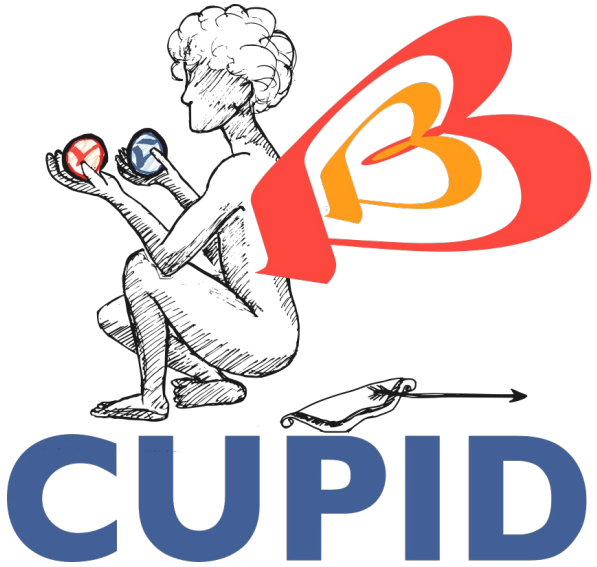
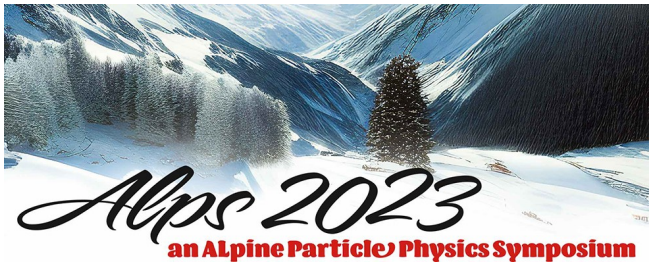


Cuore Upgrade with Particle IDentification

A. Armatol, on behalf of the CUPID Collaboration

ALPS 2023
26-31 March 2023

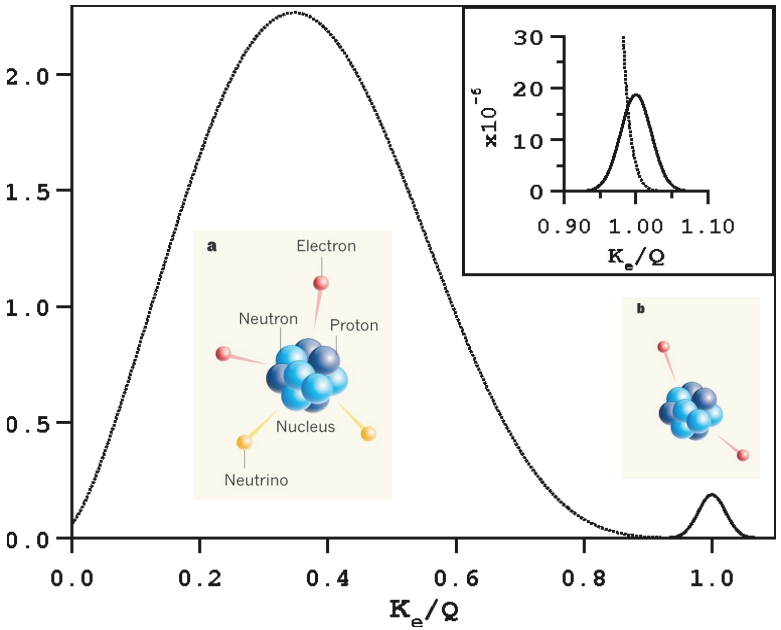


SEARCHING FOR 0ν2β

- **A hypothetical decay**:

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

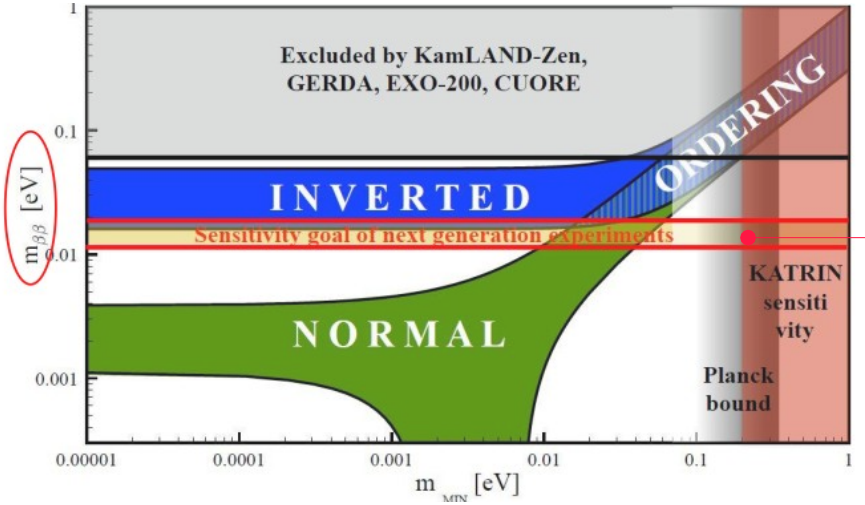
- Leads to a peak in the sum of e^- energy spectrum
- **Violates the lepton number conservation**
- Could **prove the Majorana nature** of neutrino (ν=ν)
- Gives clues about matter/antimatter asymmetry and information on mass hierarchy



