BINGO

Bi-**I**sotope 0ν2β **N**ext **G**eneration **O**bservatory

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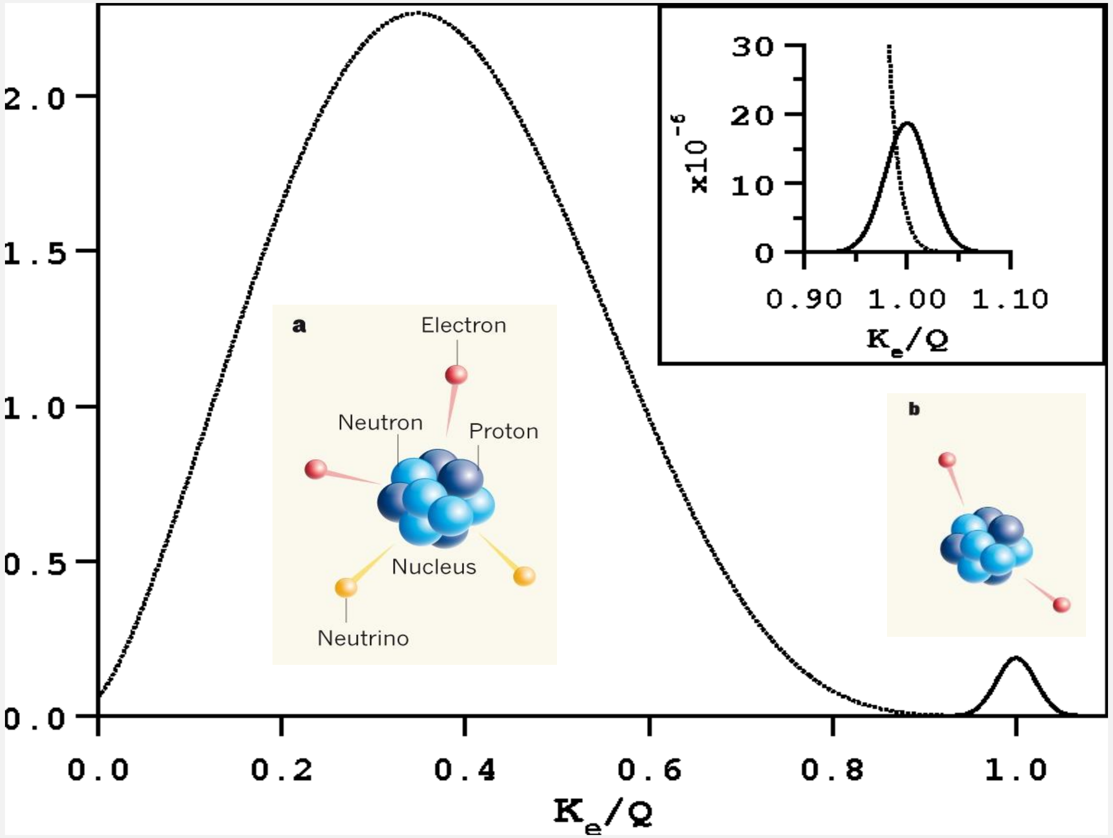
SEARCHING FOR 2β0ν

