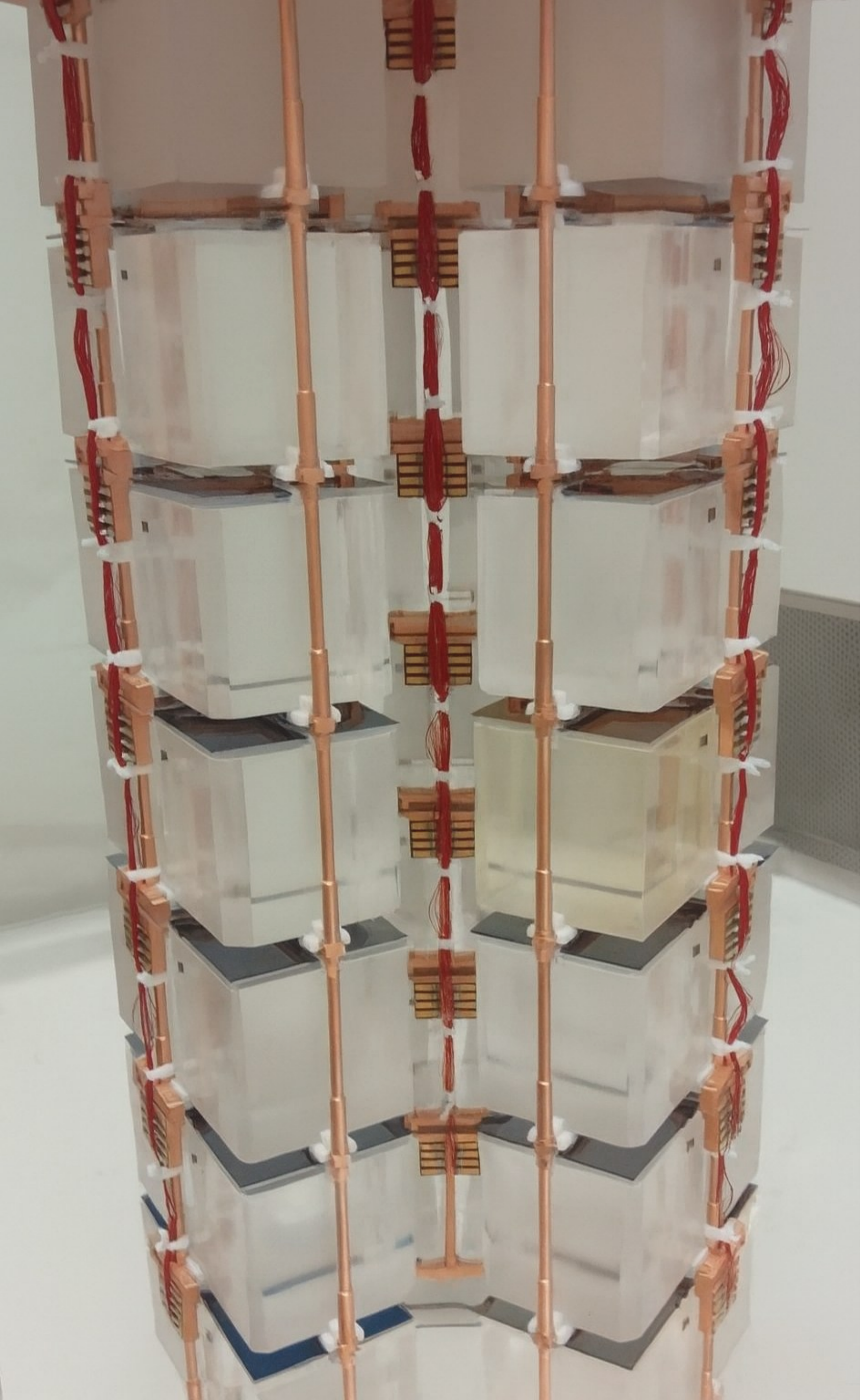
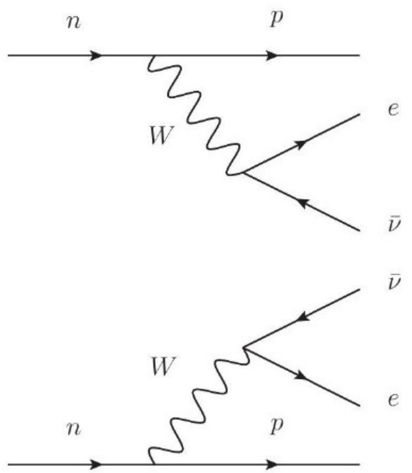


Status of the CROSS experiment

Mariia Buchynska on behalf of the CROSS collaboration

0νββ decay

2νββ

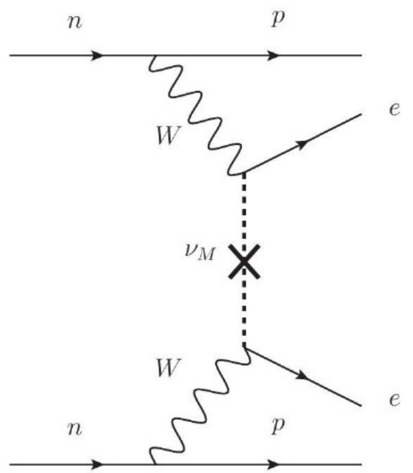


$(A,Z) \rightarrow (A,Z+2) + 2e^- + \mathbf{2\bar{\nu}_e}$

The rarest allowed nuclear weak process

Energetically possible for 35 nuclei
Only few are experimentally relevant

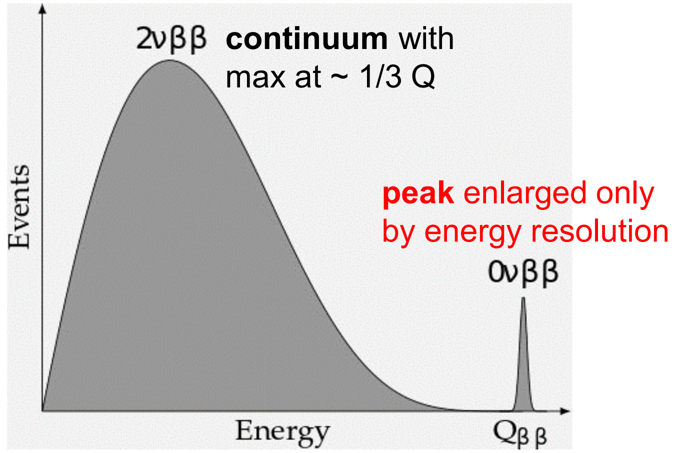
0νββ



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

- Minimal extension to the Standard Model to accommodate neutrino masses
- Explanation of smallness of neutrino masses
- Hint on explanation of matter/antimatter asymmetry in the universe

Experimental signature

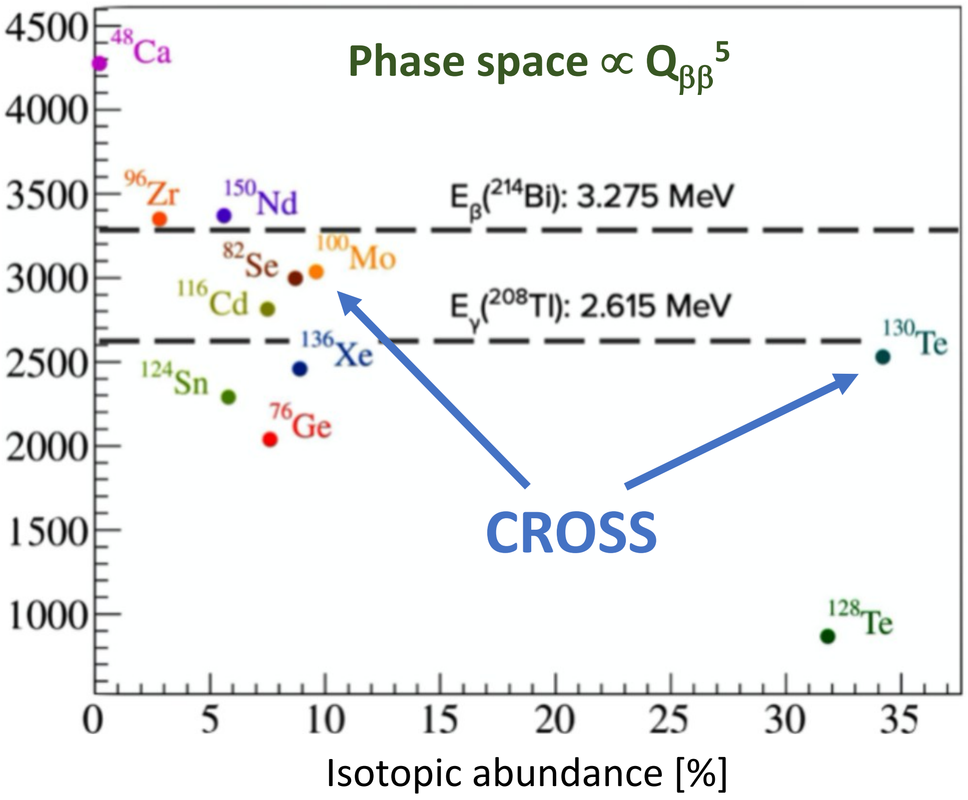


Rate: $\frac{1}{T^{0\nu\beta\beta}_{1/2}} \sim G^{0\nu} \cdot |M^{0\nu}|^2 \cdot \langle \mathbf{m_{\beta\beta}} \rangle^2$
(in case of light neutrino exchange mechanism)

$\mathbf{m}_{\beta\beta} = ||U_{e1}|^2 m_1 + e^{i\alpha 1} |U_{e2}|^2 m_2 + e^{i\alpha 2} |U_{e3}|^2 m_3|$

Experimental requirements

Possible candidates



Sensitivity

$$T_{1/2} \propto \begin{cases} \delta \times \varepsilon \times \sqrt{\frac{M \times t}{BI \times \Delta E}} \rightarrow \text{with background} \\ \delta \times \varepsilon \times M \times t \rightarrow \text{background free } (BI \times \Delta E \times M \times t \ll 1) \end{cases}$$

