# CUPID

## Cuore Upgrade with Particle IDentification

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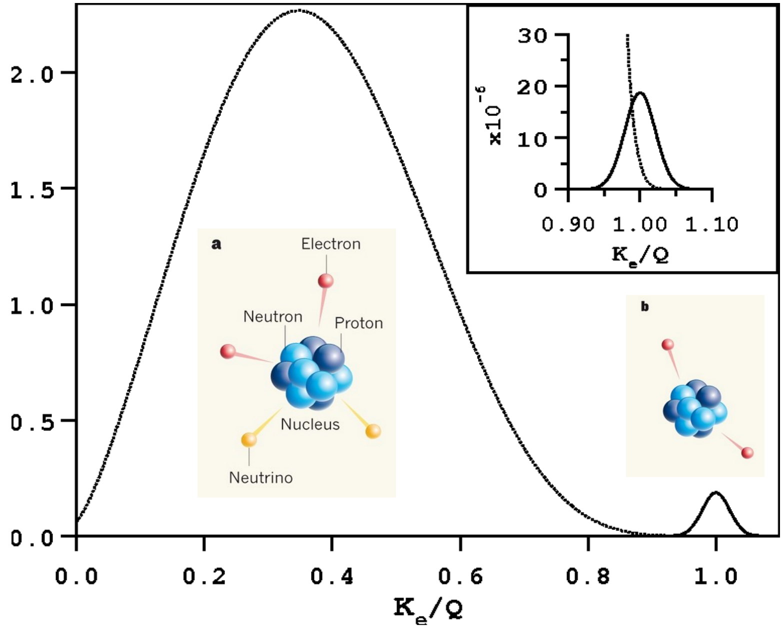
19-21 october 2022

# SEARCHING FOR 0ν2β

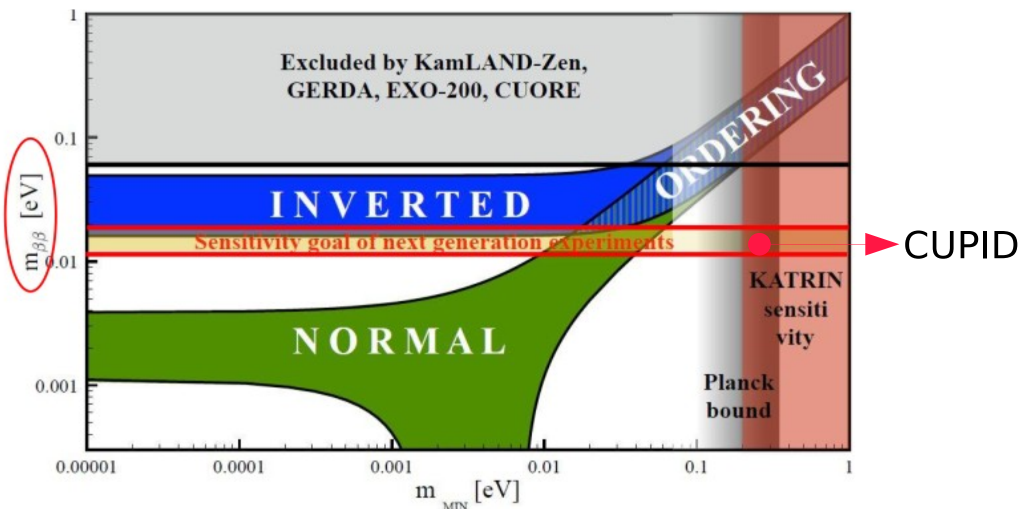
- An hypothetical decay : $(A,Z) \rightarrow (A,Z+2) + 2e^-$
- Leads to a peak in the sum of $e^-$ energy spectrum
  - Violates the lepton number conservation
- Could prove the Majorana nature of the neutrino ($\nu = \bar{\nu}$)
- Gives clues about matter/antimatter asymmetry and information on mass hierarchy




An extremely rare decay : $T^{0\nu}_{1/2} > 10^{25} - 10^{26}\ yr$

**In case of light Majorana neutrino exchange :**

Theory: $(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)|M^{0\nu}|^2 \frac{m^2_{\beta\beta}}{m^2_e}$




Experimental sensitivity: $T^{0\nu}_{1/2} \propto a \times \epsilon \times \sqrt{\frac{M \times t}{b[ckky] \times \Delta E}}$

Background index : $b(ckky) = \frac{number\ of\ bckg\ counts}{M \times t \times \Delta E}$

in the region of interest

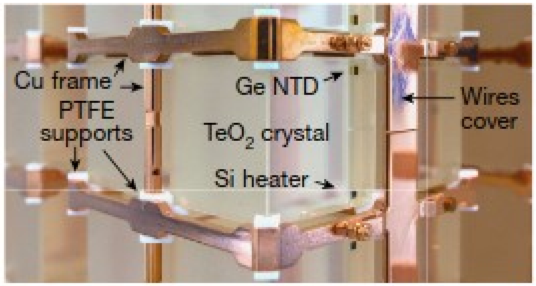
# CUORE IN A NUTSHELL

$0\nu2\beta$ isotope : $^{130}$**Te** ($Q_{\beta\beta}$=2527 keV)

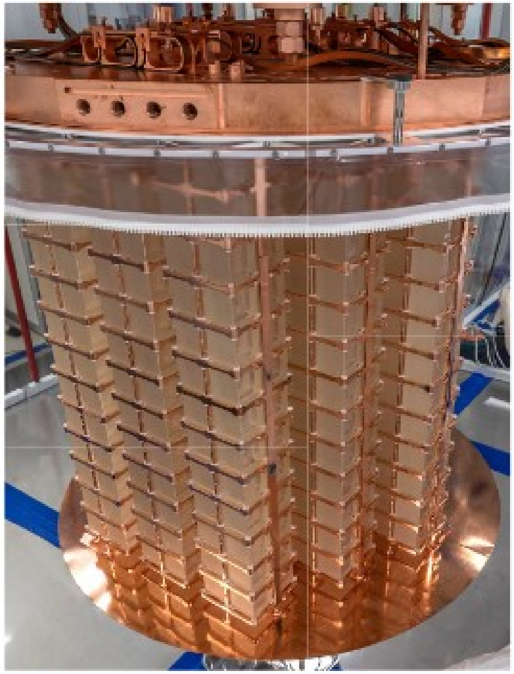
The **largest** bolometric experiment :