- 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

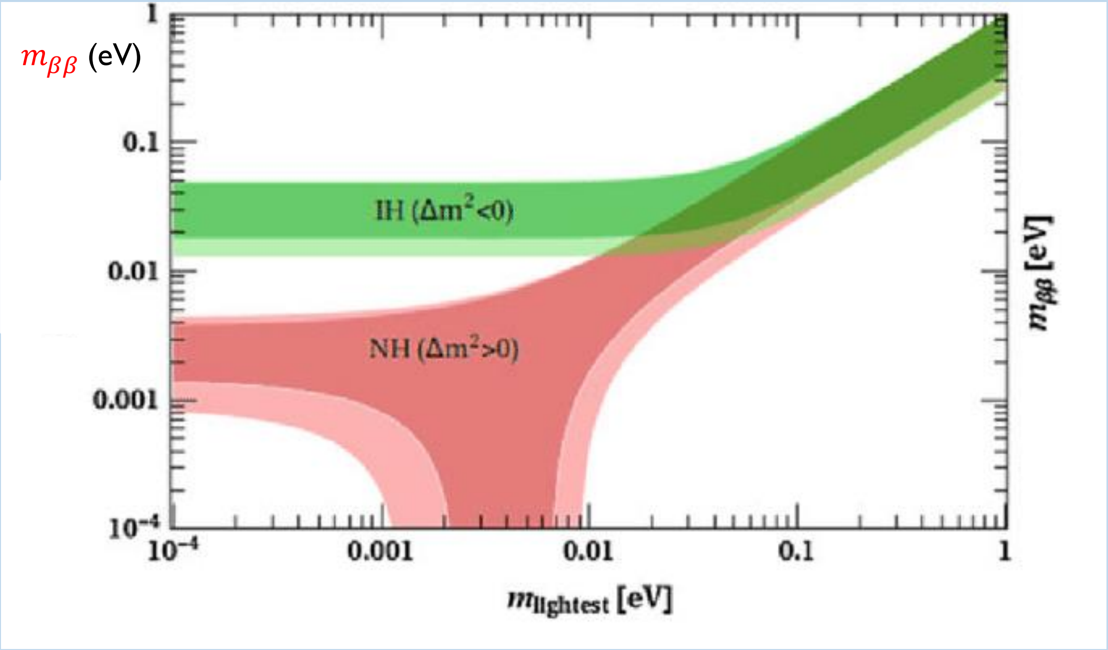


SENSITIVITY TO MAJORANA EFFECTIVE MASS

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

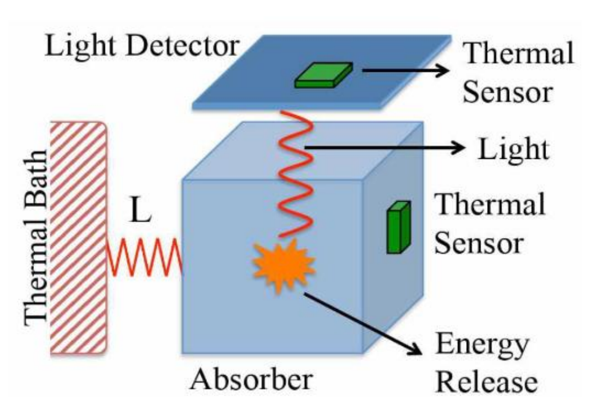
$$T^{0\nu}_{1/2} \propto a \times \epsilon \times \sqrt{\frac{M \times t}{b[ckky] \times \Delta E}}$$

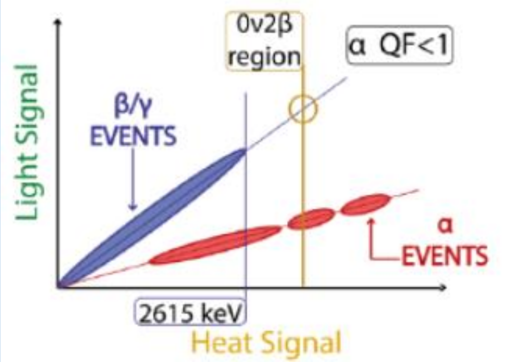
An extremely rare decay : $T^{0\nu}_{1/2} > 10^{25} - 10^{26}\ yr$