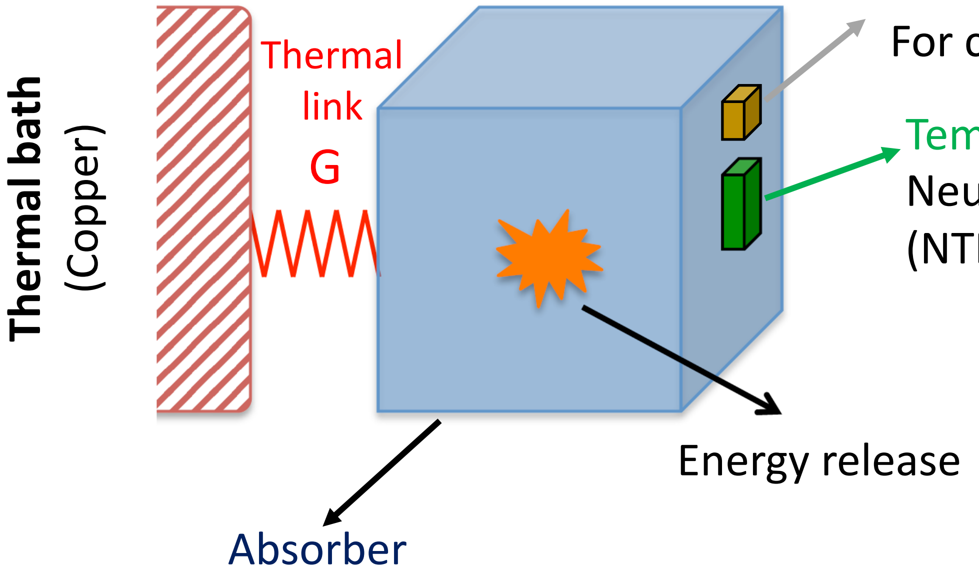
Requirements:

- $M \times t$ – exposure -> should be large
- δ – isotopic abundance -> large isotopic abundance
- ΔE – energy resolution -> good energy resolution
- ε – detection efficiency -> high detection efficiency
- **BI – low background**

Background index:

$$BI = \frac{N}{M \cdot t \cdot \Delta E} \text{ [counts/(keV·kg·y)]}$$

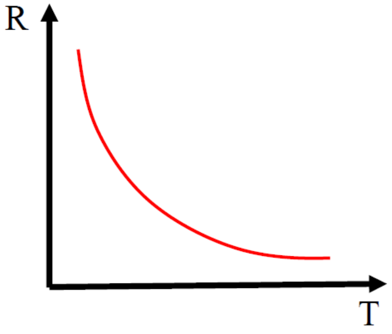
Bolometric technique



Heater:
For correction of temperature instabilities

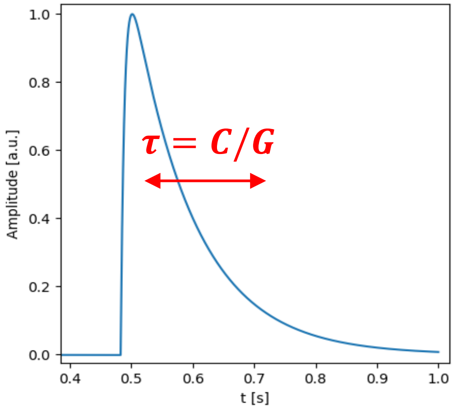
Temperature sensor:
Neutron Transmutation Doped
(NTD) Ge thermistor

$\mathbf{\Delta T \rightarrow \Delta R}$



$$R(T) = R_0 \cdot e^{\sqrt{T_0/T}}$$

Temperature rise
$\mathbf{\Delta T = \Delta E/C}$ ~0.1 mK/MeV
$C\ (T) \propto T^3$

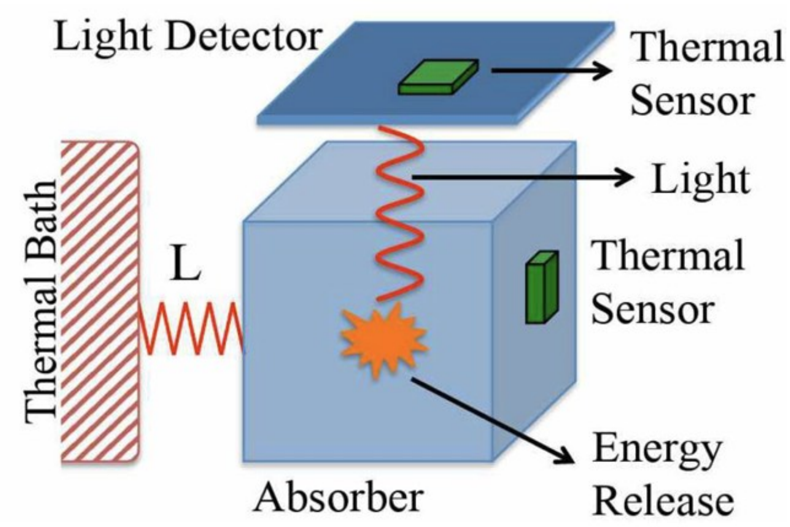


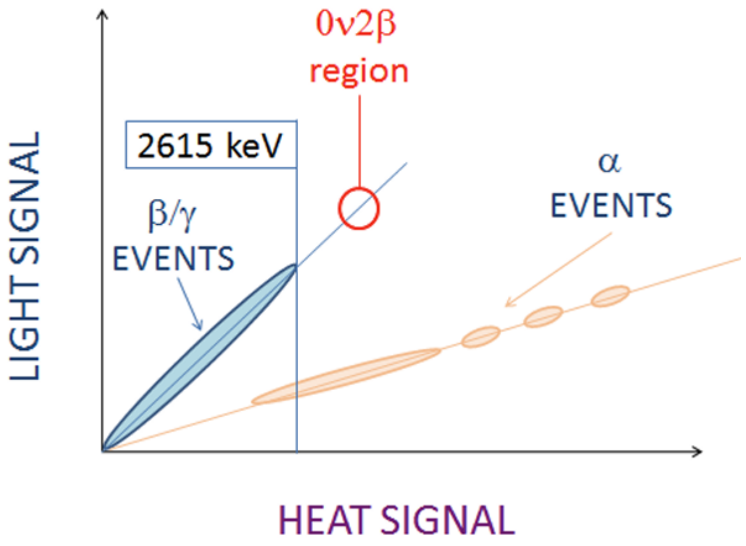
Operating temperatures: 10-30 mK

Cryogenic detectors properties:

- Good energy resolution ~ 5-10 keV at Q-value (3 MeV)
- Source = detector: high efficiency

Scintillating bolometers for alpha particles rejection





Technology proven in CUPID-0 and CUPID-Mo demonstrators

Rejection efficiency > 99.9%

Eur.Phys.J.C 76 (2016) 364
Eur.Phys.J.C 80 (2020) 44

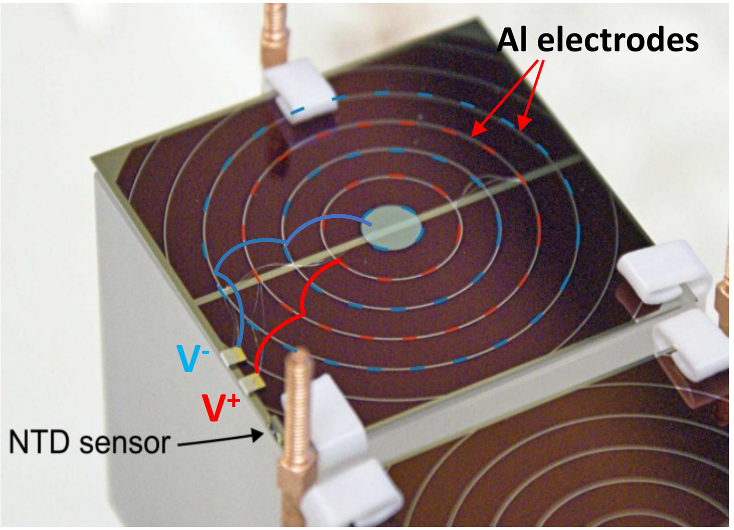
Rejection of α's due to their lower light yield compared to β/γ 's

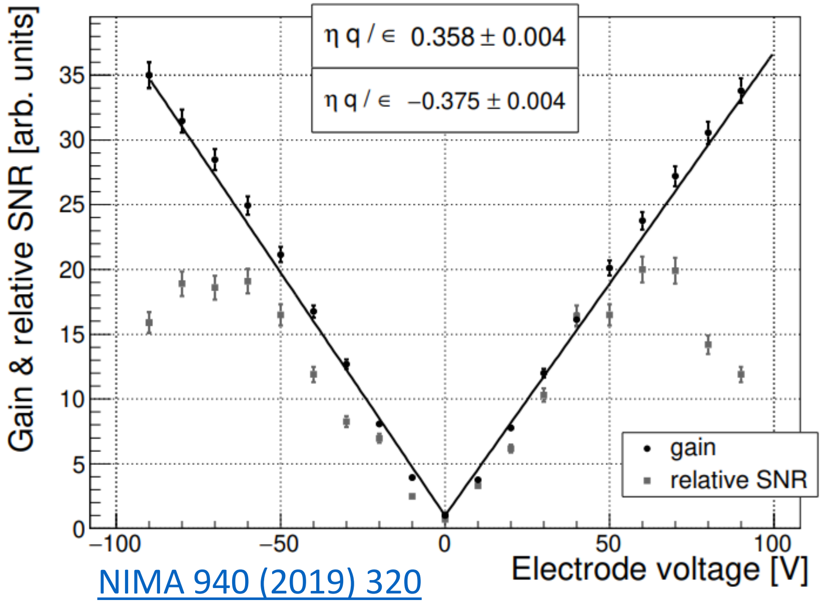
Neganov-Trofimov-Luke light detectors

Signal enhancement due to the extra heat produced by the drift of e-h pairs in the electric field (NTL effect)