988 5x5x5cm crystals of $TeO_2$
19 towers of 13 floors each

Total mass : **742 kg** (206 kg of $^{130}$Te)




**One of the most sensitive** current generation $0\nu2\beta$ **experiment**



Energy resolution : **7.8(5) keV FWHM** in ROI

Current limit with **1 ton.yr** exposure* :

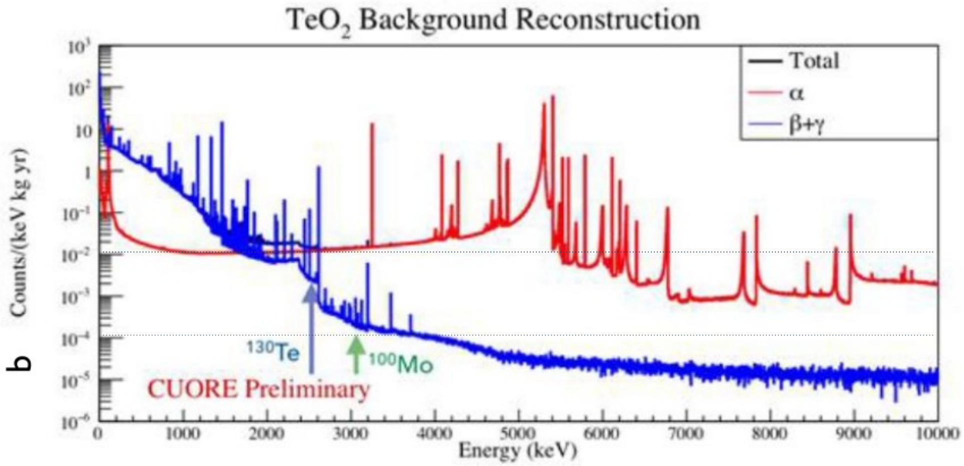
$\mathbf{T_{1/2} > 2.2 \times 10^{25}}$ **yr**
$m_{\beta\beta}$< 90-300 meV

Projected sensitivity after 5 years :

$T_{1/2} \sim 9 \times 10^{25}$ yr
$m_{\beta\beta}$< 60-280 meV

** Nature 604, 53–58 (2022)*

# FROM CUORE TO CUPID




But CUORE is **not background free** !
b~$10^{-2}$ ckky dominated by surface α

**Upgrade required** to increase the sensitivity and **reach objectives of next generation experiments** !

**Important messages from CUORE :**

° Bolometric ton scale experiments are possible

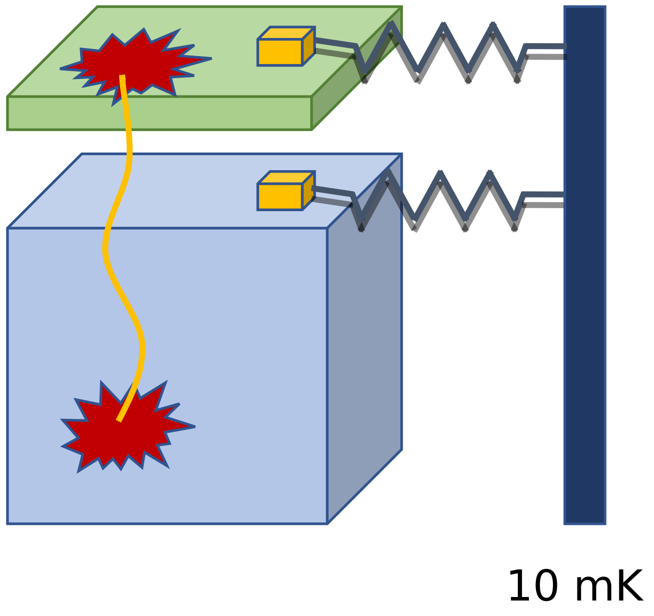
° The CUORE cryostat is suitable to host a next generation experiment like CUPID

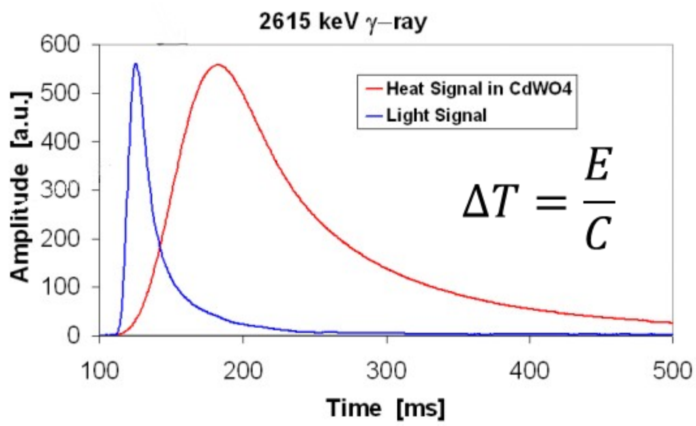
**Objective** : reduce by a factor 100 the background and reach b~$10^{-4}$ ckky with CUPID

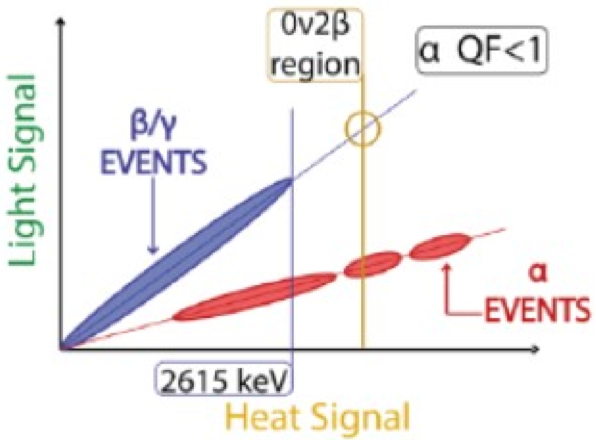
To reject the α background → Use **scintillating bolometers** and a heat/light dual readout

To mitigate the ɣ background → **Change of isotope**, from $^{130}$Te to **$^{100}$Mo** which has a Q-value > 2.615 MeV ($Q_{\beta\beta}$=3034 keV)

# BOLOMETRIC TECHNIQUE




- Scintillating main absorber embedding a 0v2β candidate
- Light detector (Ge wafer)
- Thermistor $R = R_0 \cdot \exp\left(\sqrt{T_0/T}\right)$ NTD (Neutron Transmutation Doped) Ge
- Thermal bath