DETECTION METHOD AND BACKGROUND LIMITATIONS

SCINTILLATING BOLOMETERS



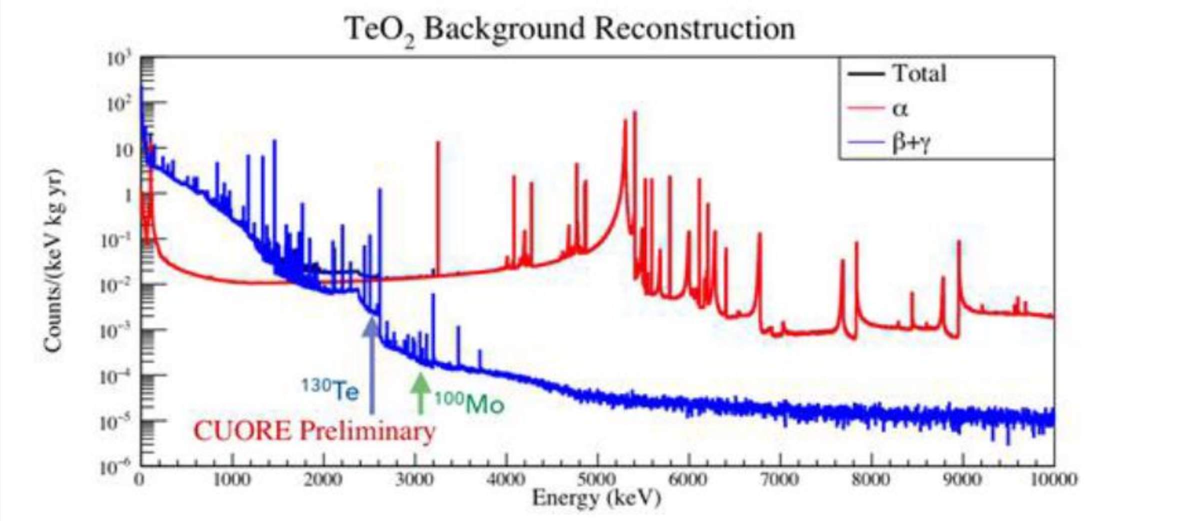


- Cryogenic detectors : $\Delta T = \frac{E}{C}$ working around 15 mK
- Detector = source
- 2 signals : heat and light → α discrimination

Ideal for 2β0ν search because of :

- High energy resolution (<5 keV FWHM in the ROI)
- Large masses achievable by using an array of crystals
- High detection efficiency (80-90%)
- Large isotope choice for the absorber among the 2β0ν candidates

CUORE BACKGROUND MODEL



CUORE

Largest bolometric experiment ever

Thermal bolometers : ^{130}Te embedded in TeO_2 crystals

b ~ 10^{-2} ckky limited by α events

CUPID

« Cuore Upgrade with Particle IDentification »

Scintillating bolometers : ^{100}Mo embedded in Li_2MoO_4 crystals

b ~ 10^{-4} ckky reachable thanks to isotope move and α discrimination

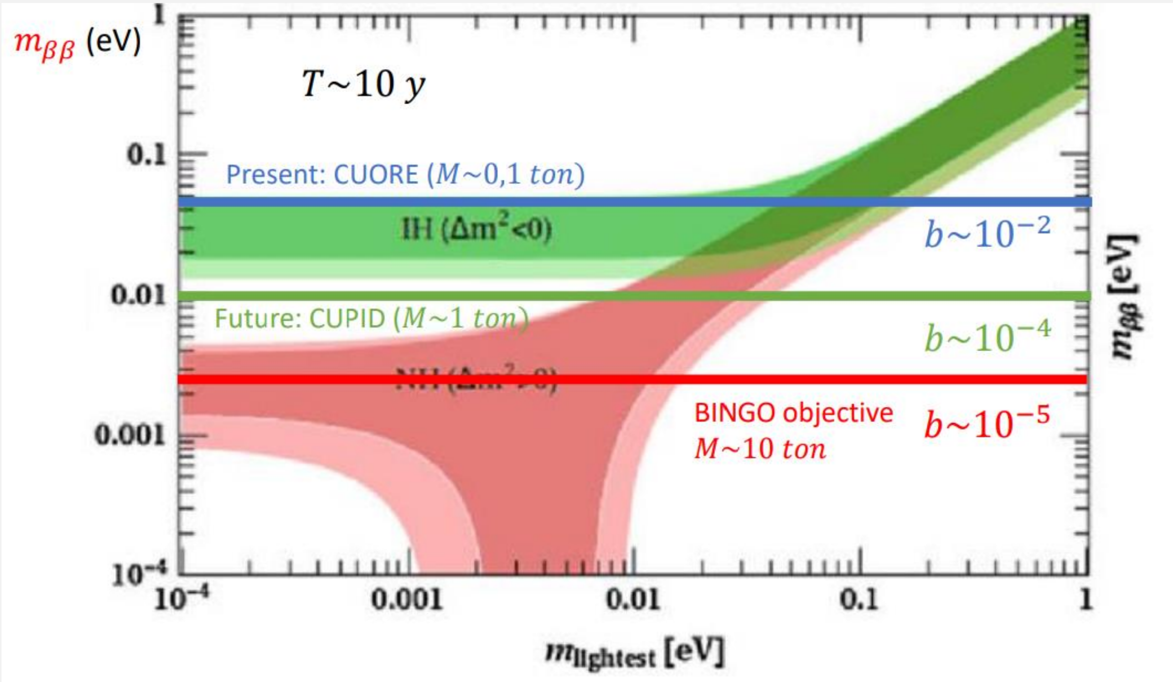
GOAL OF BINGO

- BINGO proposes innovative technologies and methods in order to prepare the next-next generation of 0v2β bolometric experiments.

- The main objective of BINGO is to reduce significantly the number of background events in the region of interest compared to what is currently achievable.