Total heat: $\mathbf{E_{tot} = E_0 \cdot Gain_{NTL}}$

$\mathbf{Gain_{NTL}} \propto \mathbf{V_{bias}} = V^+ - V^-$



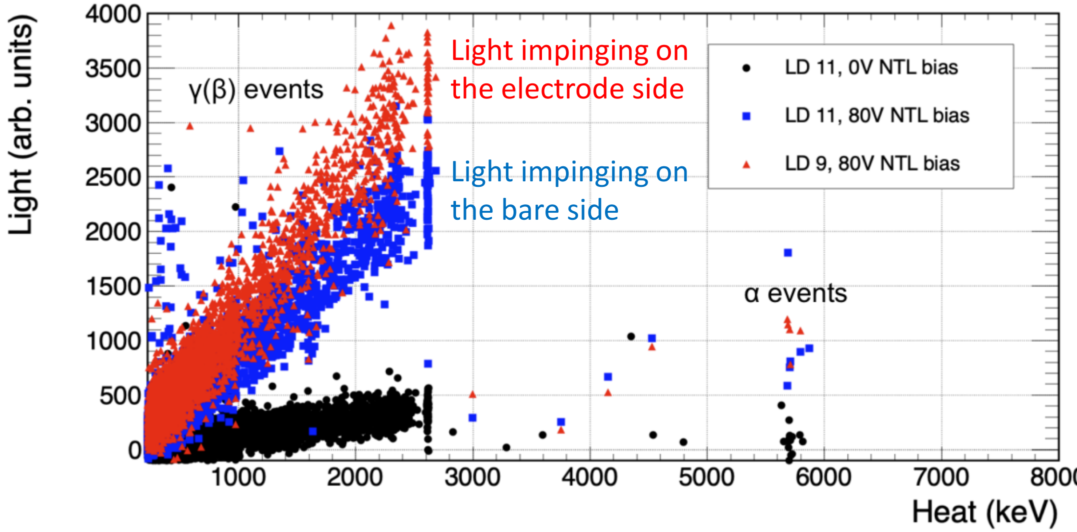


NIMA 940 (2019) 320

Important for CUPID to estimate rejection capability of the random coincidences of 2νββ events

Main requirements:

- **fast signal**
- **high signal-to-noise ratio**

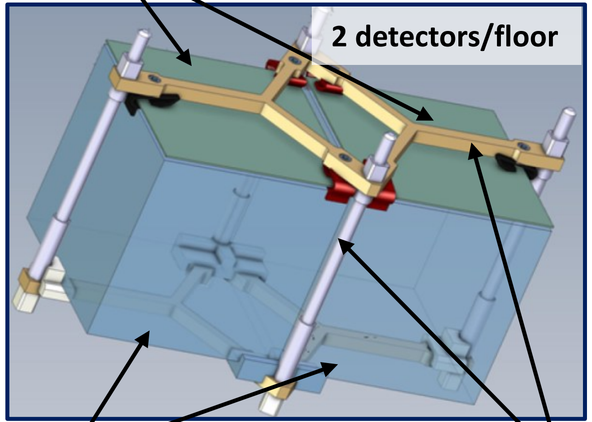


For CROSS only α/β separation required

CROSS demonstrator: structure

3 towers -7 floors/tower -2 detectors/floor

NTL LDs (45 x 45 mm^2)



Crystals (45 mm side)

M [Li_2MoO_4] ~ 280 g
M [TeO_2] ~ 550 g

Copper structure
Low (6%) Cu/Li_2MoO_4 mass ratio

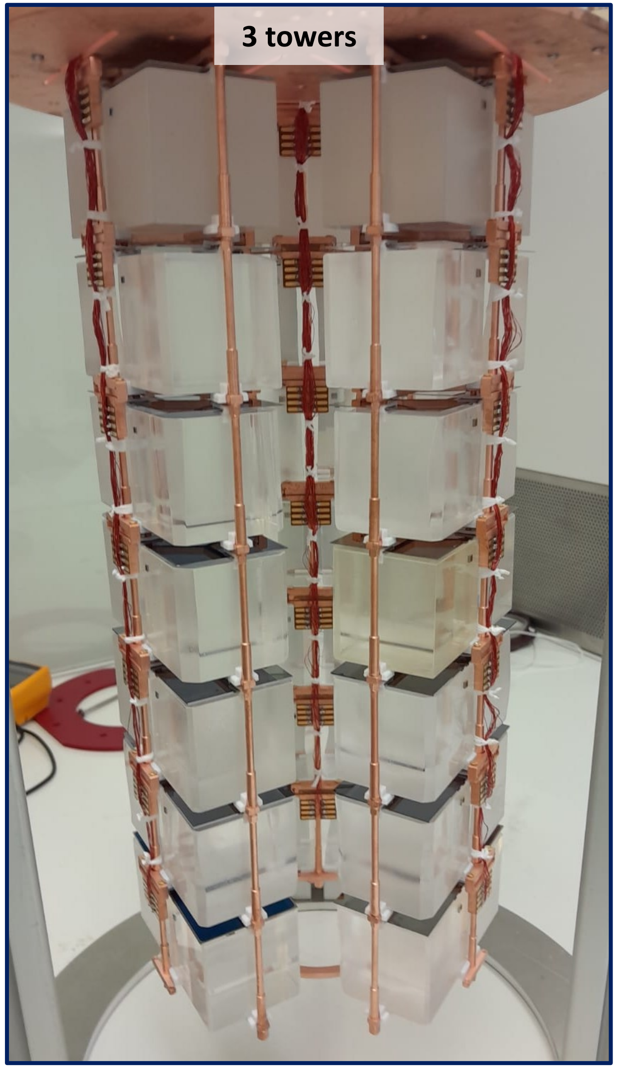
JINST 19 (2024) P09014

$\otimes$ **7**

$^{130}TeO_2$

$\otimes$ **3**

Assembled CROSS demonstrator



June, 2025

CROSS demonstrator: composition

Tellurium crystals

6 $^{130}TeO_2$ crystals (enrichment level >90%)

Mass of ^{130}Te : 3.0 kg

Molybdenum crystals

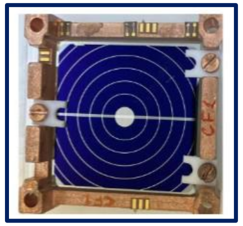
36 Li_2MoO_4 →
- 32 enriched in ^{100}Mo (enrichment level >95%)
- 2 natural Mo
- 2 depleted in ^{100}Mo (for background studies)

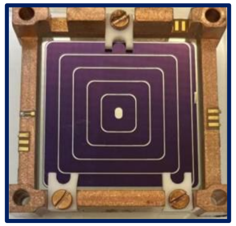
Mass of ^{100}Mo: 4.9 kg

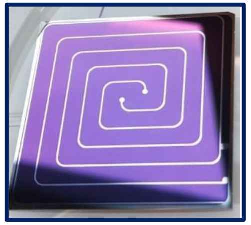
NTL LDs

42 NTL LDs → 26 Germanium, 16 Silicon

26 Germanium





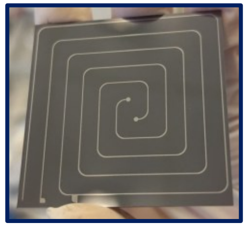


with different electrodes geometry

⬇

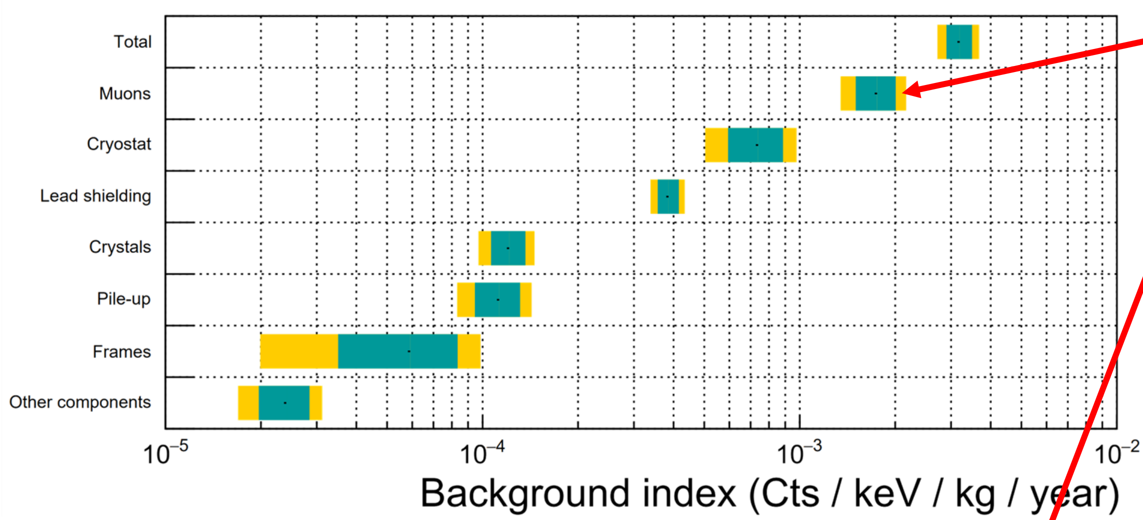
test bench of several electrodes configurations for CUPID

