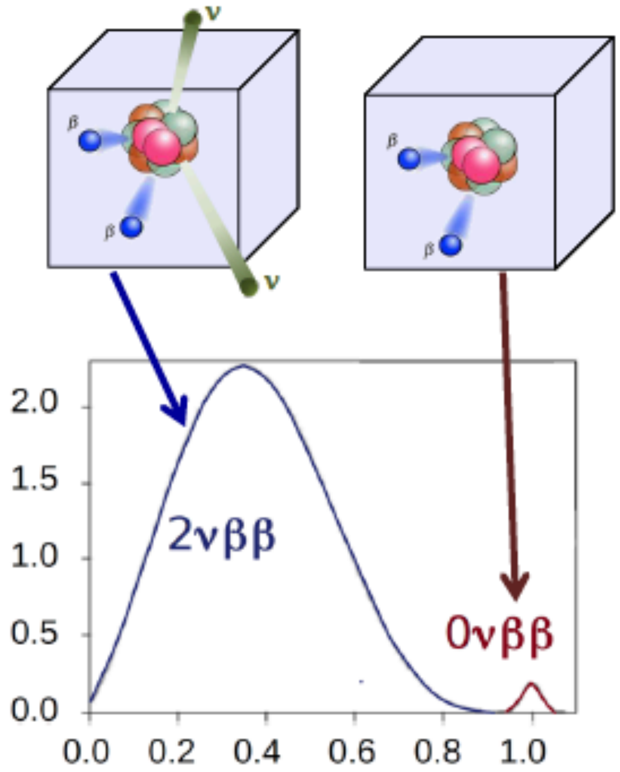
- lepton number violation
- neutrinos are Majorana particles
- measures effective electron neutrino mass

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

## 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.:

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

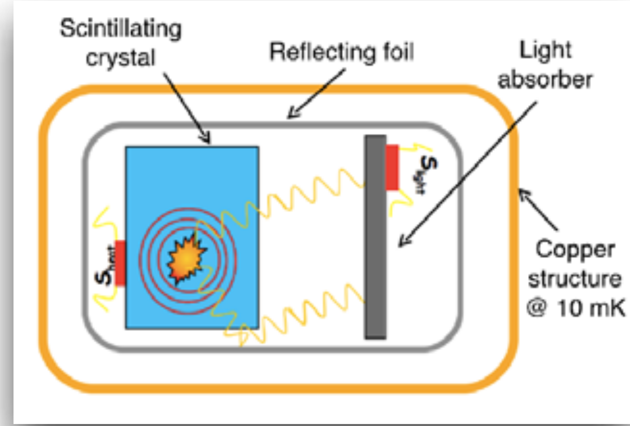
$$S^{0\nu} \propto \epsilon\, i.a.\, MT \qquad b = 0$$

- $M$: Total active mass in kg
- $\epsilon$: Detector efficiency
- $i.a.$: Isotopic abundance
- $b$: Background in c/keV/kg/y
- $\Delta E$: Detector resolution @ ROI in keV
- $T$: Exposure time in y

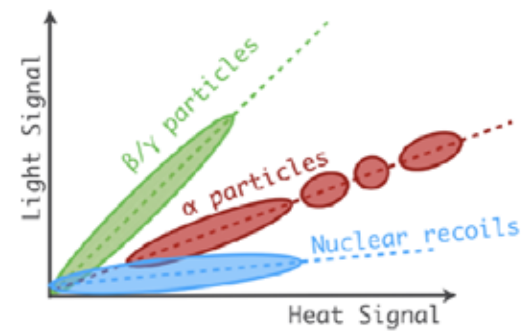
# Scintillating Thermal Detectors (STDs)

A bolometer is a highly sensitive **calorimeter** operated @ cryogenic temperature (~10 mK).

**Energy** depositions are measured as **temperature** variations of the absorber.




- STDs features:
  - high energy resolution O(1/1000)
  - wide choice of compound **Te**$O_2$, Zn**Mo**$O_4$, Zn**Se**
  - high detection efficiency (source = detector)
  - scalable to large masses
  - **particle ID**




The simultaneous read-out of **HEAT** and **LIGHT** allows particle identification

If the absorber is also an **efficient scintillator** the energy is converted into **heat** + **light**

A background-free experiment is possible:

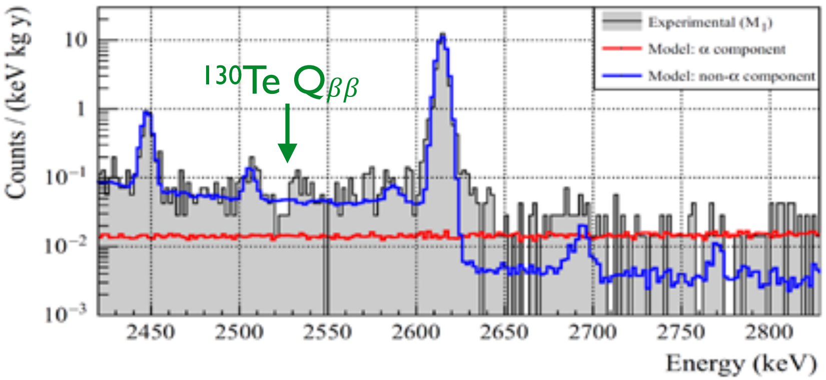
α-background: identification and rejection