**Dual readout :**

Two signals per event

α-event discrimination (>99% in the ROI)

**Ideal for 0v2β search :**

Detector=Source approach → High efficency (~ 80 – 90 %)

Excellent energy resolution (down to ~5 keV in the ROI)

Large masses achievable using arrays of crystals

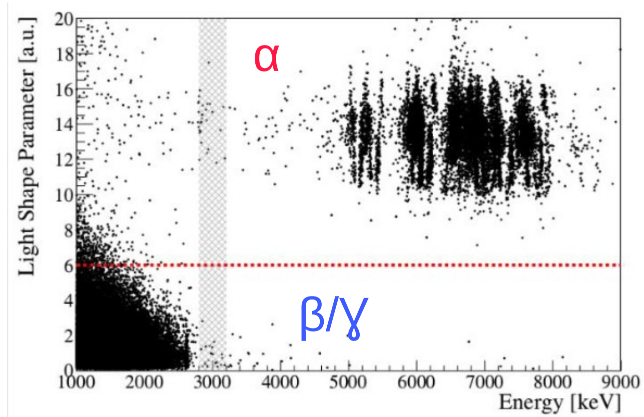
Large flexibility for the absorber material choice

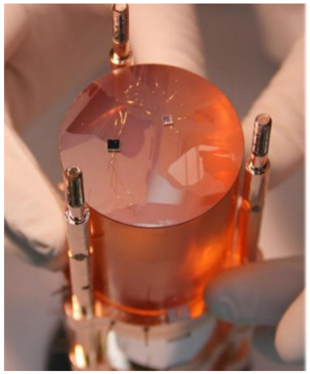
# ISOTOPE AND CRYSTAL CHOICE

## First demonstrator using scintillating bolometers : CUPID-0 in LNGS

24 $Zn^{82}Se$ crystals ($Q_{\beta\beta}$=2998 keV)
with 95 % enrichement in $^{82}Se$
31 Ge light detectors
Total mass : 5.17 kg of $^{82}Se$
Excellent α rejection
Best limit on $^{82}Se$ $0\nu2\beta$

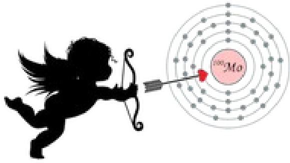
Phys. Rev. Lett. 129, 111801



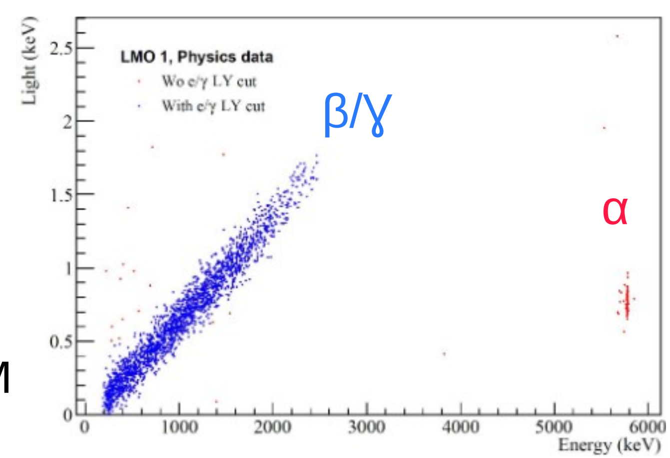



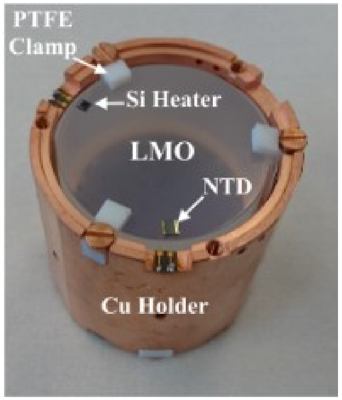
BUT **not the best choice for CUPID** : **High internal contamination** of the crystal + not an excellent energy resolution (**~23 keV FWHM**)

## The choice for CUPID : CUPID-Mo in LSM



20 $Li^{100}MoO_4$ crystals ($Q_{\beta\beta}$=3034 keV)
with 95 % enrichement in $^{100}Mo$
20 Ge light detectors
Total mass : 2.34 kg of $^{100}Mo$
1.47 kgxyr exposure
**Full α rejection** (>99%)
Best limit on $^{100}Mo$ $0\nu2\beta$ : $T_{1/2}$> $1.8\times10^{24}$ yr*
**Excellent energy resolution** : 7.4 keV FWHM
**Radiopure crystals** : U/Th ≤ 1 μBq/kg