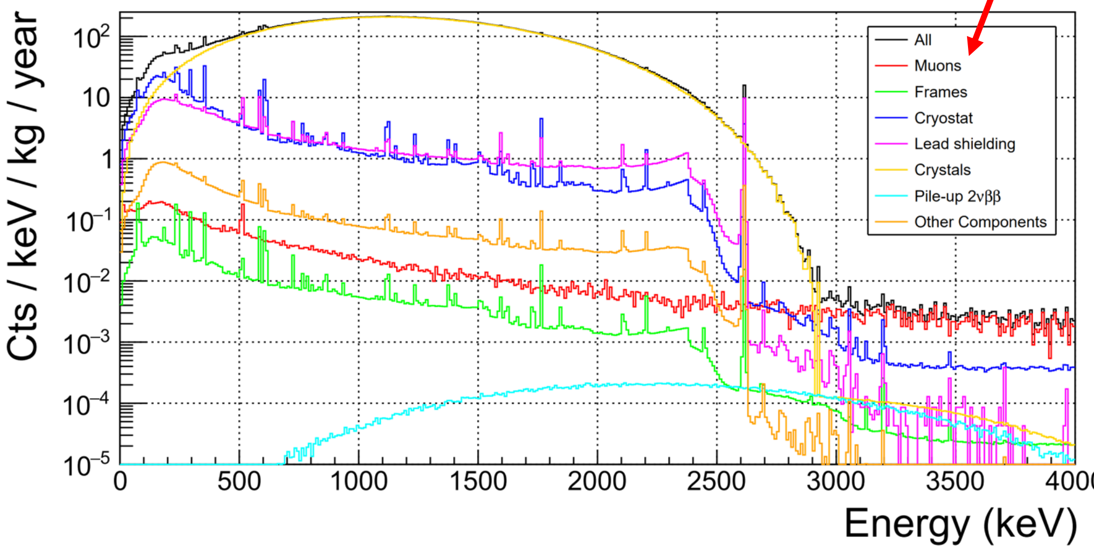
16 Silicon



spiral electrodes geometry

CROSS background estimation





Dominant component: **muons**

Depth of LSC: 2450 mwe

Importance of the muon veto

arXiv:2510.27406

9 sectors:

- 4 lateral
- 4 bottom
- 1 top

Rejection of events in coincidence between one veto sector and light detectors

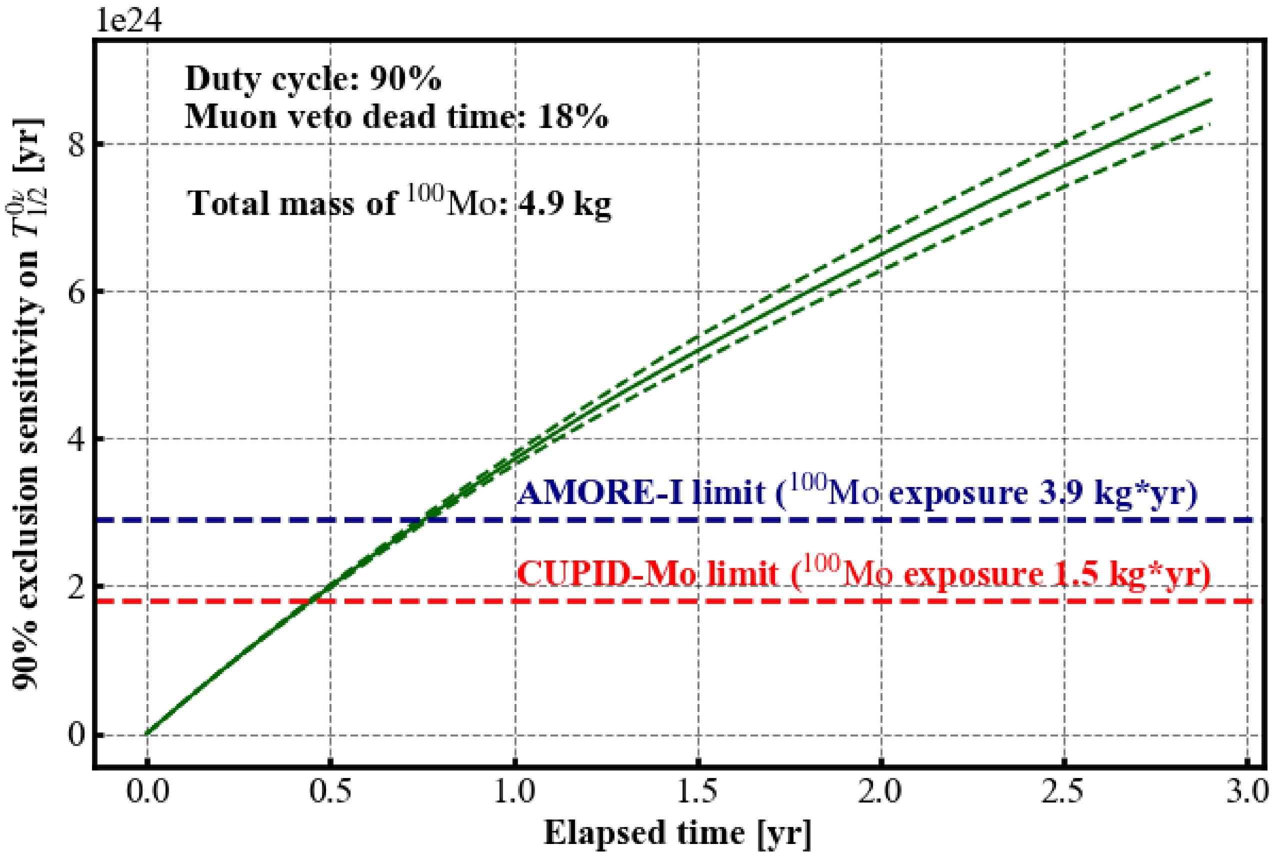
(**rejection efficiency: 99.7%**)

Total veto rate: 80-100 Hz

Dead time: 18 %

Total BI: $(3.2 \pm 0.5) \cdot 10^{-3}$ **counts/keV/kg/year (ckky)**

CROSS expected sensitivity



Assumptions:

Resolution: **7 keV FWHM @ $Q_{\beta\beta}$**
ROI: 17.1 keV (from CUPID-Mo analysis)
BI: $(3.2 \pm 0.5) \cdot 10^{-3}$ **ckky**

Total efficiency: 70.2%

- containment efficiency: 78%
- cut efficiency: 90%

CROSS status

CROSS Timeline

2 month delay because of
the chiller failure

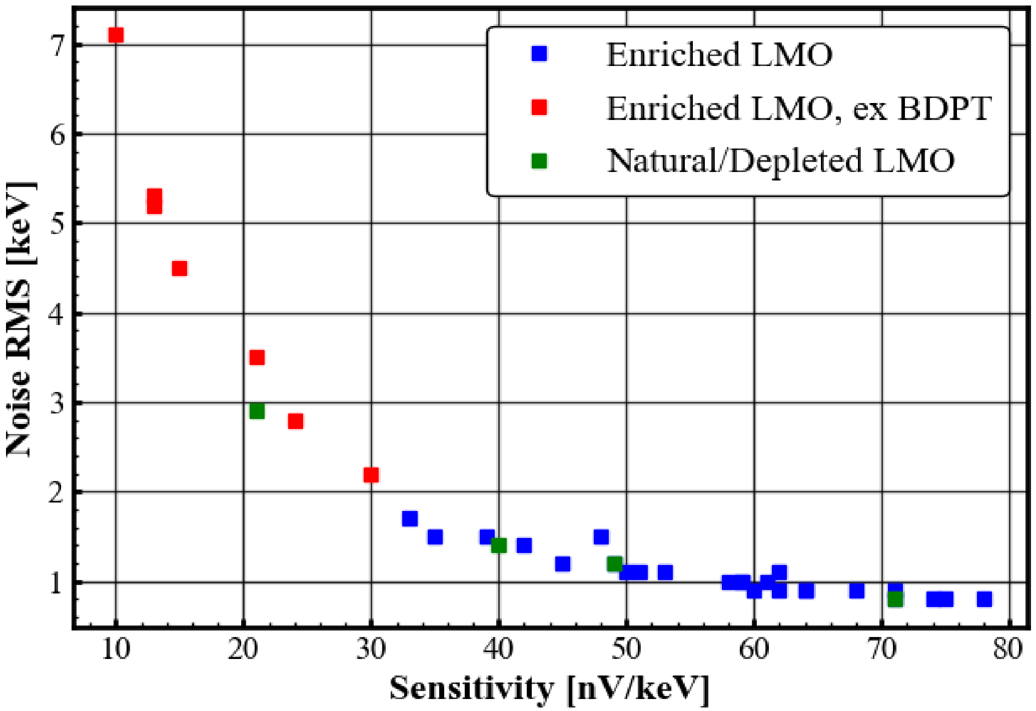
Demonstrator assembled and ready for transportation	Detectors attached to the cryostat and connected	Cryostat closed	Base temperature reached	First measurements started
26 June 2025	18 July 2025	1 August 2025	15 October 2025	12 November 2025

Current status:

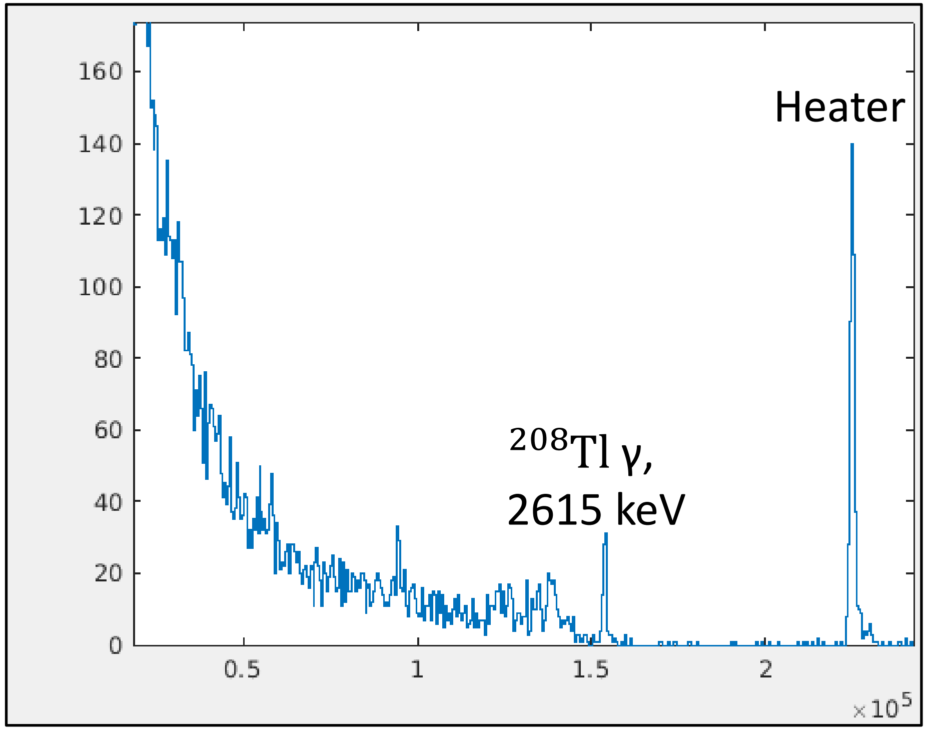
- The cryostat is at the base temperature now (T = 25 mK)
- All the detectors are connected, but one
- More than 350 hours of data collected up to now (mainly calibration runs) for optimization of working points, source position, evaluation of detectors performance, detectors calibration etc.