β-background: ββ isotope with large Q-value

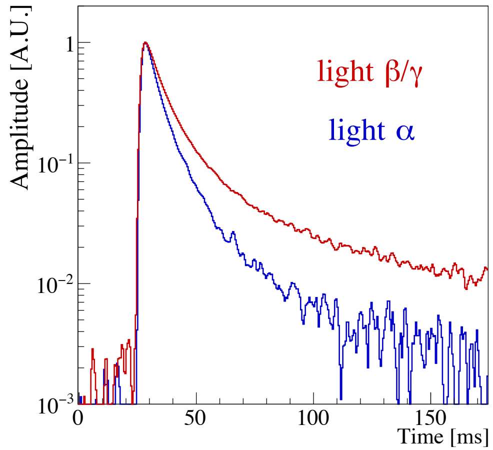
# CUPID-0 (**C**UORE **U**pgrade with **P**article **ID** prototype)

Since bolometers are fully active detectors, they show a large background component due to energy degraded $\alpha$ particles

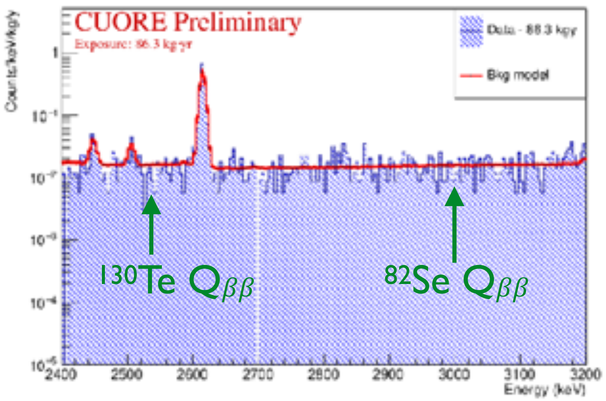
In CUORE-0 the degraded $\alpha$ background was a minor contribution at $^{130}$Te $Q_{\beta\beta}$ (2527.5 keV)



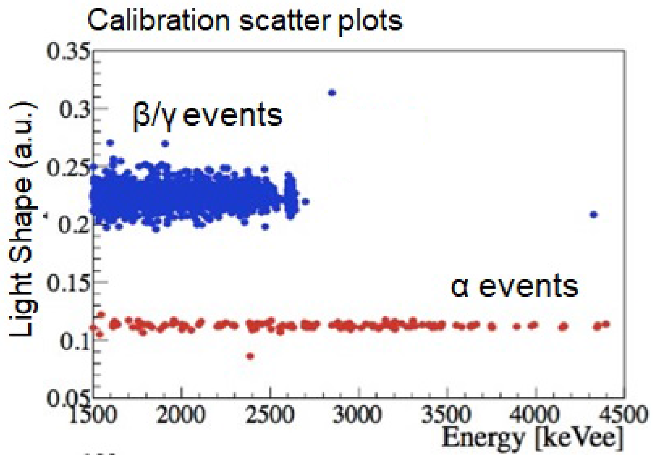

CUPID-0 use a higher $Q_{\beta\beta}$ isotope and rejects $\alpha$ signals using the scintillation LIGHT




In CUORE it dominates over the 2615 keV ($^{208}$Tl) multi-Compton: it's the major component in the ROI



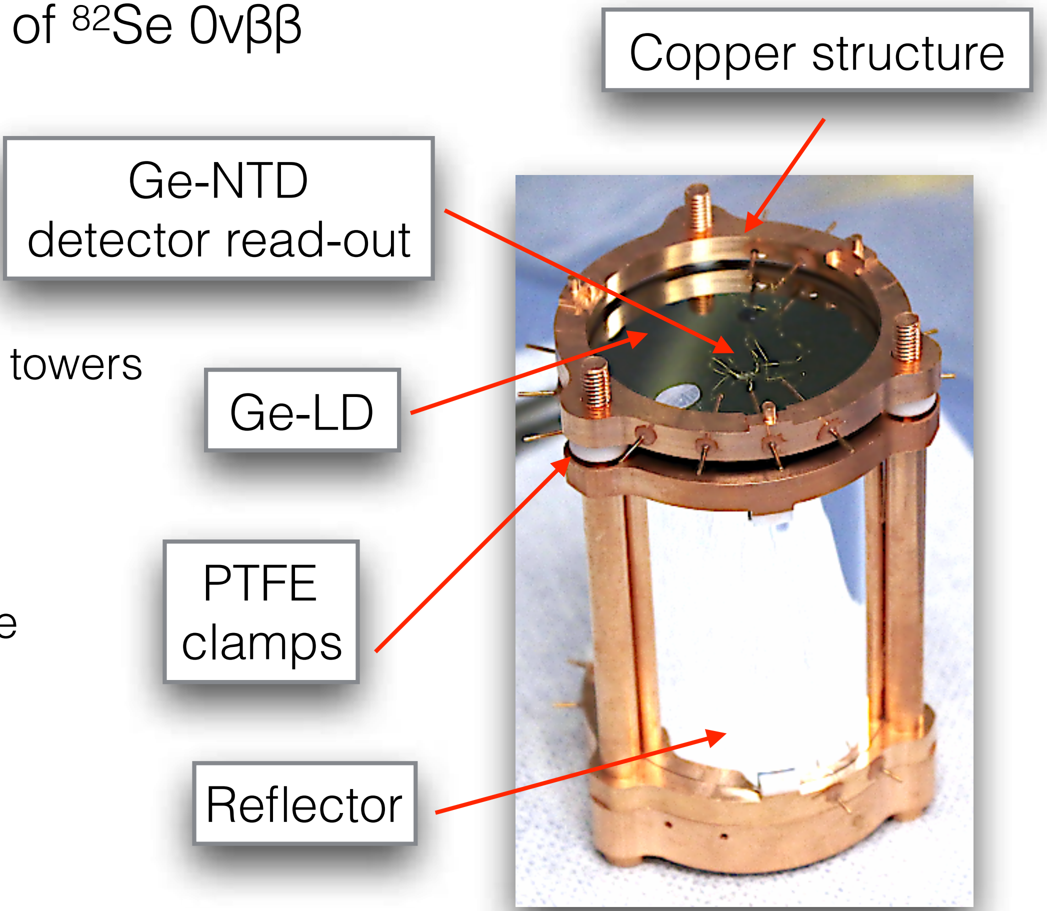

Excellent discrimination can be obtained based on the shape of the light pulse



# CUPID-0 Detector

CUPID-0 is the first array of scintillating bolometers
for the investigation of $^{82}$Se 0νββ