*arXiv:2202.08716v1 [nucl-ex] 17 Feb 2022

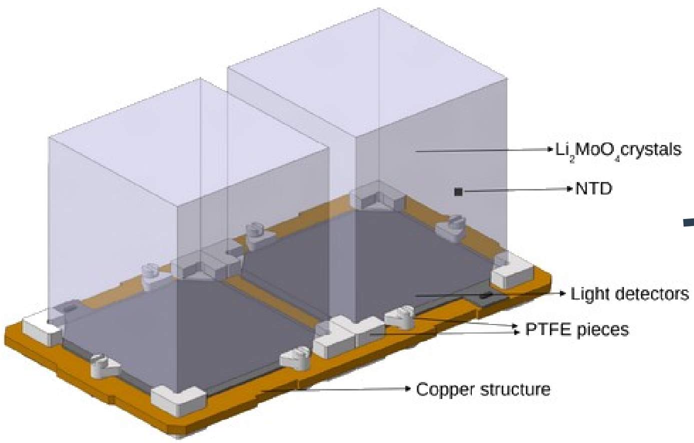
# CUPID BASELINE DESIGN

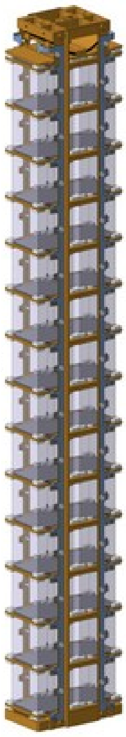
CUORE CRYOSTAT

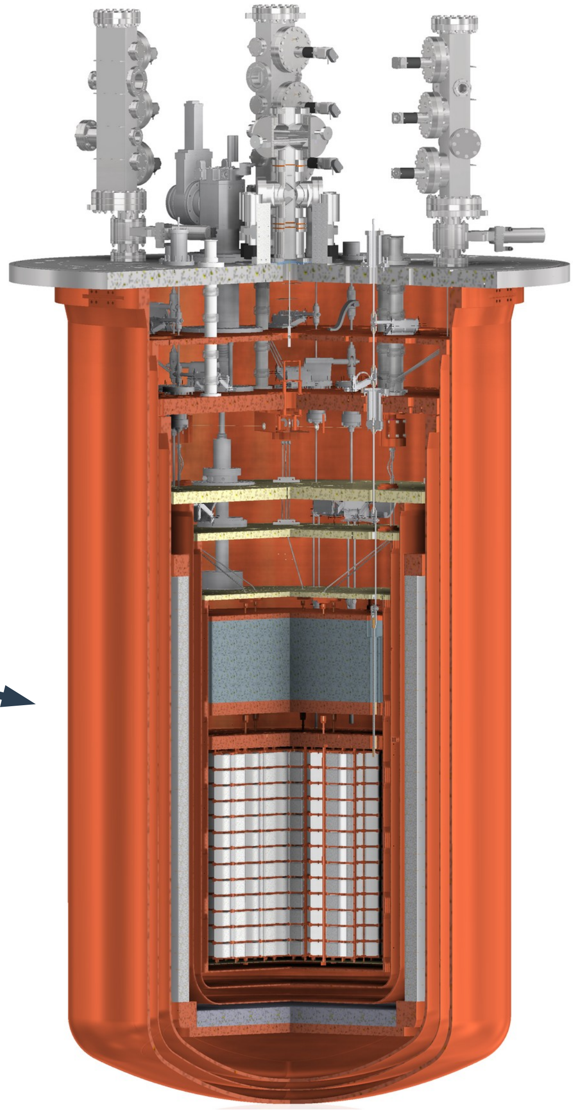
-Use of the CUORE cryostat at LNGS
(available in ~2024)

- **1596 45x45x45mm³ $Li_2{}^{100}MoO_4$ crystals** of ~280g each

- Arranged in **57 towers** of **14 floors**
- Total mass : 450 kg with
~**240 kg of $^{100}$Mo** thanks to a >95% enrichment



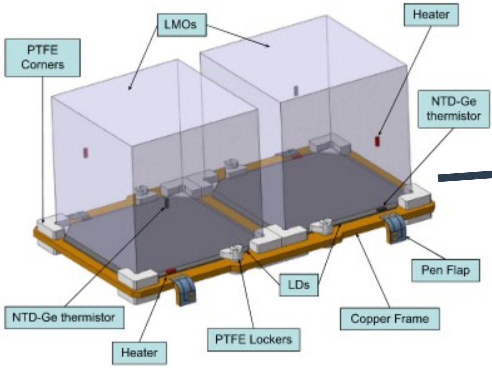



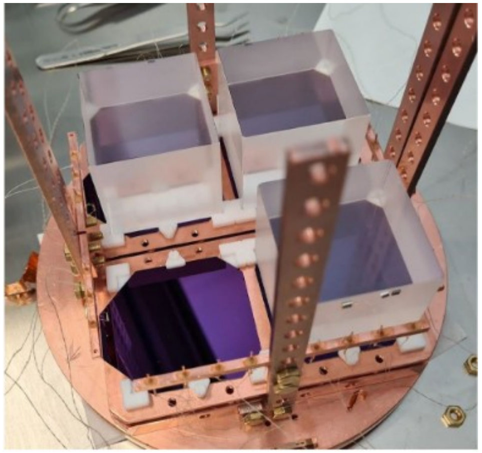


- **Ge light detectors** with SiO antireflective coating
(each crystal has top and bottom LD)

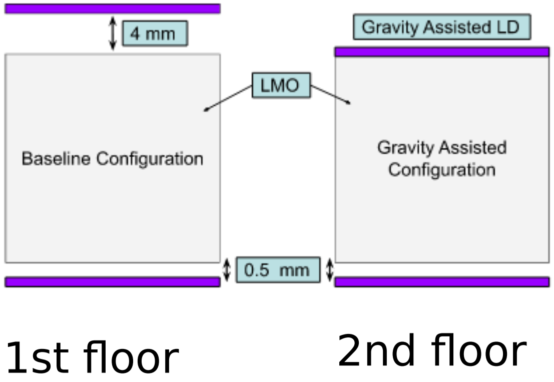
- **Muon veto** for muon induced background suppression

## Optimization of the first CUPID detector module



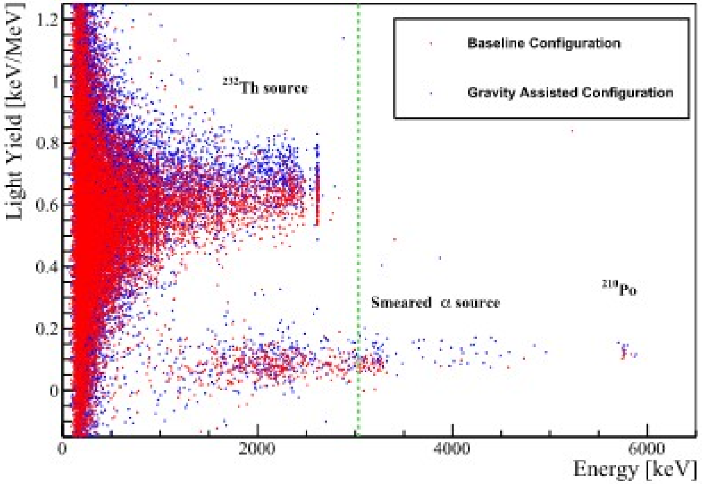
Eur. Phys. J. C 82, 810 (2022)




First test of the CUPID module in LNGS :

- The goal was to **check performance and light collection**. A gravity assisted configuration was also tested.

- 8 LMO crystals arranged in 2 floors of 4.