An extremely rare decay: $T_{1/2} > 10^{25} - 10^{26}$ yr

In case of light Majorana neutrino exchange :

Theory: $(T_{1/2}^{0\nu})^{-1} = G^{0\nu}(Q,Z)|M^{0\nu}|^2 \frac{m_{\beta\beta}^2}{m_e^2}$



CUPID

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

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

in the region of interest

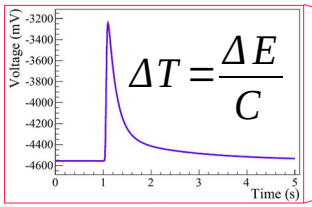
CUORE IN A NUTSHELL

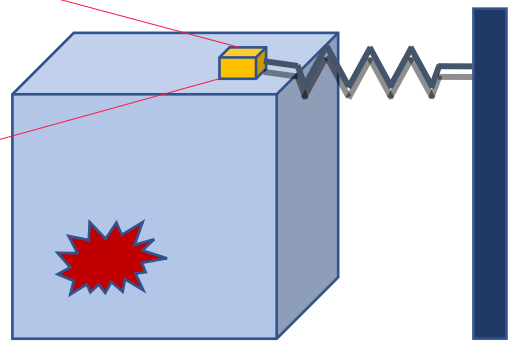
0ν2β isotope : **^{130}Te** ($Q_{\beta\beta}$=2527 keV)

The **largest** bolometric experiment :

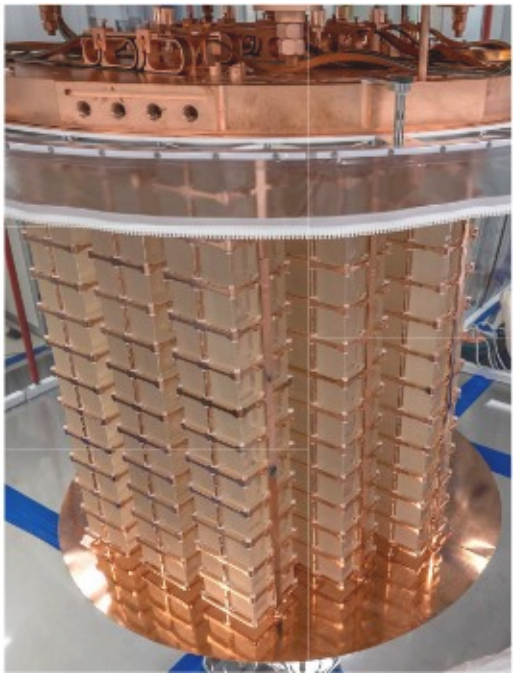
988 5x5x5cm crystals of TeO_2
19 towers of 13 floors each

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





- Ideal calorimeter
- Energy to phonons conversion
- @ Cryogenic temp



CUORE

One of the most sensitive current generation 0ν2β **experiments**

Current limit with **1 ton.yr** exposure* (**288 kg.yr** ^{130}Te):