- $^{82}$Se Q-value 2998 keV (above $^{208}$Tl line)
- 95% enriched Zn$^{82}$Se bolometers
- 26 bolometers (24 enr + 2 nat) arranged in 5 towers
  - 10.5 kg of ZnSe
  - 5.17 kg of $^{82}$Se —> 3.8x10$^{25}$ ββ nuclei
- LD: Ge slab operated as bolometer. One face coated with 60 nm $SiO_2$ —> Light collection enhancement ~50%
- Simplest modular detector -> scale up
  - Copper structure (ElectroToughPitch)
  - PTFE clamps
  - Reflecting foil (VIKUITI 3M)

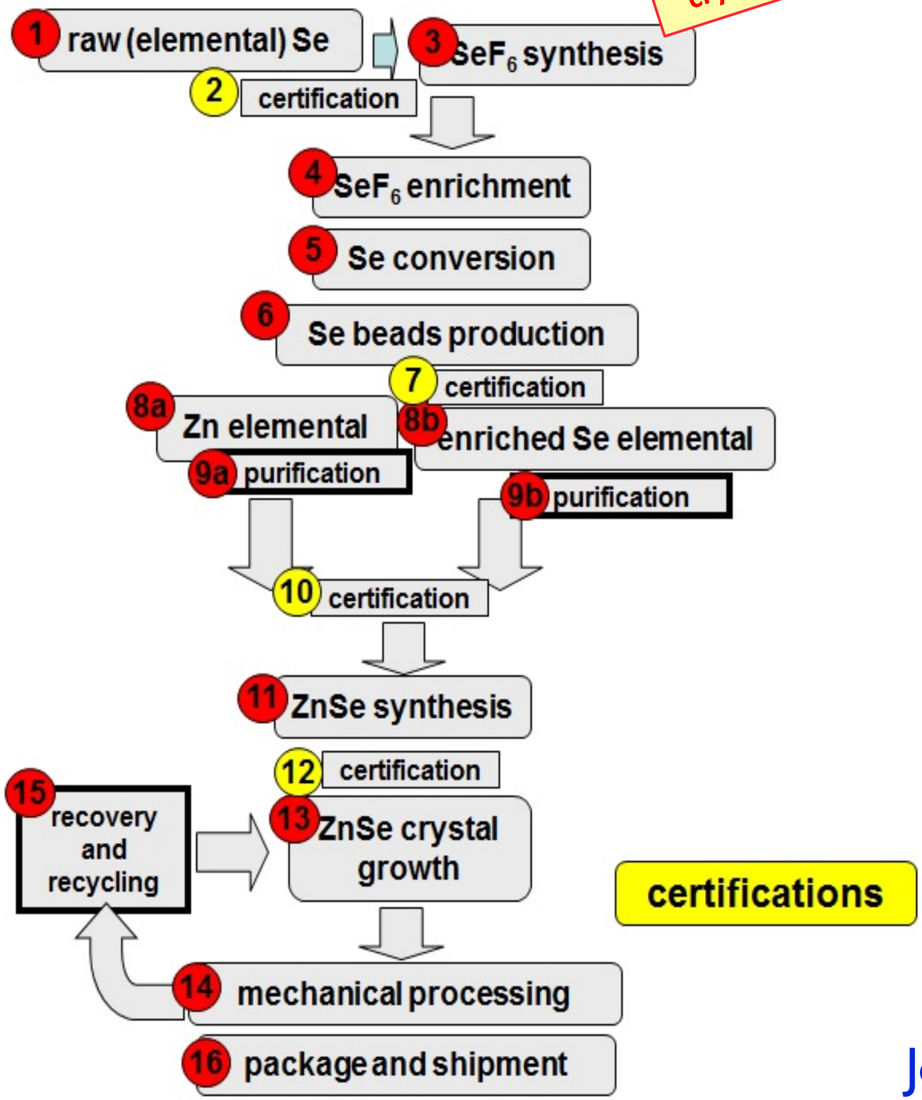



Main goal :
Minimize mass of passive materials next to the detector

# $Zn^{82}Se$ crystals production

**crystals production cycle**

similar for any crystal candidate





Journal of Crystal Growth 475 (2017) 158–170

# $Zn^{82}Se$ crystals production

**enrichment**: $^{82}Se$ from 8.82% to 96.30% (URENCO, Almelo, Holland)

**$Zn^{82}Se$ synthesis and crystal growth**:

(ISMA Kharkiv Ukraine with strong INFN contribution)

**final processing (cutting and polishing)**:

@ LNGS, INFN Italy

**production yields**:

synthesis: 98.35%

(99.55% at S-1, 99.40% at VTT and 99.40% at HTT)

crystal growth*: 95%

cutting*: 96,72%

shaping and polishing*: 99%

*including recovered material for recycling

**radio-purity measured during crystal production**

| Nuclides | HPGe γ-spectroscopy at LNGS: Metal $^{82}Se$ [μBq/kg] | HPGe γ-spectroscopy at LNGS: Metal Zn [μBq/kg] | $Zn^{82}Se$ bolometric test (Hall C): Crystal [μBq/kg] |
|---|---|---|---|
| $^{232}Th$ | | | 7±2 |
| $^{228}Th$ | <110 | <95 | 26±2 |
| $^{224}Ra$ | <61 | <36 | 27±3 |
| $^{238}U$ | | | 10±2 |
| $^{226}Ra$ | <110 | <66 | 33±4 |
| $^{210}Po$ | | | 150±8 |