- **Good performance obtained :**

- LD $FWHM_{bsl}$ =35-70 eV (<100 eV)

- α rejection > 99.9 %

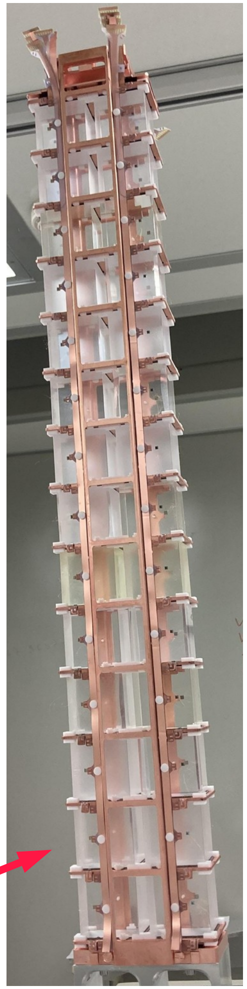
- Energy resolution = 5.9 keV FMWH

- **Validation of the LD quasi-square shape** and of **the way to hold them** + **discarding of the gravity assisted configuraton** for LDs.
- First step towards the first tower….

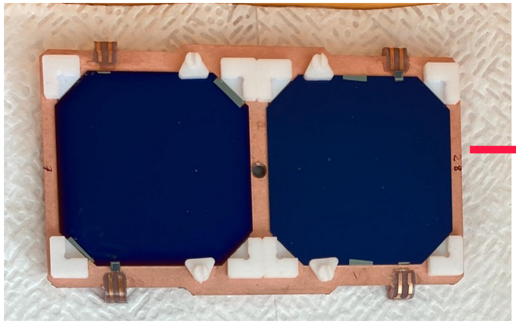
## The CUPID Baseline Design Prototype Tower (BDPT)

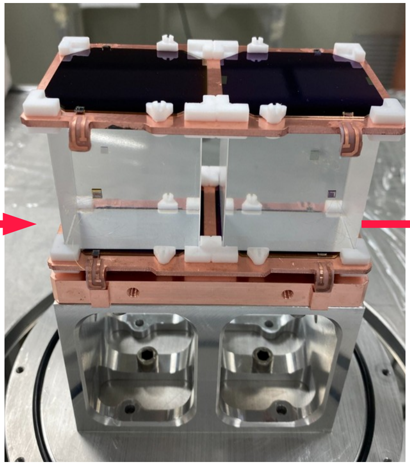
**First test of the BDPT at LNGS composed of :**

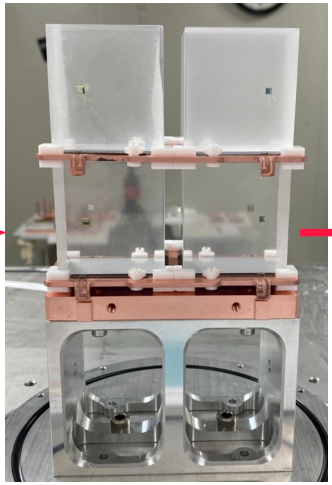
- **14 baseline modules** stacked in a tower
- **28 LMO** crystals from different origins :
  - 6 new naturals from BINGO
  - 8 enriched from CROSS
  - 6 naturals from a chinese provider
  - 8 naturals already tested in LNGS
- **30 Ge light detectors**

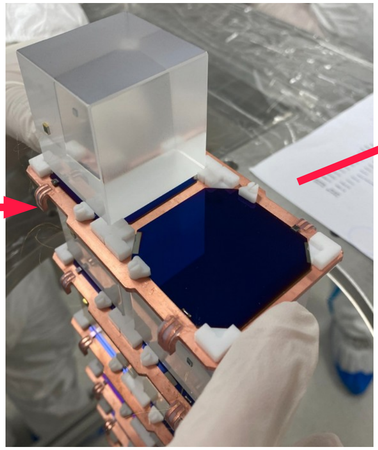


**Easy to assemble :**









# RECENT RESULTS AND R&D

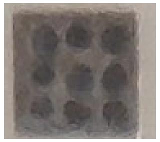
## The CUPID Baseline Design Prototype Tower (BDPT)

**Allows to test several things :**

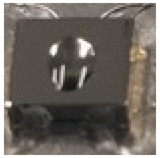
- **Different glue** for the NTDs tested :

- Araldite rapid


- Araldite slow

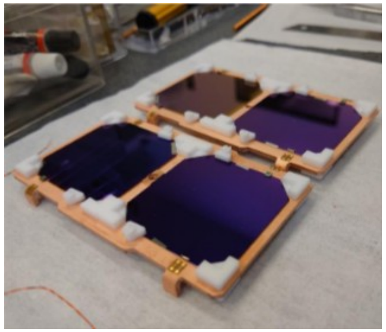
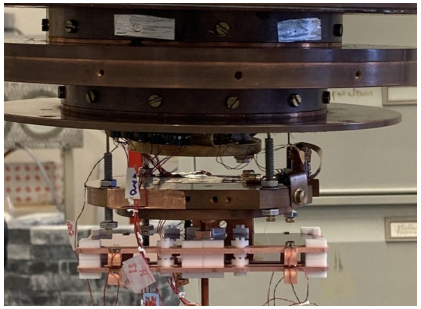
- UV glue




- Test the **behaviour at low temperature** (temperature gradient, cooling down…)

- **Performance homogeneity** between floors

All the gluing of the detectors done in Orsay at IJCLab + 2 modules of 4 LDs were tested upstream in our cryostat and have obtained promising results !