CROSS status: crystals performance

Performance of Li_2MoO_4 crystals



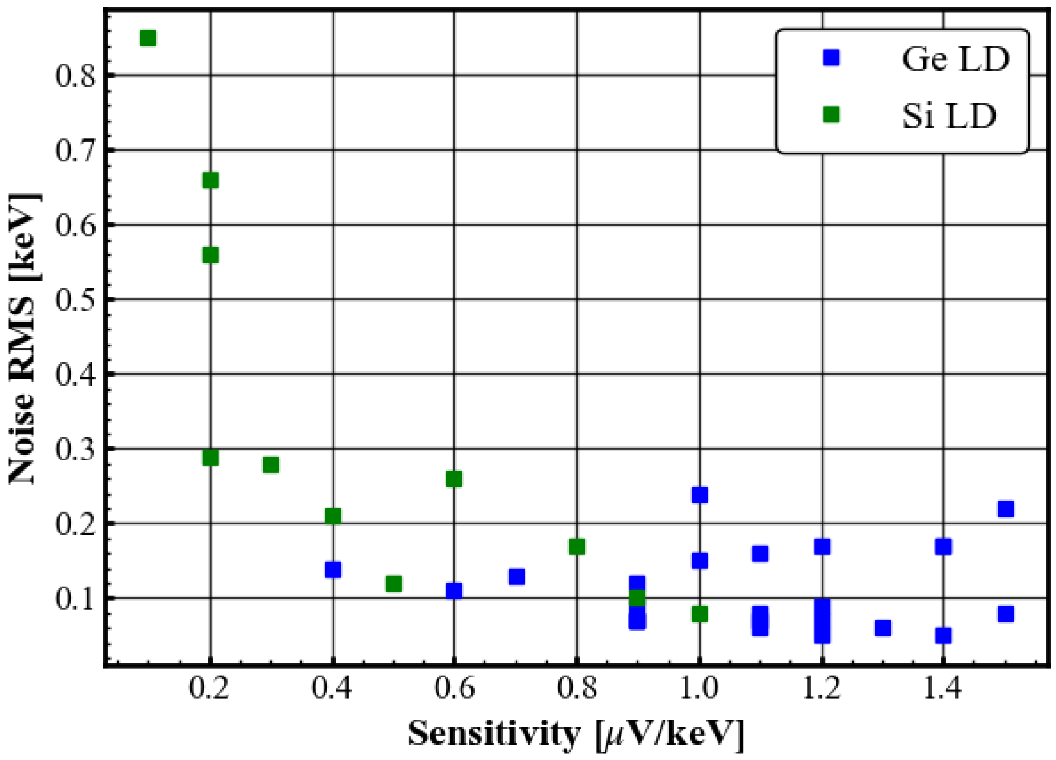
Example of the energy spectrum of one Li_2MoO_4

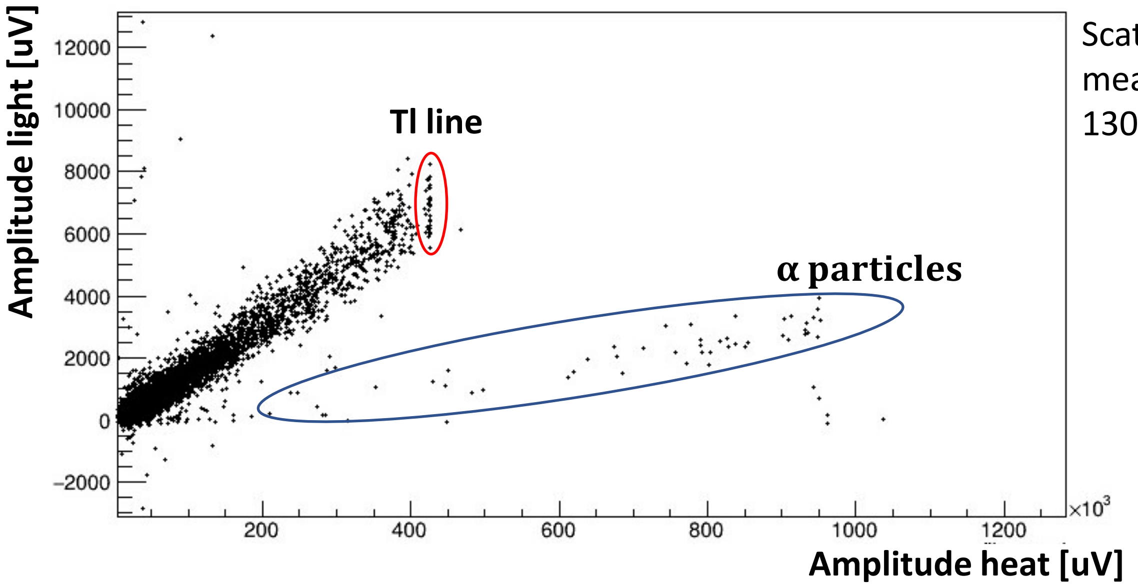


- **High energy to amplitude conversion** for most of the crystals with the exception of ex BDPT crystals, (performance degradation due to humidity exposure)
- **Low noise level (11 channels < 1 keV noise RMS!)**
- **LMO data are comparable with an energy resolution 5-7 keV FWHM @ 2615 keV for most of the detectors -> close to our goal**

CROSS status: LDs performance

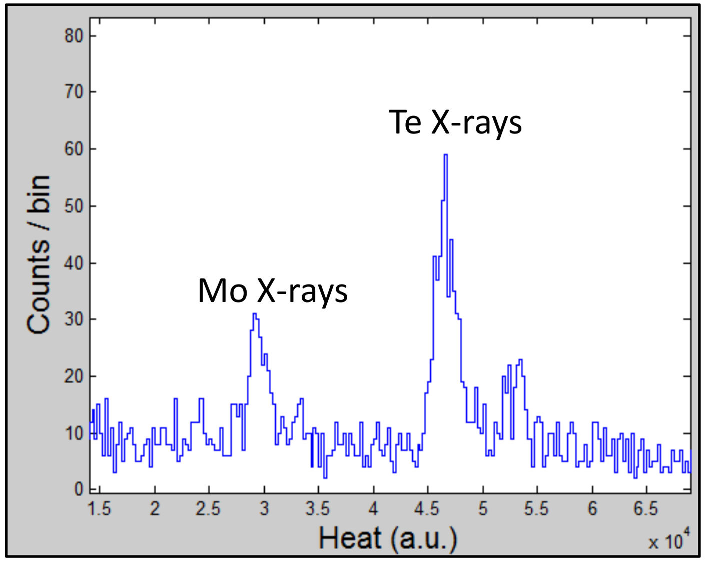
Performance of the light detectors (no NTL bias)





Scatter plot from measurements with 130V NTL bias

Energy spectrum from calibration run for LDs



- **Good sensitivity and low noise of the Ge LDs** (13 LDs with RMS noise ≤ 100eV; 18 with the noise ≤ 150 eV, out of 24)
- **Based on the current data α/β separation can be achieved on the most of the detectors**
- Slightly worse performance of Si LDs (although few of them have performance similar to Ge) -> needs further investigation if it is connected to LD itself or assembly

Conclusions

CROSS is developing innovative technologies to reduce background noise in **0ν2β** decay searches using bolometers and advanced **NTL light detectors**.

Over the past years, several key developments have been tested:

- **Surface film coating of crystals** to discriminate between bulk and surface events, for both α and β particles
- **Development and optimization of NTL light detectors** to enhance light detection sensitivity
- **A novel mechanical structure** designed to minimize the amount of passive material surrounding the detectors
- **A purification and crystallization chain** for enriched **$^{130}TeO_2$ crystals**

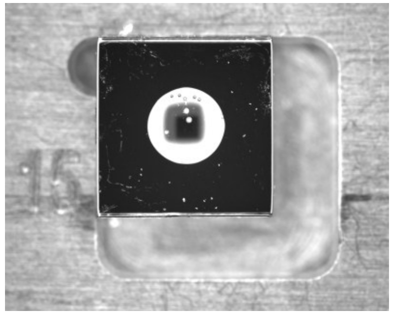
Final CROSS demonstrator is a competitive experiment on the ^{100}Mo 0νββ.

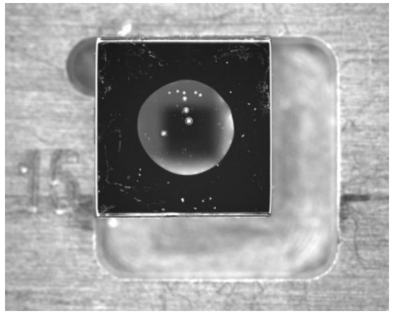
Results on detectors performance will provide valuable input for the next-generation 0νββ experiments.