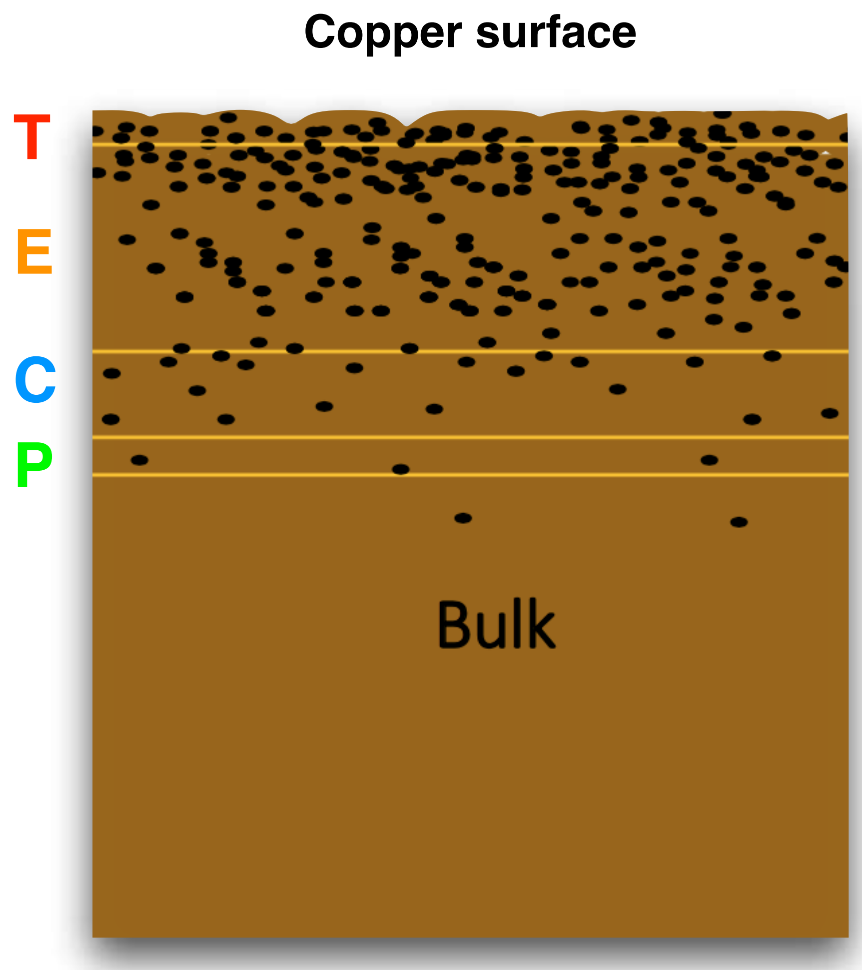
*J.W. Beeman et al., Eur. Phys. J. C76 (2016) 7, 364*

**confirmed by CUPID-0 data**
O. Azzolini et al. , Eur. Phys. J. C. (2018) 78:428

# CUPID-0 Copper Cleaning

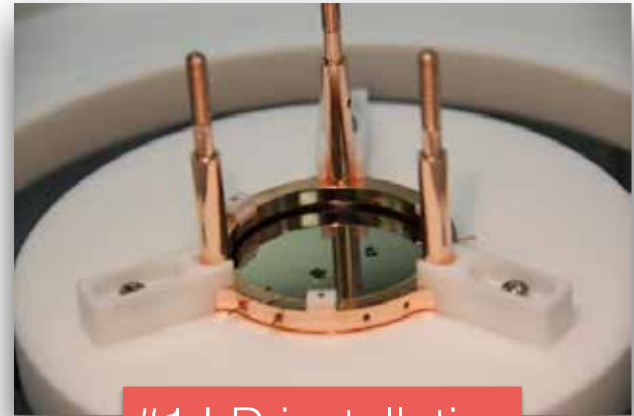
Copper cleaning procedure for mitigating surface contaminations

- **Pre-cleaning:** lubricant removal from machining
- Tumbling: abrasion + smoothening
  - removal 1.2 um (0.06 um/h)
- Electropolishing: smoothening
  + contaminants dissolution
  - removal 100 um (12 um/h)
- Chemical etching: SUBU+passivation
  - removal 10 um (120 um/h)
- Plasma etching: desorption
  - 0.2 um (1um/h)

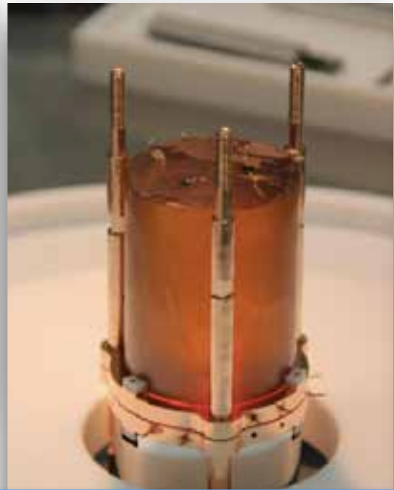


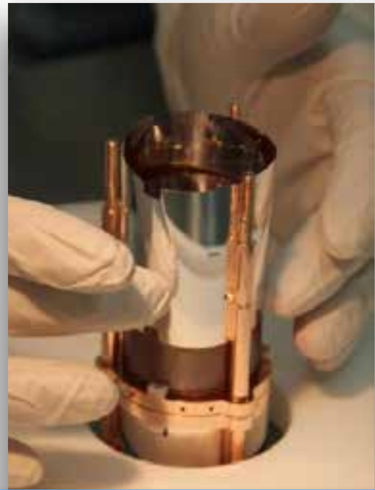
# CUPID-0 assembly

Detector assembly performed in ~2 weeks inside a low-Rn underground clean room at LNGS