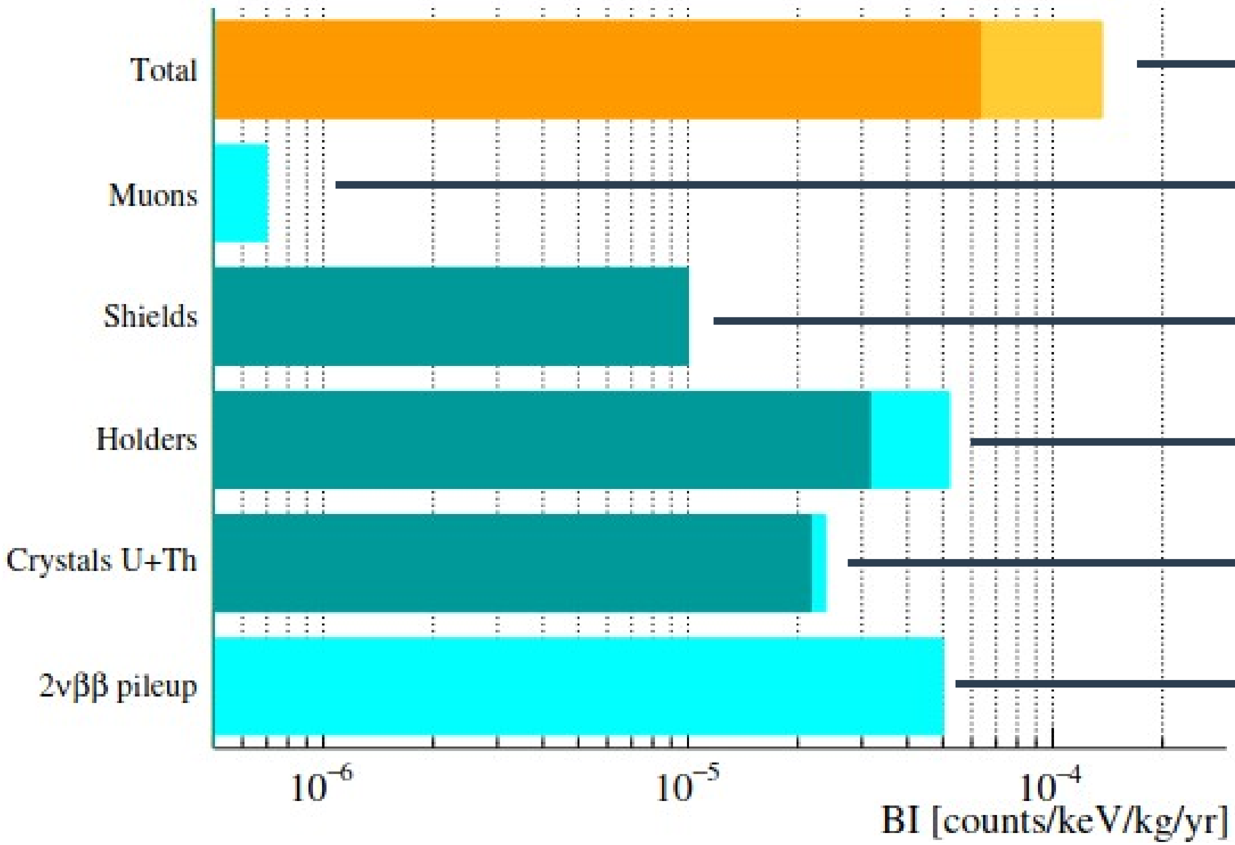



Analysis of the measurements ongoing, and results under review of the collaboration.  It should be soon presented !!

# CUPID PROJECTED BACKGROUND

Projected background index : **b=1x10$^{-4}$ ckky**

Robust background model built with **CUORE**, **CUPID-0** and **CUPID-Mo**




Total b~10$^{-4}$ ckky

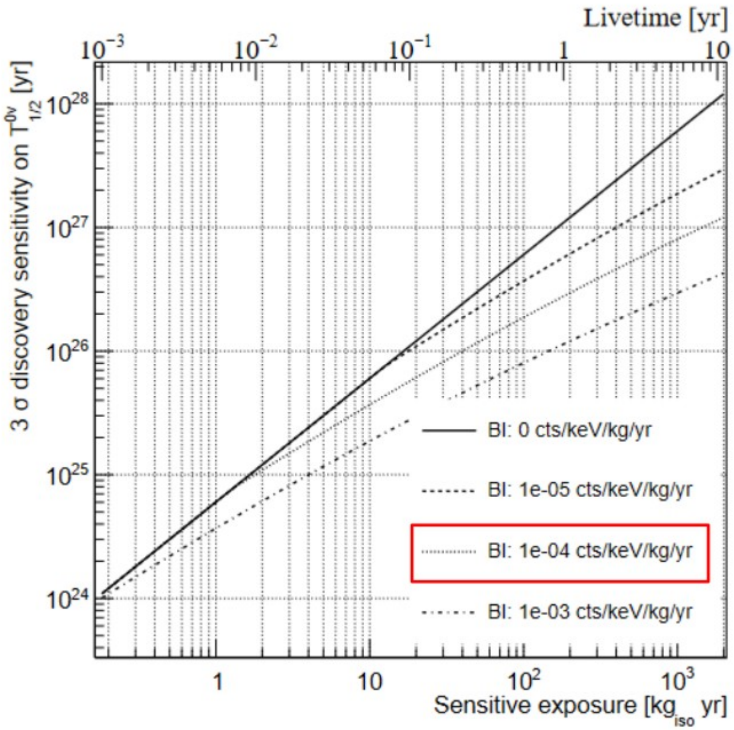
Muon veto

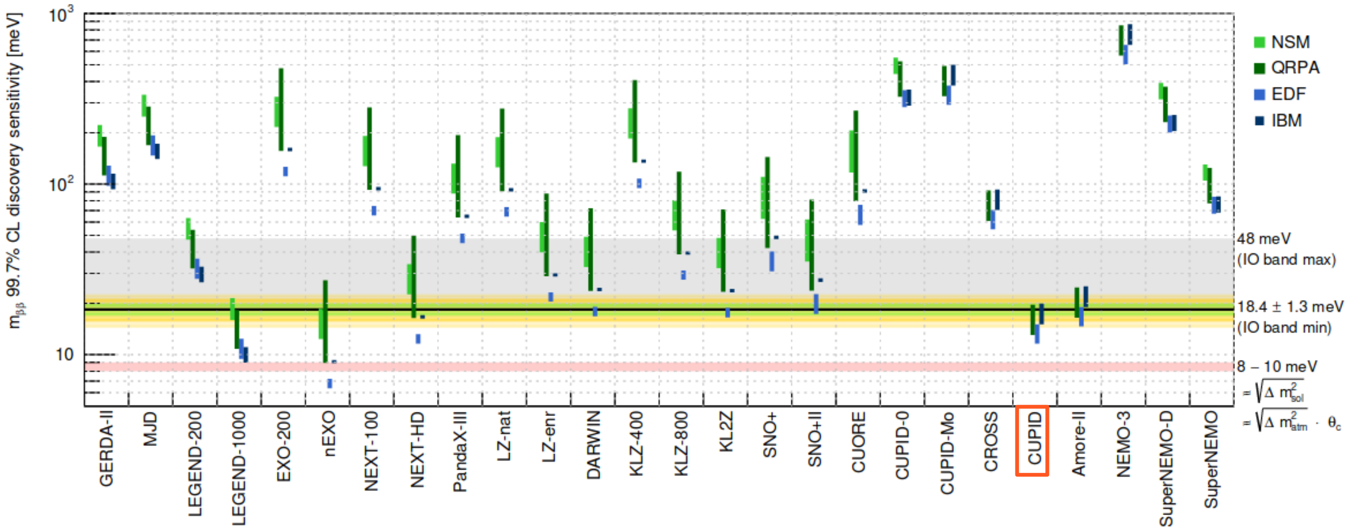
} Well known from previous experiments

Validated by CUPID-Mo

Most critical source, work still on going to characterize and validate the rejection power

# CUPID DISCOVERY SENSITIVITY




*From arXiv:2202.01787 [hep-ex]*

With **5 keV FWHM** in ROI+ **b~10$^{-4}$ ccky** + **10 years** livetime :
Half-life 3σ discovery sensitivity
**$T_{1/2}$ > 1x10$^{27}$ yr → $m_{\beta\beta}$ < 12-20 meV**

**Exploration of the inverted hierarchy region !**

# CONCLUSION

- CUPID aims to be **one of the most sensitive next generation 0ν2β experiment** and explore the inverted ordering region.