$T_{1/2}$> 2.2x10^{25} yr

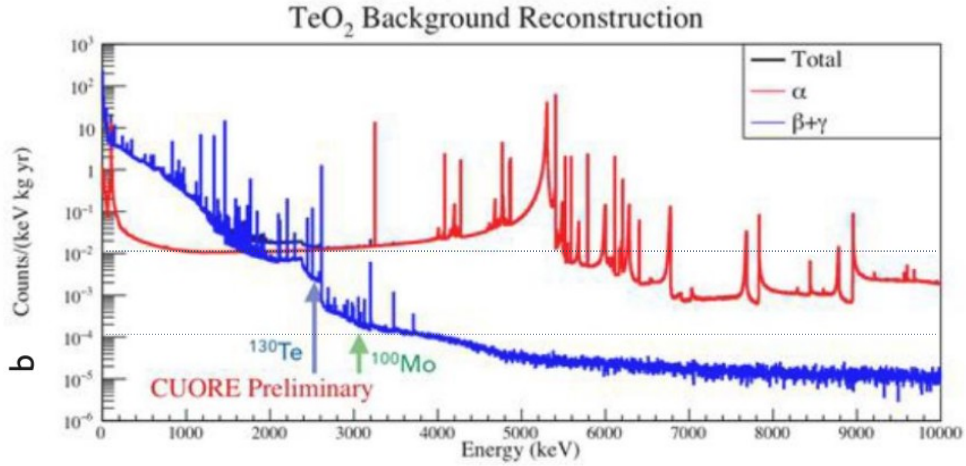
$m_{\beta\beta}$< 90-305 meV

See S. Quitadamo's talk for more details

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

** Nature 604, 53–58 (2022)*

FROM CUORE TO CUPID



But CUORE is **not background free** !
b~10^{-2} ckky in the ROI 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

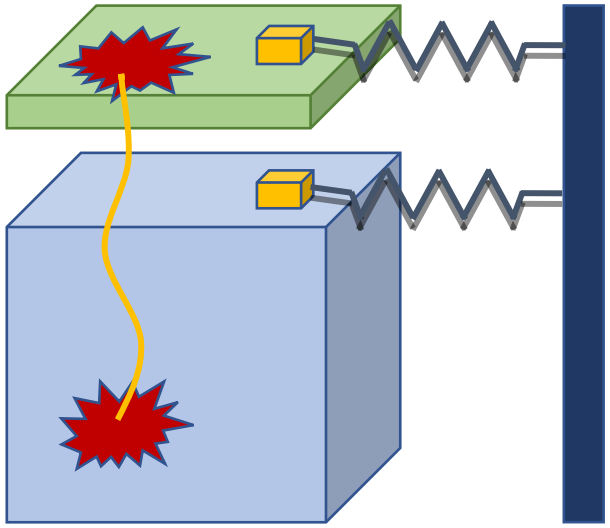
° The CUORE cryostat is suitable to host a next generation experiment like CUPID

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

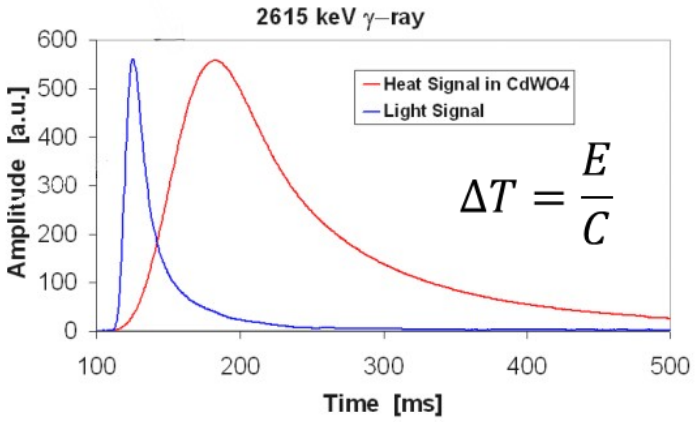
To reject the α background → Use **scintillating bolometers** and a heat/light dual readout

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

SCINTILLATING BOLOMETERS



10 mK



Dual readout :

Two signals per event

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

Ideal for 0ν2β search :

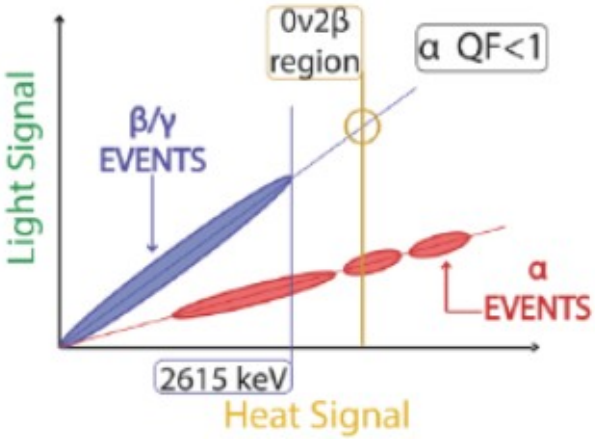
Detector=Source approach
→ High efficency (~ 80 – 90 %)

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

Large masses achievable using arrays of crystals

Large flexibility for the absorber material choice

- Scintillating main absorber embedding a 0ν2β candidate
- Light detector (Ge wafer)
- Thermistor $R = R_0 \cdot \exp\left(\sqrt{T_0/T}\right)$ NTD (Neutron Transmutation Doped) Ge
- Thermal bath