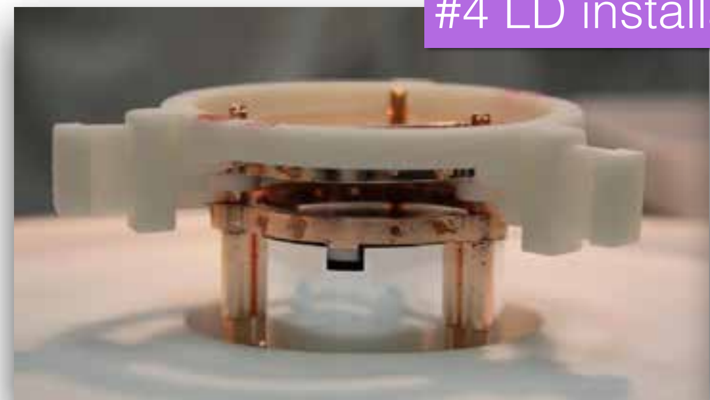
#1 LD installation

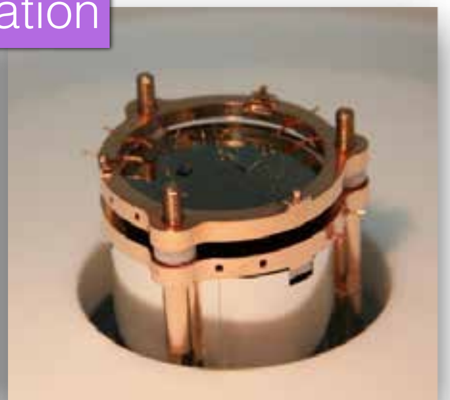




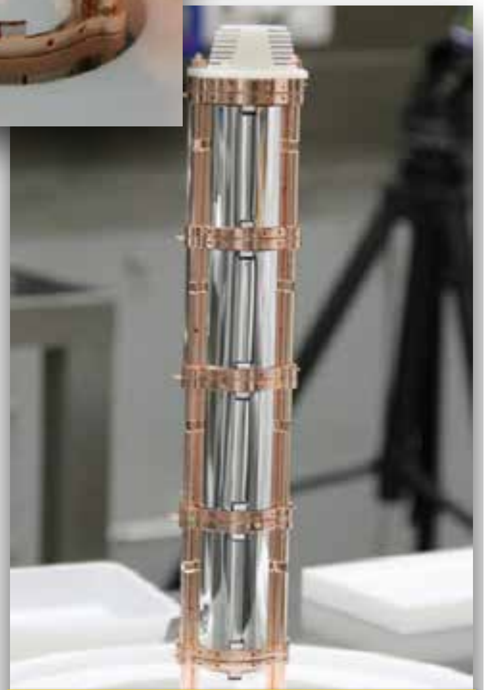
#2 ZnSe and light reflector installation

#3 Fixing of ZnSe





#4 LD installation



#5 Tower completed

# CUPID-0 installation

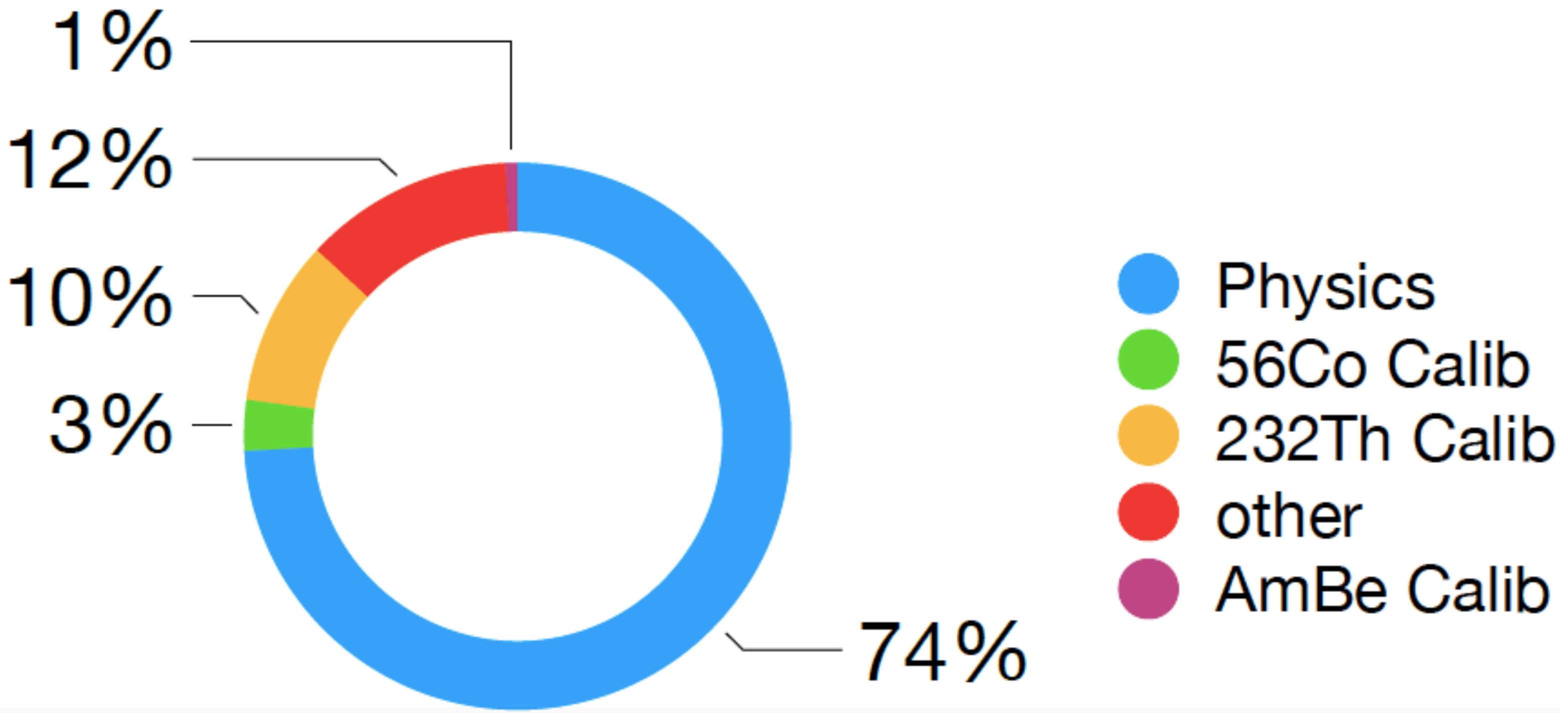
Detector installed in the former CUORE-0 cryostat after some improvements:

- Refurbishment of the Rn-abatement system next to the cryostat (to reduce in particular $^{214}$Bi)
- A second stage pendulum to reduce vibrational noise (fundamental for the LD performance)
- New Cryostat wiring: can host up to 120 det.

In June 2017 the commissioning was finished and the data taking started

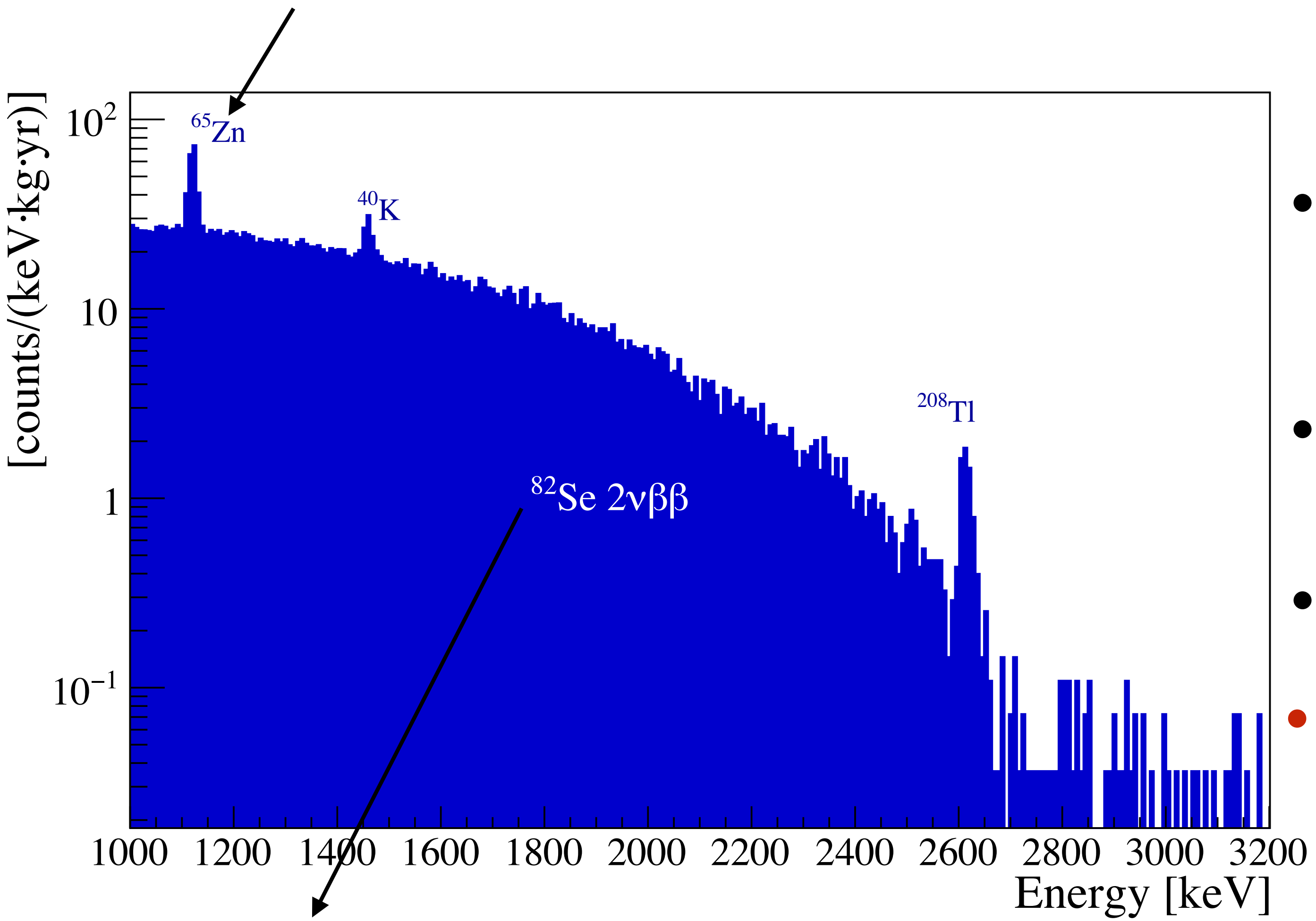
# CUPID-0 exposure

- Exposure for 0νββ: 9.95 kg x yr ($3.88 \times 10^{25}$ emitters x yr)
- Official data-taking, from 01/06/2017 to 14/12/2018: about 560 d.