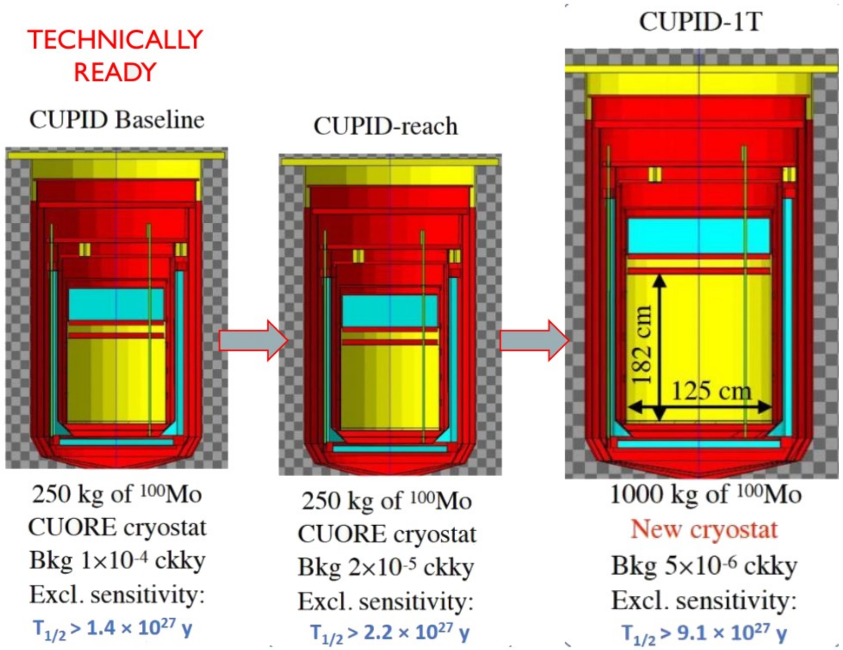
- The **cryogenic structure already exists** and shows excellent performance.

- The **required performance of the single module** composed of $Li_2MoO_4$ crystals **is demonstrated** (α rejection, radiopurity, energy resolution).

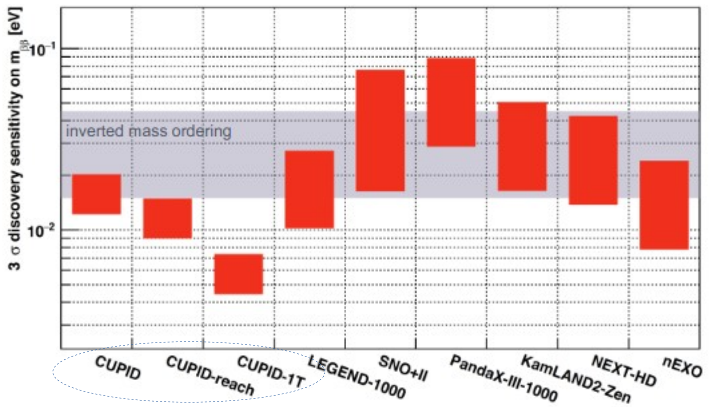
- The **test of the first tower is ongoing** and results will be soon presented.

- A **robust background model** shows b~$10^{-4}$ ckky as reachable.

**Phased approach :**



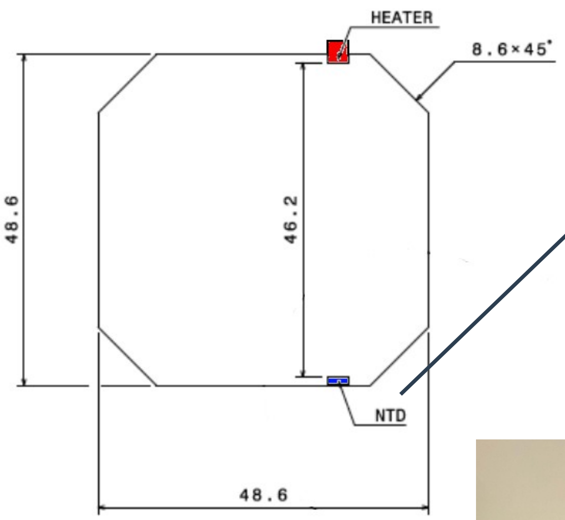

See P. Loaiza's talk



# BACK UP SLIDES

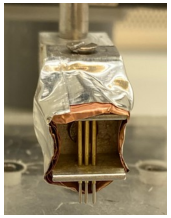
# BDPT : LDs GLUING

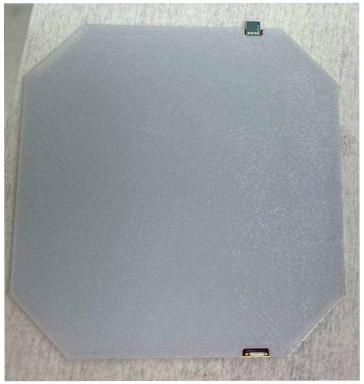
A mask was 3D printed to respect the positions of the heater and the NTD (especially the distance of 1.2 mm maximum to the edge).