- Two of the most promising isotopes will be used : ^{100}Mo embedded in Li_2MoO_4 and ^{130}Te embedded in TeO_2

- **Bi-Isotopic approach** : observation in 2 candidates allows discovery and confirmation

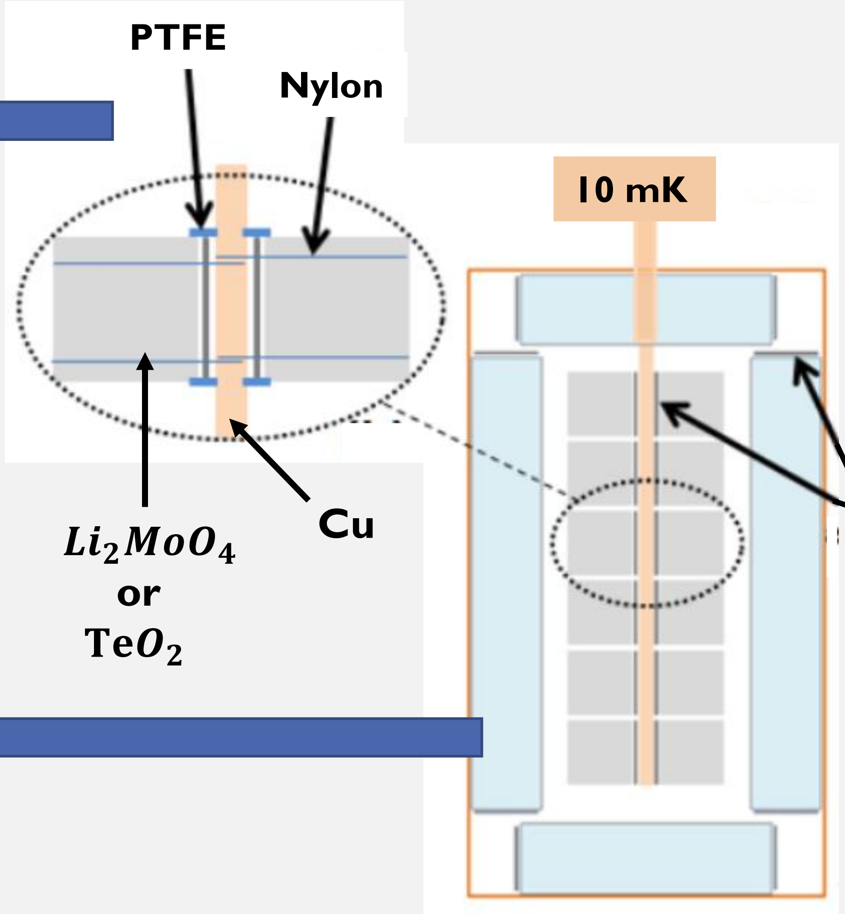


- Prepare the exploration of the normal hierarchy region

HOW TO REACH 10^{-5} CKKY ?

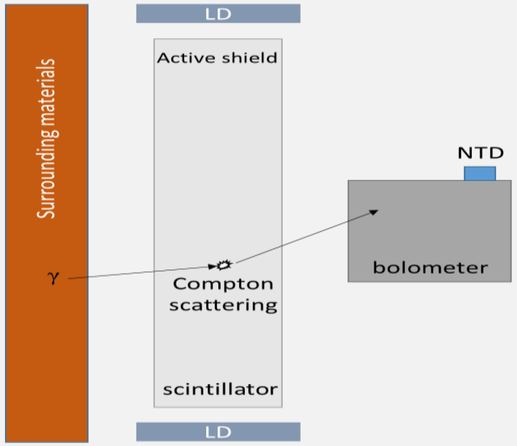
(I) A revolutionary detector assembly:

- Reduce the Cu amount seen by the main absorber → reduction of the total surface radioactivity contribution
- Having a compact assembly → anticoincidence cuts



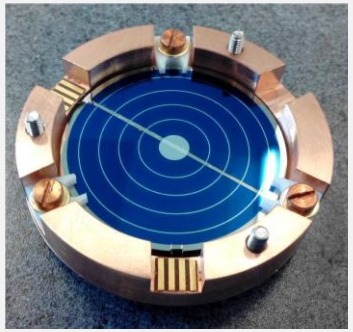
(II) For the first time, a cryogenic (at 20mK) active veto :

- Composed of scintillators ($ZnWO_4$ or BGO)
- Suppress the external gamma background (specifically essential for TeO_2)