# CUPID-0 full spectrum - 5.46 ($Zn^{82}Se$) kg y exposure

Cosmogenic activation

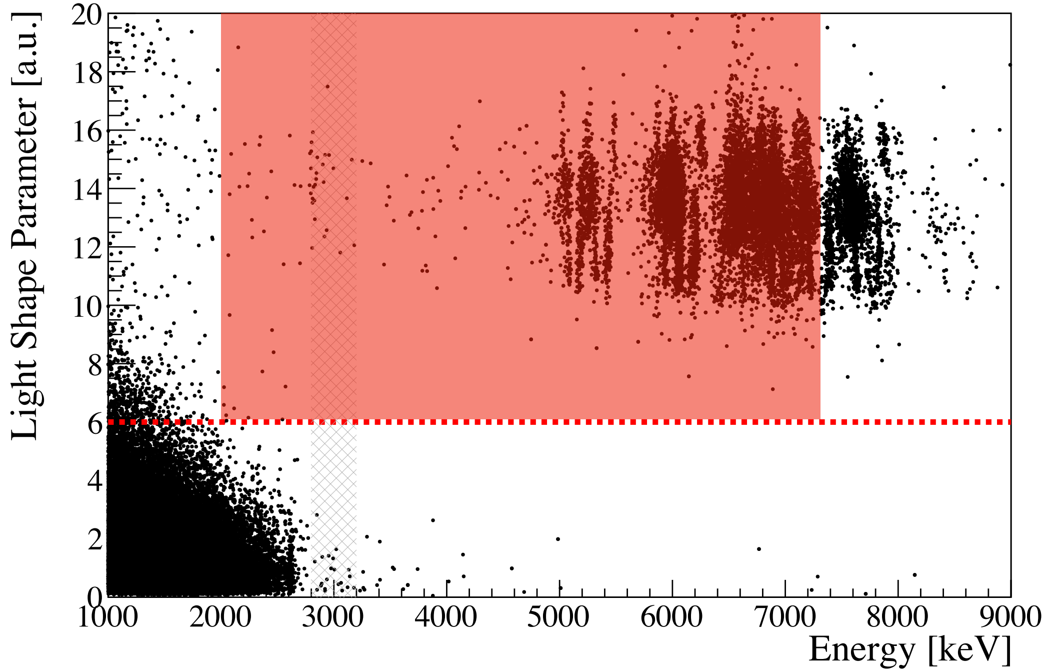



- Rejection of "non-particle-like" events through pulse shape on thermal pulses.
- Anti-coincidence between ZnSe crystals
- $\alpha$ rejection by light shape
- Delayed coincidences veto

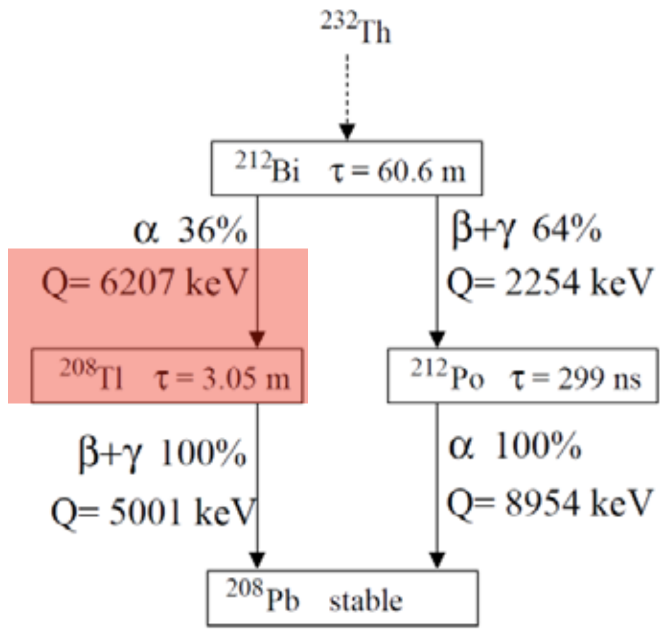
$T_{1/2} = (9.2 \pm 0.7) \cdot 10^{19}$yr