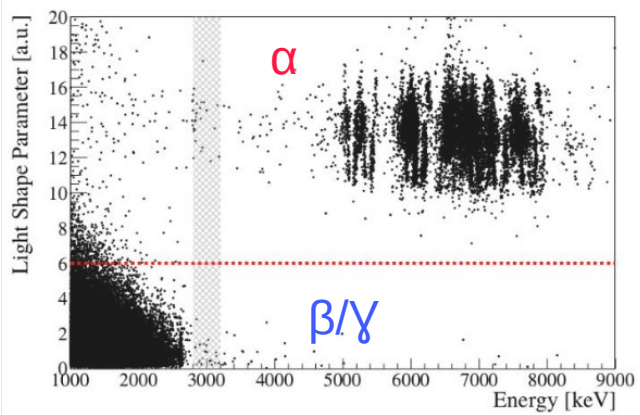


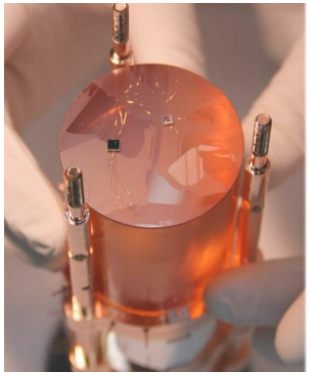
ISOTOPE AND CRYSTAL CHOICE

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 : 5.13 kg of ^{82}Se
8.82 kg·yr exposure in ^{82}Se
Full α rejection (>99%)
Best limit on ^{82}Se 0ν2β : $T_{1/2} > 4.6 \times 10^{24}$ yr*

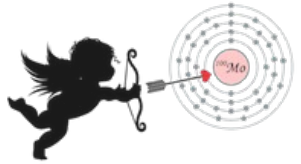
*Phys. Rev. Lett. 129, 111801



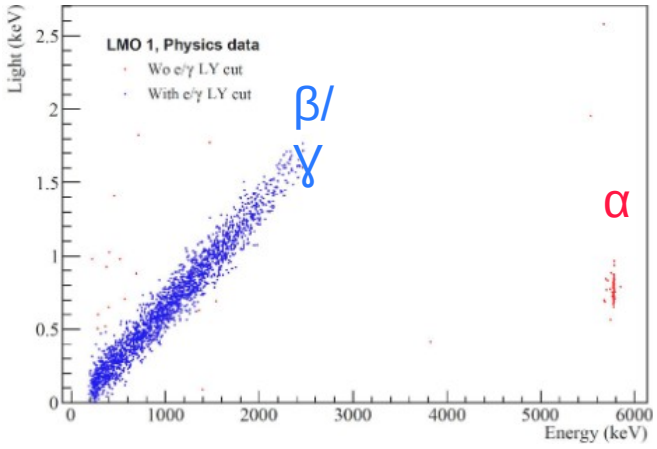


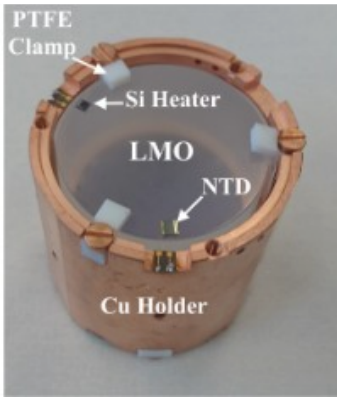
BUT **not the best choice for CUPID** : **High internal contamination** of the crystal + not an excellent energy resolution at $Q_{\beta\beta}$(**21.8 keV FWHM**)

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 kg·yr exposure in ^{100}Mo
Full α rejection (>99%)
Best limit on ^{100}Mo 0ν2β : $T_{1/2} > 1.8 \times 10^{24}$ yr*
Excellent energy resolution : 7.4 keV FWHM
Radiopure crystals : U/Th ≤ 1 μBq/kg





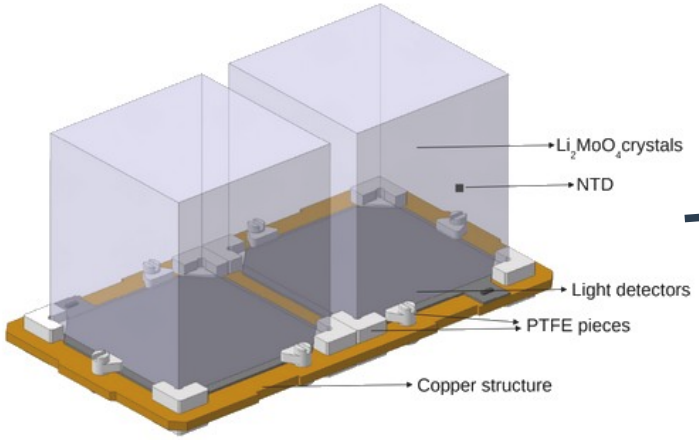
*arXiv:2202.08716v1 [nucl-ex] 17 Feb 2022