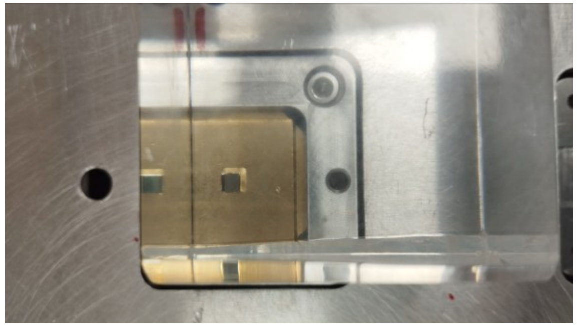
- Detectors are installed and at the base temperature now.
- First measurements show good performance of Li_2MoO_4 and Ge LD in terms of noise and sensitivity.
- Measurements to estimate LDs performance with NTL bias started, preliminary evaluation of performance should come in the next days.

Stay tuned for the new results!

Preparation for the final demonstrator



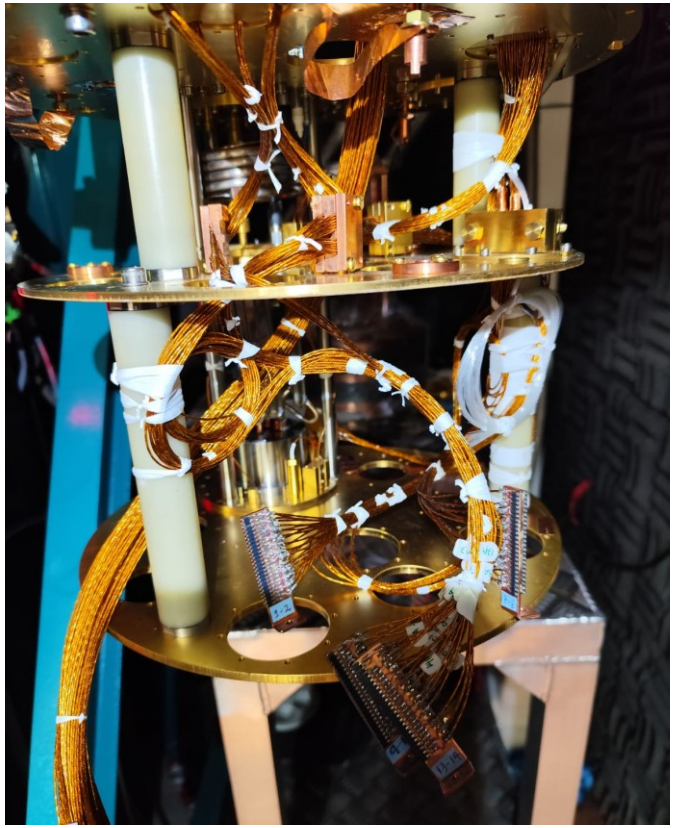




NTDs gluing with the robot (at CEA)