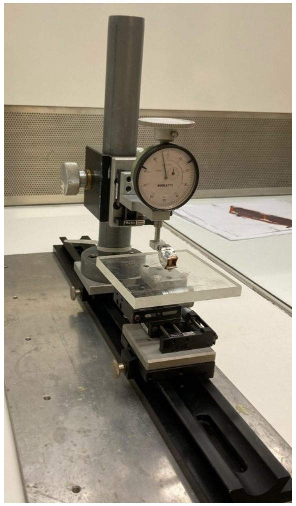



**NTD 41b (3x0.5x1 mm³, ~5.5 mg) :**

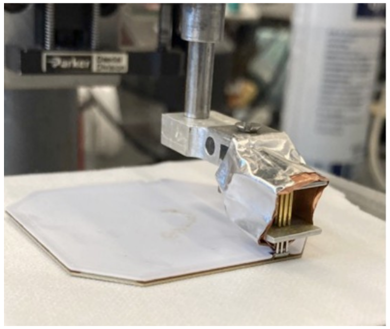
- 3 spots of rapid araldite (Ø ~ 0.55 mm) done with a gluing tool composed of three aligned pogopins.

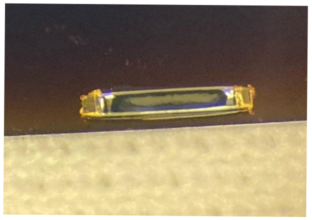






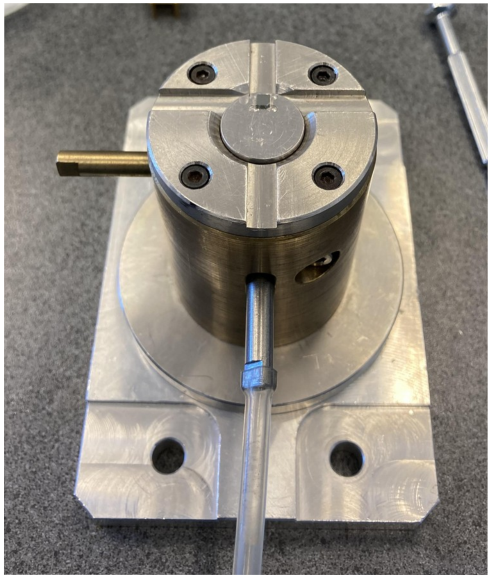
- The NTD was then placed on the spots by hand without any 50 µm spacer.
- After having cleaned the pins, they were used to press on the NTD during the drying (~1H30).





# BDPT : LMO GLUING

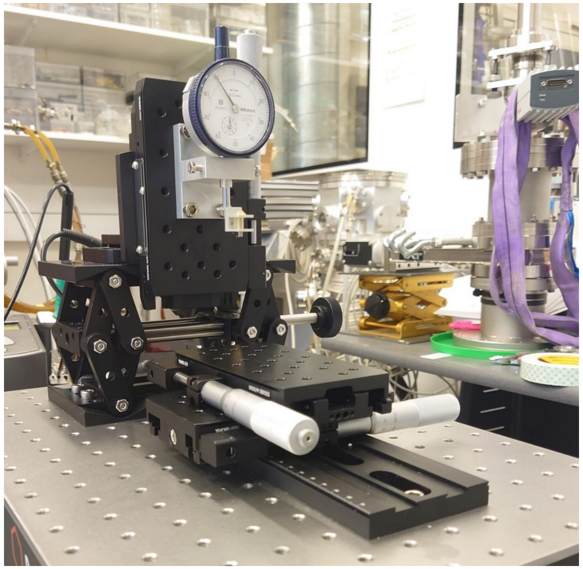
## Gluing tool and procedure



NTD 41b 3x3x1 mm$^3$

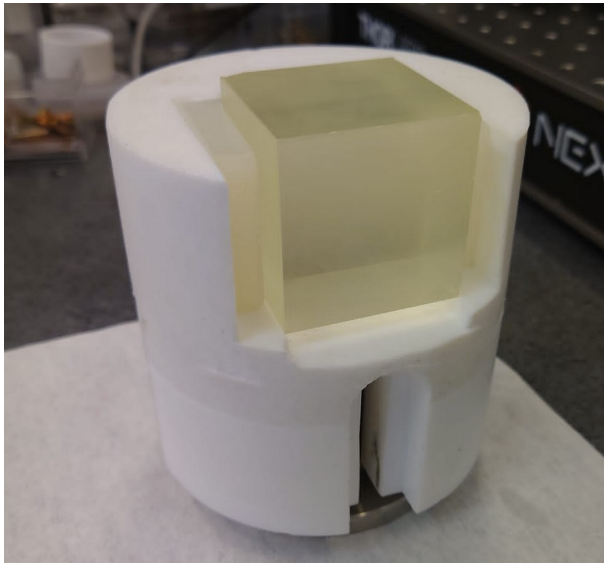
- The NTD is carefully placed on a small hole and sucked by a pump to prevent it to move.

- The circular surface is adjustable to make sure that the NTD is 0.05 mm away from the edges.



- Glue spots are made on the NTD using this gluing machine on which a pogo pins matrix is attached.

- The amount of glue is controlled by dipping the pins in a known depth of glue.



- Finally the crystal is « deposited » on the NTD using this teflon piece allowing to slowly go down.

- It allows also to have the NTD at the right position on the crystal surface.

# BDPT : LMO GLUING

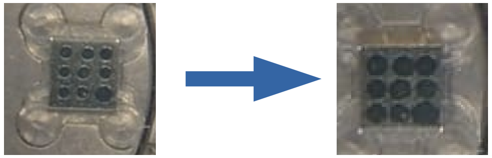
## Gluing methods

- One procedure to make the spots per type of glue to adapt to the viscosity and to the time needed to dry.

### Araldite rapid

3x3 pogo pins matrix

Pump turned off after 6 min



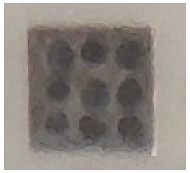
Spots evolve and become bigger

Average spots diameter = 0.8 mm

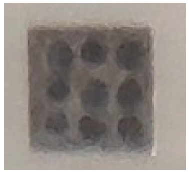
Time on the tool : ~20 min

### Araldite 2011

3x3 pogo pins matrix



We can not stop the pump since the spots would evolve too much and almost make a veil.



Spots kept like that

Time on the tool : ~8 h

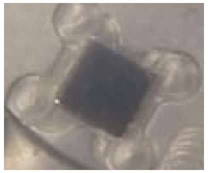
### UV glue

3x1 pins matrix

The glue is too liquid to make separate spots

Average mass of glue deposited = 0.22 mg

It becomes a veil once the crystal is put on



Then we flash it during 10s using a powerful UV lamp

Time on the tool : ~5 min

A glue sample has also been prepared for radioactivity measurement