CUPID BASELINE DESIGN

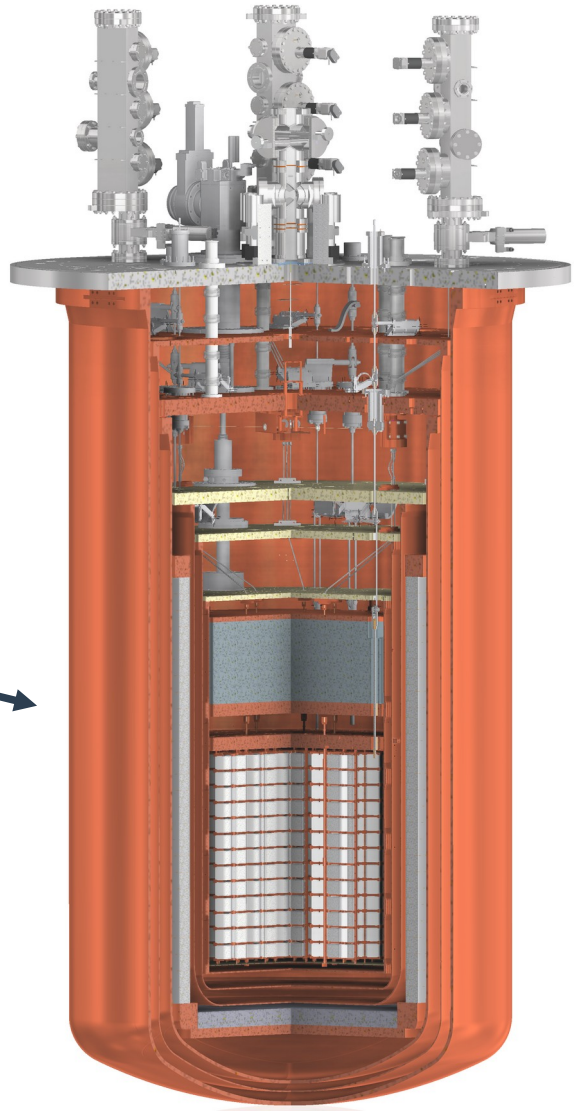
-Use of the CUORE cryostat at LNGS
(available in ~2024)

- **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



CUORE CRYOSTAT

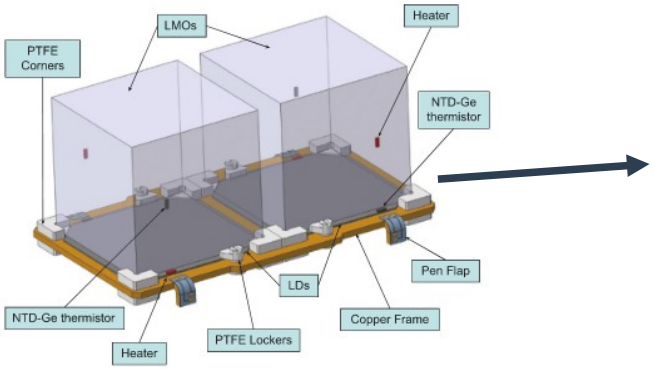


- **Ge light detectors** with SiO antireflective coating
(each crystal has top and bottom LD)

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

RECENT RESULTS AND R&D

Optimization of the first CUPID detector module

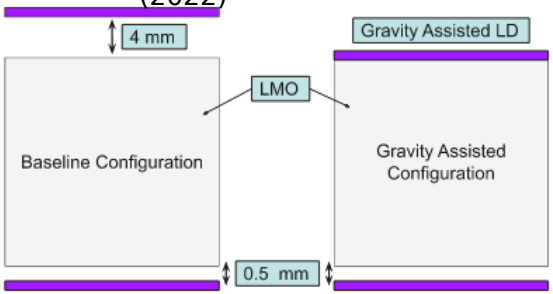


First test of the CUPID module in LNGS :