A. S. Barabash, https://doi.org/10.1016/j.nuclphysa.2015.01.001

# $\beta/\gamma$ background: $^{232}$Th internal and surface contaminations




Tag

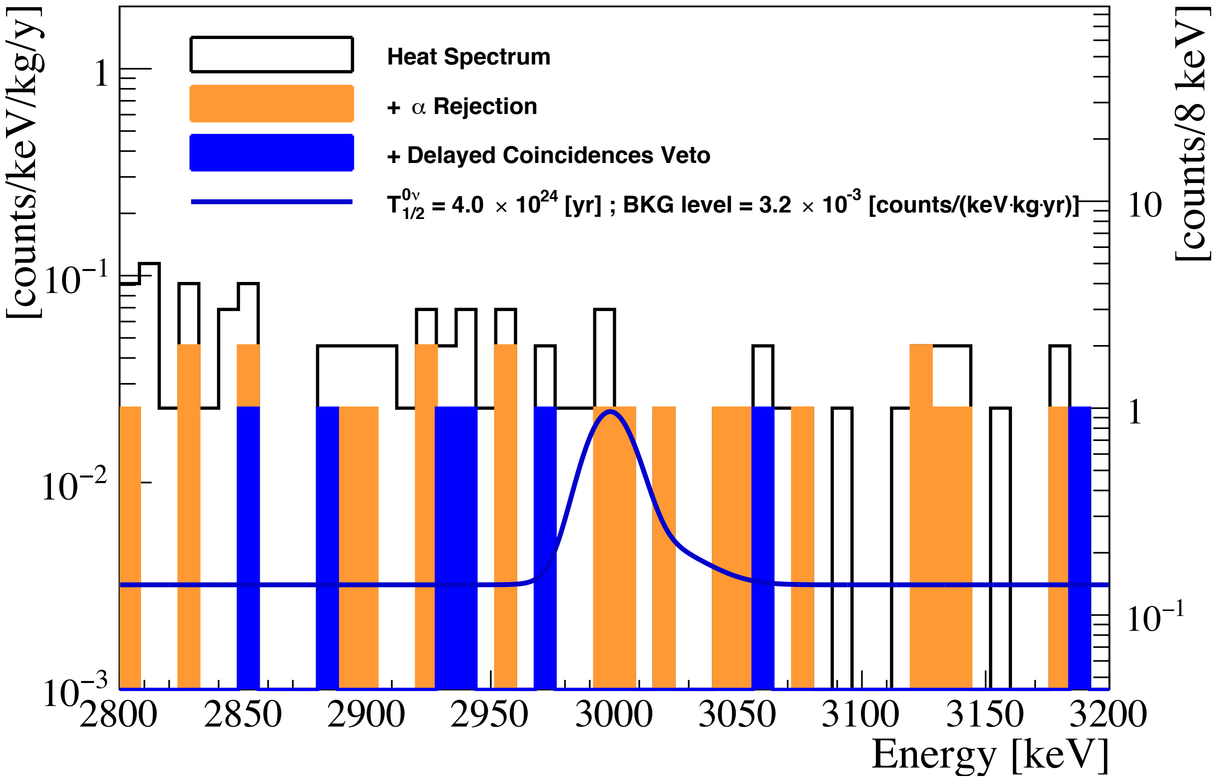



We apply a 3 half-life time veto after all $^{212}$Bi **α** events

Rejection of the $^{208}$Tl induced background (**internal** crystal contamination)

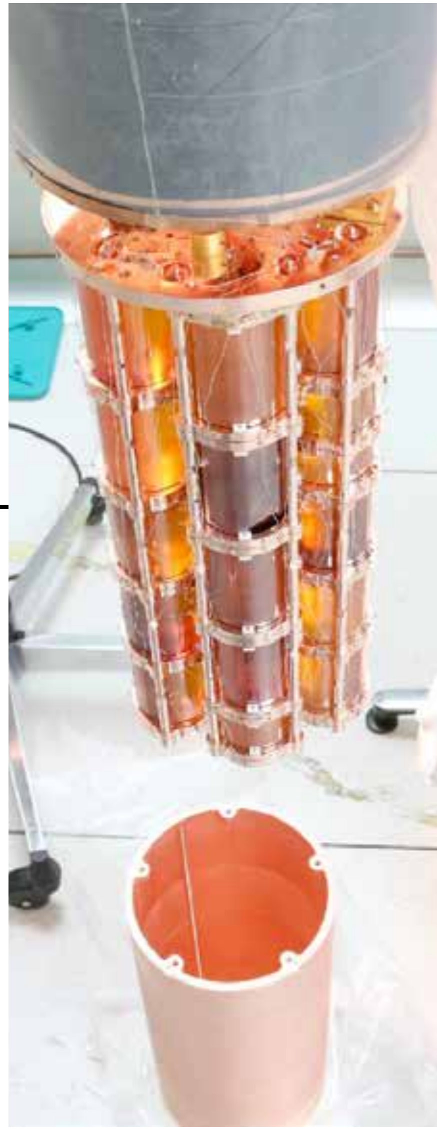
**Surface** crystal contamination -> we veto after all **α** interactions with energy between 2 and 6.5 MeV

# CUPID-0 limit - 5.46 (Zn$^{82}$Se) kg y exposure




| | |
|---|---|
| Exposure | 5.46 (Zn$^{82}$Se) kg y |
| Background | $3.2^{+1.3}_{-1.1}$ counts/keV/ton/y (Zn$^{82}$Se) |
| Lower limit, half-life: | $T_{1/2}(0\nu) \geq 4.0 \times 10^{24}$ y (90% C.L.) |
| Eff. (trigger + data sel. + ββ containment) | 75 ± 2 % |

# CUPID-0: What Next ?



January 2019: stop data taking for a major detector upgrade:

- Remove the reflective foils
- Install a new clean copper shield
- Introduce a (partial) muon veto

# CUPID-0: What Next?

What can we learn with detector upgrades:

- Check the bulk/surface ratio of the external radio-contaminations
- Improve the detector stability and understand the origin of $^{208}$Tl contamination
- Study the muon contribution via MC/data comparison or muon tagging
- …

# Conclusions

CUPID-0: first large array of enriched scintillating bolometers for the study of $^{82}Se$ $0\nu\beta\beta$

- Proved the potential of PID for background rejection
- Will continue with the Phase-II program

Despite the small exposure, best 90% C.I. limit on the $0\nu\beta\beta$ of $^{82}Se$

**$\tau_{1/2} > 4.0 \cdot 10^{24}$ yr in 2.90 kg yr of $^{82}Se$**

**(Nemo results: $\tau_{1/2} > 3.6 \cdot 10^{23}$ yr in 3.5 kg yr of $^{82}Se$)**

New data release soon, together with other studies ($2\nu\beta\beta$, CPTV, Bkg model…)