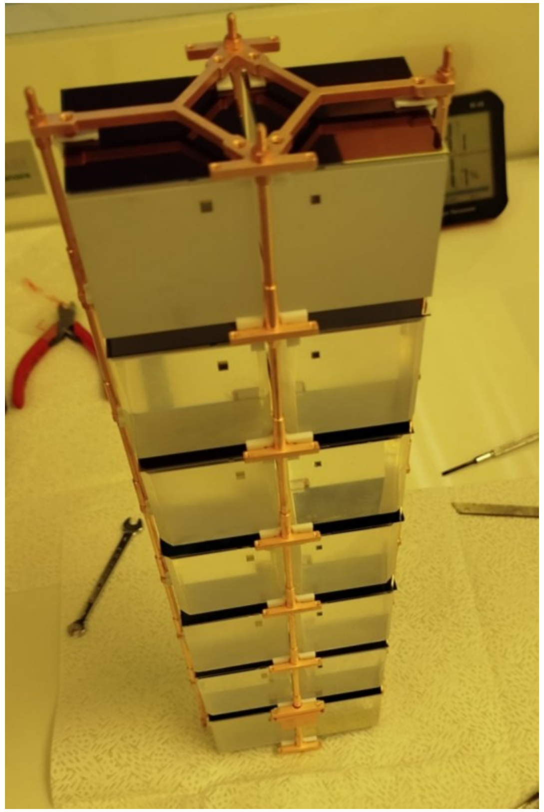
Heaters gluing

Test of the copper structure

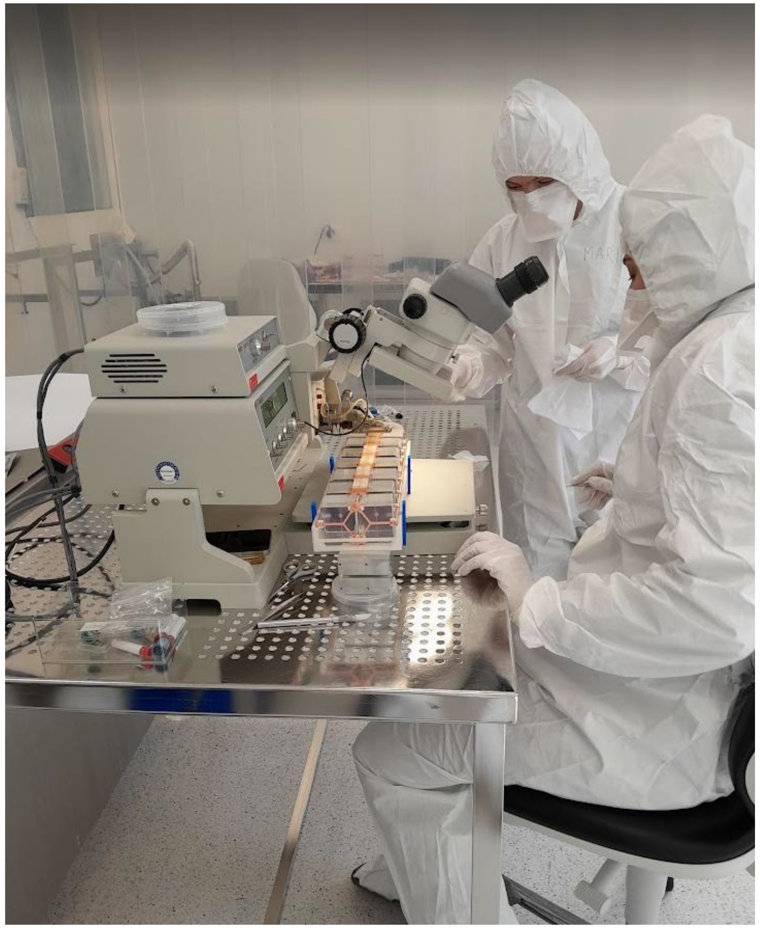


Installation of additional cabling

CROSS demonstrator assembly

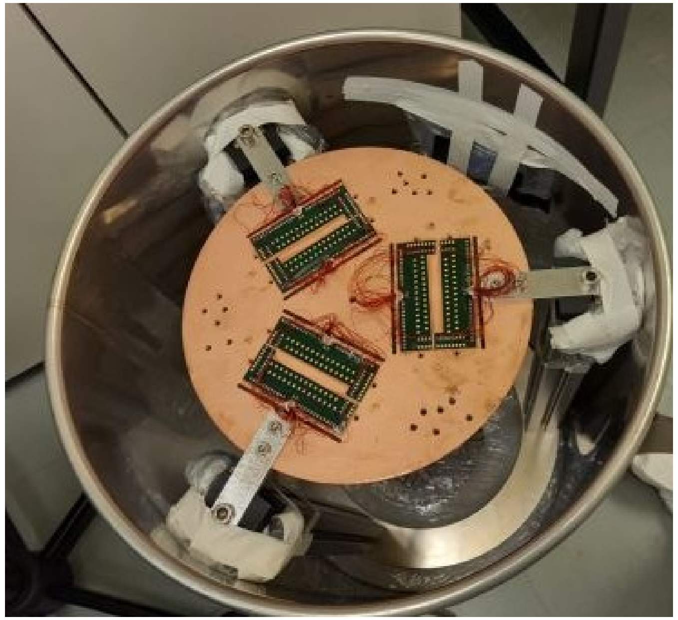


Assembly of the towers

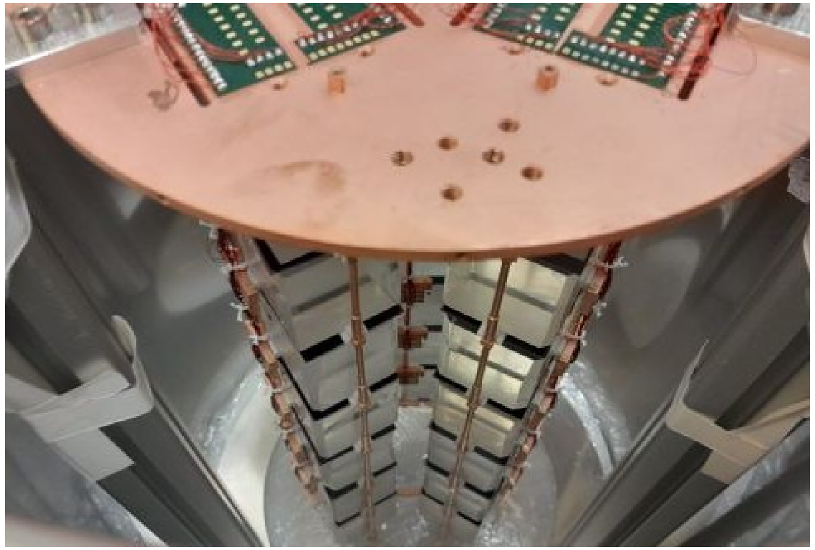


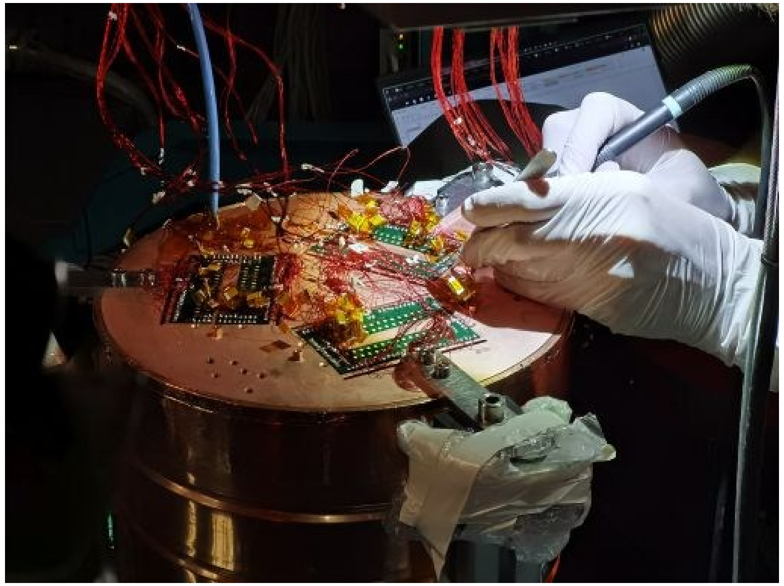
Bonding

Transportation and installation

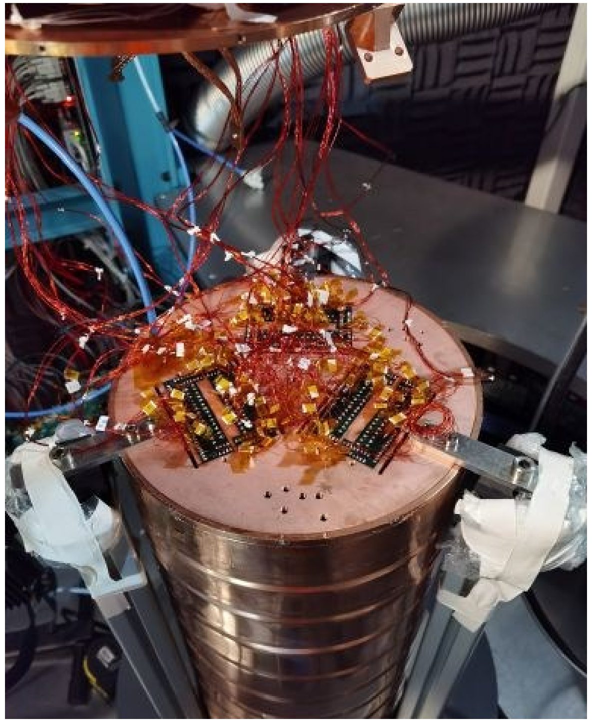


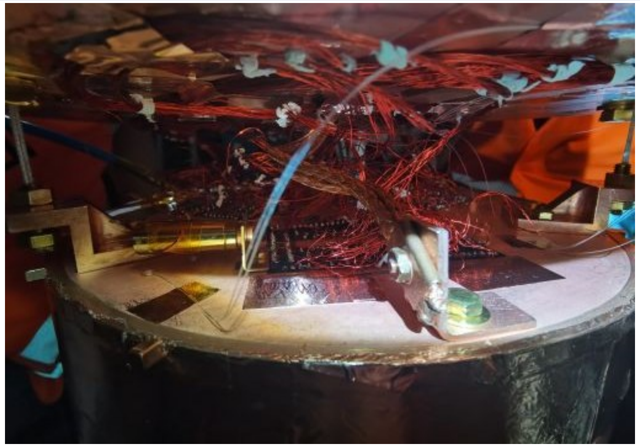
Preparation for the transportation





Soldering





Detectors attached to the cryostat

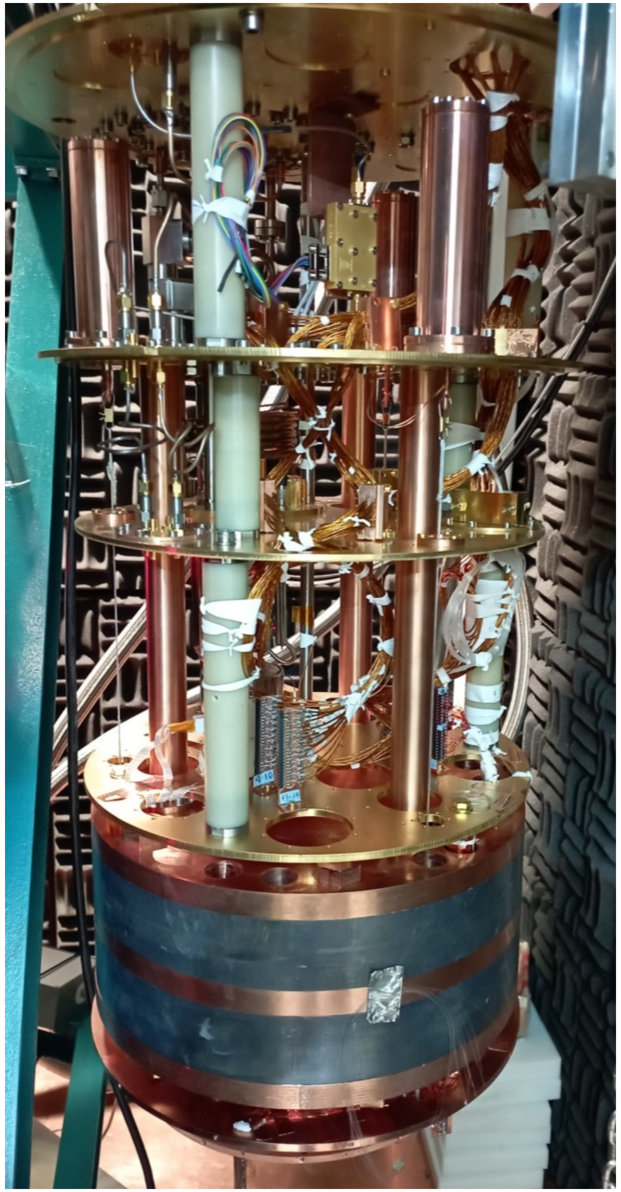
CROSS underground facility at LSC

Cryostat installed and commissioned in April 2019

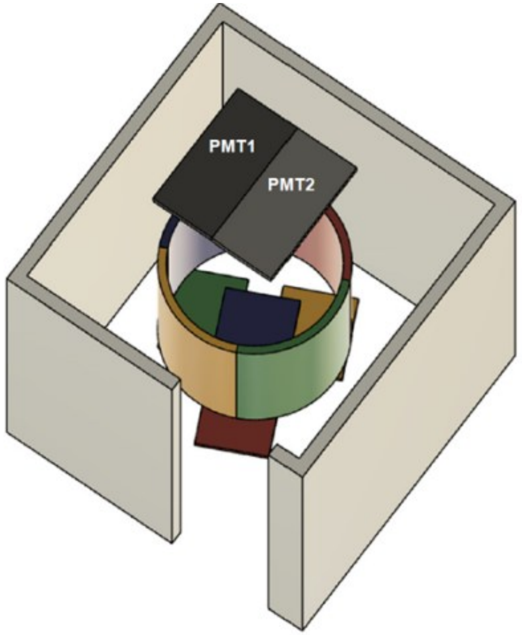
Passive shields:

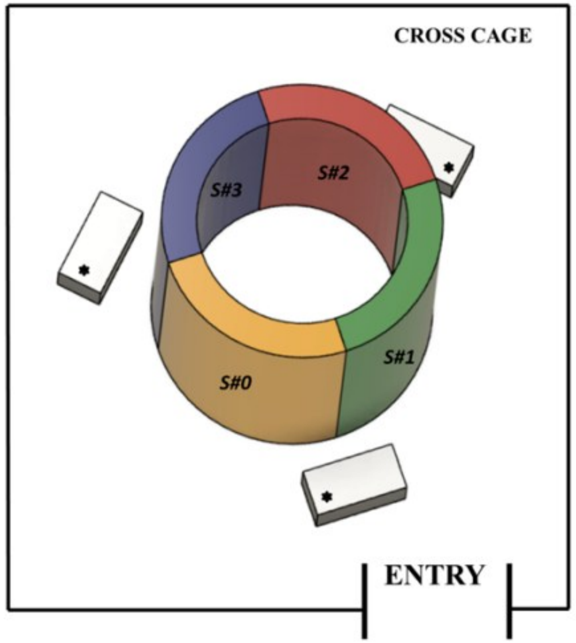
- antiradon shield
- external lead shielding
- internal lead shielding