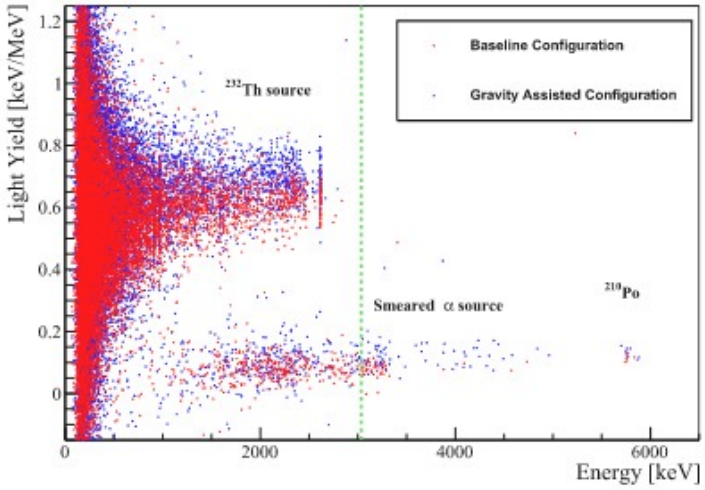
- The goal was to **check performance and light collection**. A gravity assisted configuration was also tested.

- 8 LMO crystals arranged in 2 floors of 4.

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



1st floor 2nd floor



- **Good performance obtained :**

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

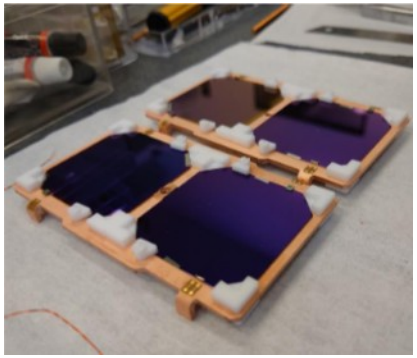
- α rejection > 99.9 %

- Energy resolution at Q-value = 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 :

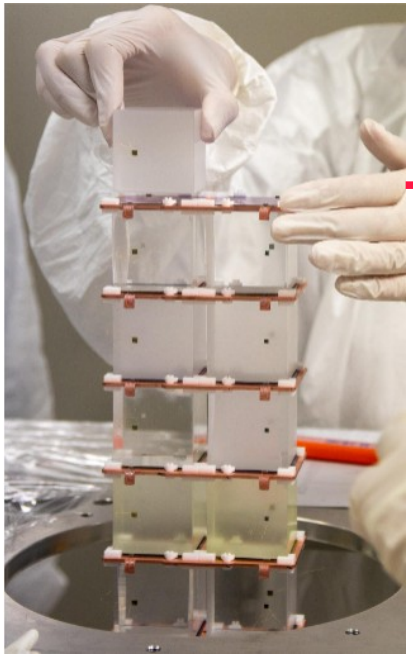


- **14 baseline modules** stacked in a tower

- **28 LMO** crystals from different origins

- **30 Ge light detectors**

Several studies pursued :
Vibrational properties
Thermalization on each floor
Type of glue
And others...



Validation of the tower assembly procedure ✓

✓ **Tower installed at LNGS**

Run 1 (spring loaded)
Run 2 (spring unloaded)

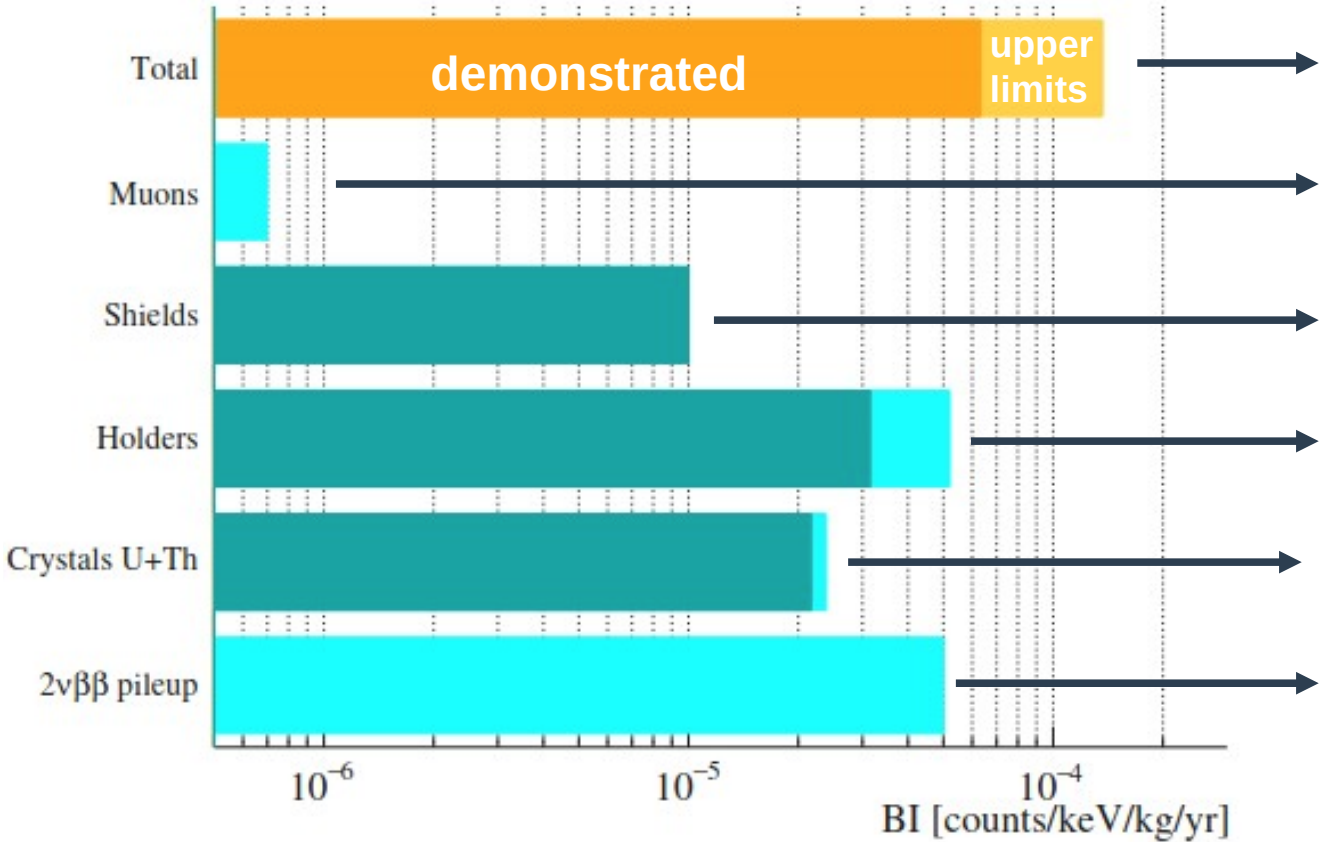
Run 3 (further test on vibrations and thermalisation) - ongoing