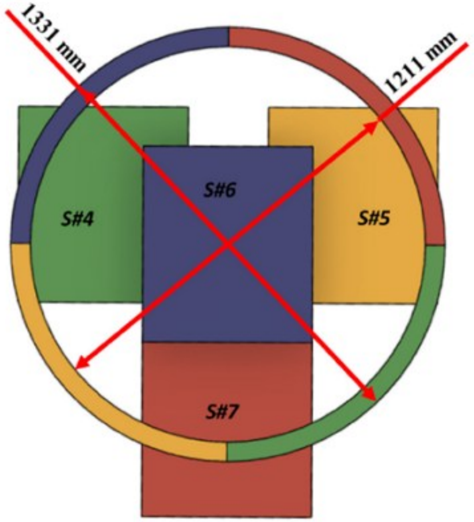
Active: muon veto system



Muon veto





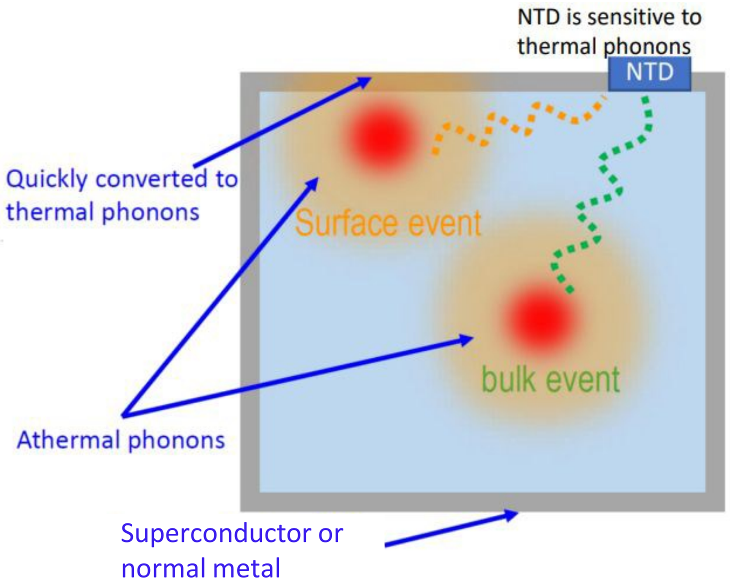


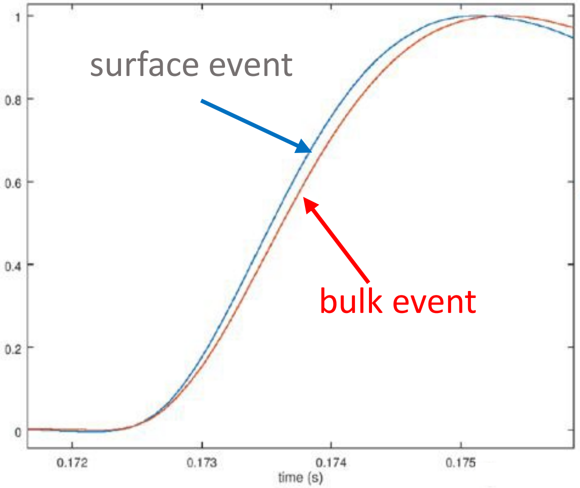
Top

Lateral

Bottom

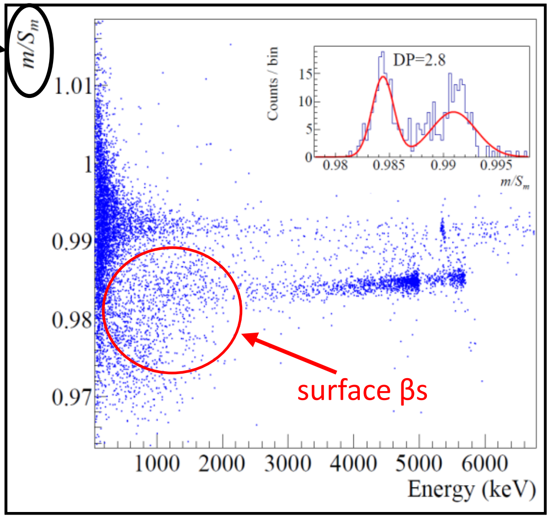
Metal coating for surface events discrimination





Pulse-shape discrimination parameter

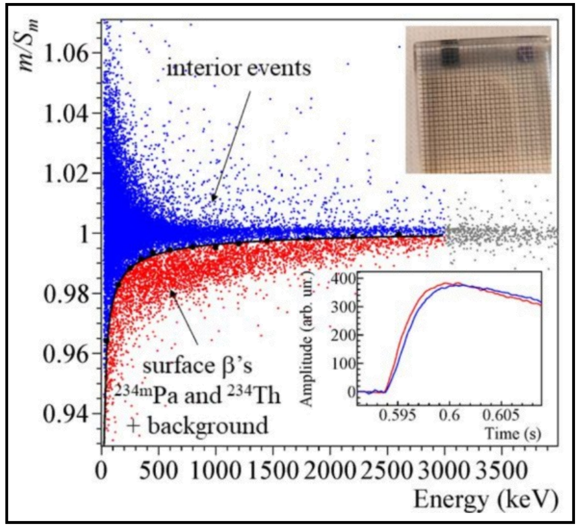
with 10 nm Pd coating



Results obtained with small ($2 \times 2 \times 1$ cm^3) Li_2MoO_4 crystals coated with Al-Pd grid:

- Discrimination power (DP) of surface α's ≥ 4.5σ
- β surface events selection efficiency ~ 93%
- Baseline resolution is not affected

$$DP = \frac{\mu_{\beta/\gamma} - \mu_\alpha}{\sqrt{\sigma^2_{\beta/\gamma} + \sigma^2_\alpha}}$$



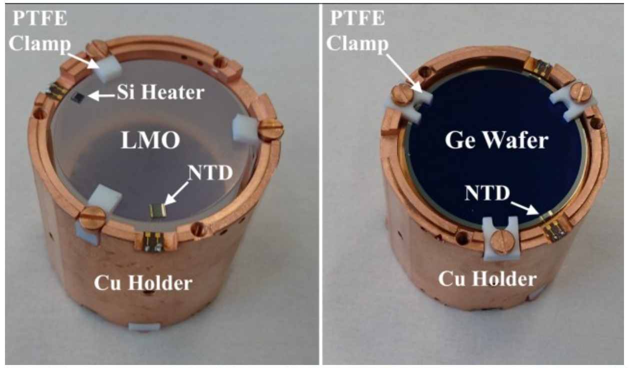
Appl. Phys. Lett. 118, 184105 (2021)

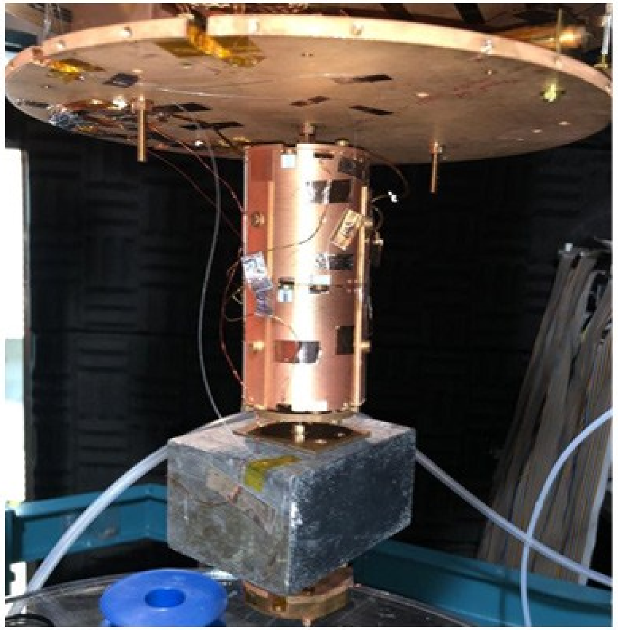
Difficulties with transfering this technology to larger samples ($4.5 \times 4.5 \times 4.5$ cm^3)

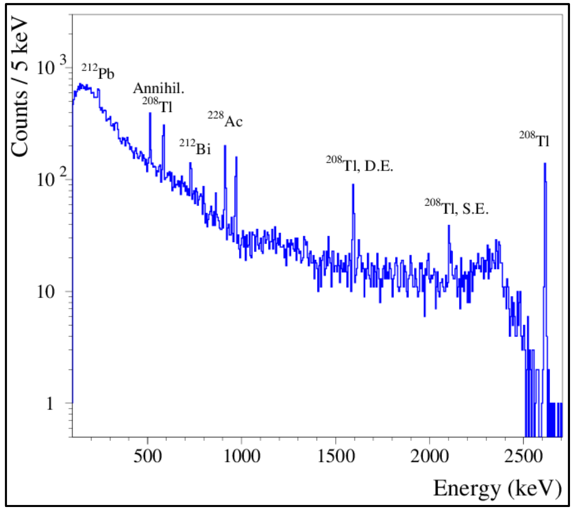
Technology is discarded from the final demonstrator **BUT** this will not affect its 0νββ sensitivity, because

- we are not limited by surface β's background
- for α-s rejection -> **scintillating bolometers technique**

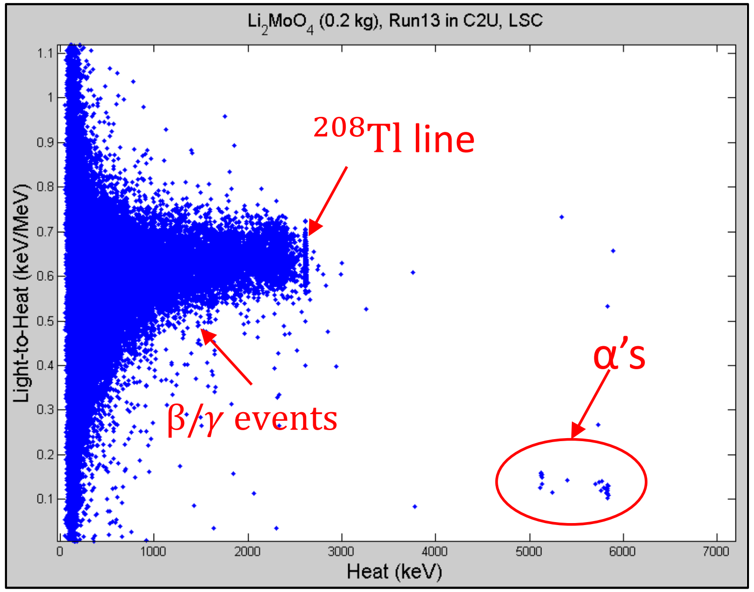
Validation of cryogenic setup: test with 2 CUPID-Mo modules







Energy spectrum from calibration run (78h)



Light to heat ratio vs heat

Crystal performance

	Detector	FWHM @2615 keV (keV)
CROSS	LMO-5	5.7(13)
	LMO-12	5.2(11)
CUPID-Mo	mean: 6.6 ± 0.1	

Eur.Phys.J.C 82 (2022) 11, 1033

LDs performance

	Detector	$\sigma_{baseline}$[keV]
CROSS	LD-5	64
	LD-12	72
CUPID-Mo	LD-5	66
	LD-12	69

Eur.Phys.J.C 80 (2020) 44