First results : good bolometric performance, still some study to make

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

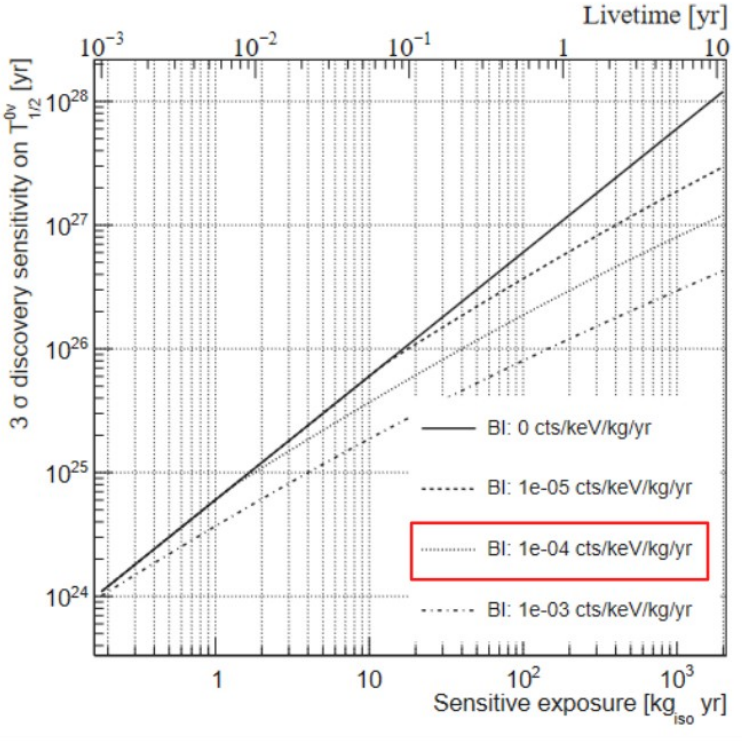
} Well known from previous experiments

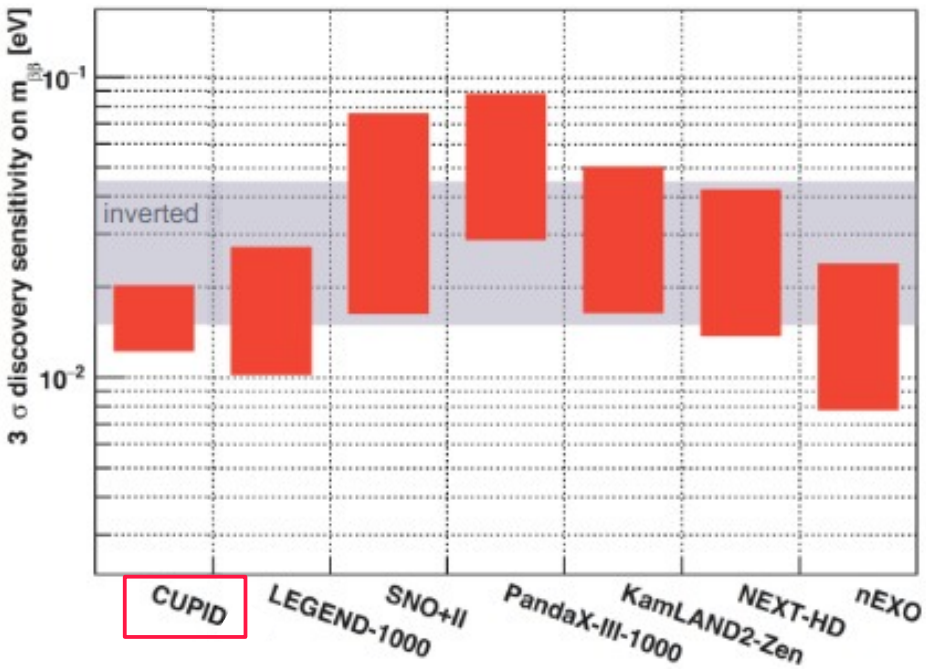
Validated by CUPID-Mo

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

**The CUPID interest group, CUPID pre-CDR, (2021 version)*

CUPID DISCOVERY SENSITIVITY





With **5 keV FWHM** in ROI+ **b~10^{-4} ccky** + **10 years** livetime :

Half-life exclusion sensitivity at 90% C.L. :

$T_{1/2}$ > 1.4x10^{27} yr → $m_{\beta\beta}$ < 10-17 meV

Exploration of the inverted hierarchy region !

CUPID PHASED APPROACH

-

TECHNICALLY READY

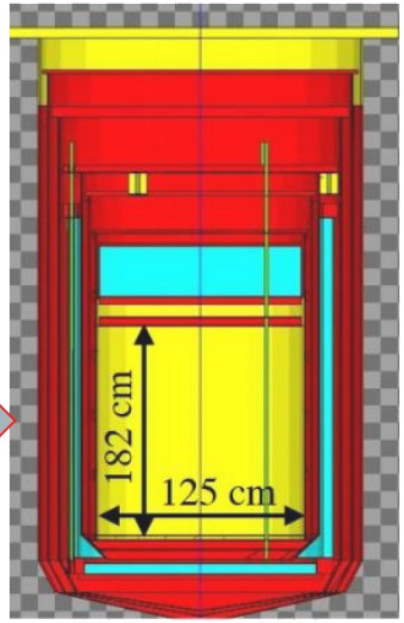
CUPID Baseline

250 kg of ^{100}Mo
CUORE cryostat
Bkg 1×10^{-4} ckky
Excl. sensitivity:
$T_{1/2} > 1.4 \times 10^{27}$ y

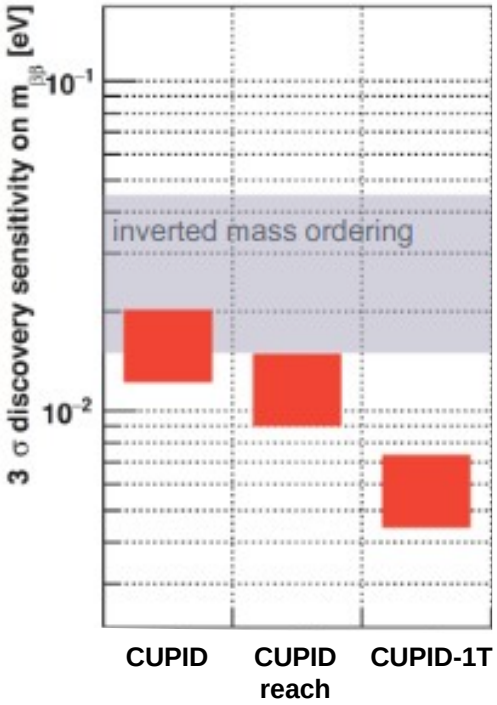
CUPID-reach

250 kg of ^{100}Mo
CUORE cryostat
Bkg 2×10^{-5} ckky
Excl. sensitivity:
$T_{1/2} > 2.2 \times 10^{27}$ y

CUPID-1T



1000 kg of ^{100}Mo
New cryostat
Bkg 5×10^{-6} ckky
Excl. sensitivity:
$T_{1/2} > 9.1 \times 10^{27}$ y



CONCLUSION

- CUPID aims to be **one of the most sensitive next generation 0ν2β experiments** and to 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, exellent 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.

- CUPID is a **promising** and **cost-effective experiment**