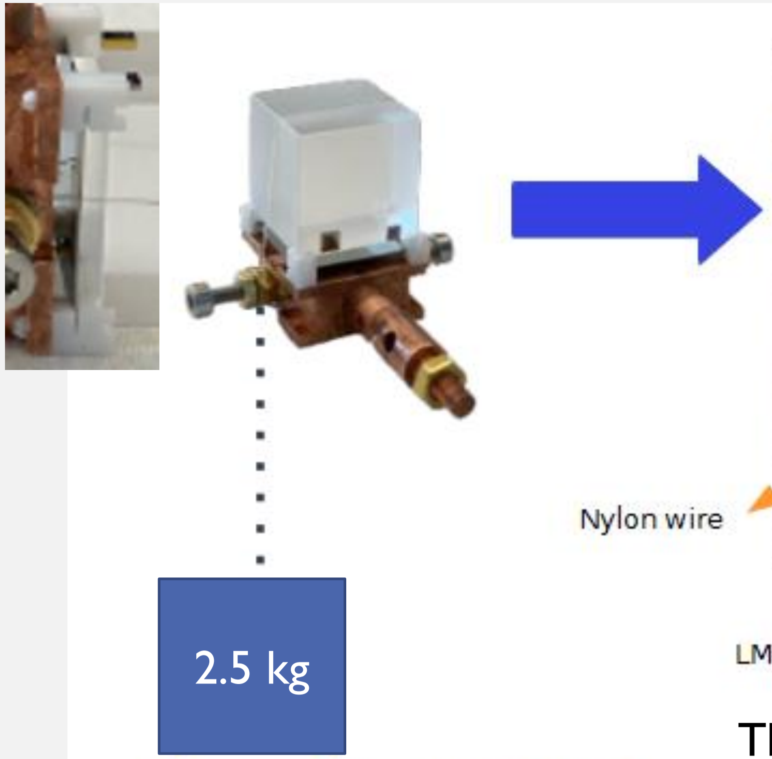


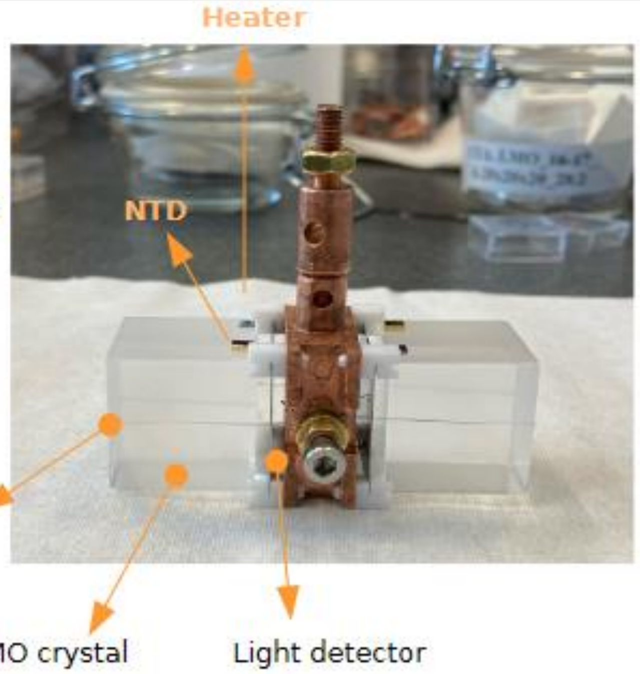
(III) Neganov-Luke LD :

- Amplification of the light signal thanks to Neganov-Luke effect
- Essential to detect Cherenkov light emitted by the TeO_2
- Low threshold needed (~50 keV) to well reconstruct the spectrum of events crossing the veto
- It helps to reject random coincidences



FIRST TEST ON THE NEW ASSEMBLY SYSTEM





One nylon wire is installed to hold the crystal with a 2.5kg weight. The pressure allows also to smash the LD thanks to teflon pieces and to prevent it from moving.

This operation is repeated for both crystals in order to apply the same force.

Two 20x20x20 mm^3 LMO crystals
And two 20x20x0.25 mm^3 Ge LDs

<u>In classical structure (CROSS/CUPID TDR) :</u>

- ~20 cm^2 of passive Cu
- ~1 cm^2 of PTFE/PLA

<u>In BINGO approach :</u>

- Nylon wire, Ø0.35 mm, 14 cm long: ~ 1.5 cm^2
- PTFE/PLA support: < 1 cm^2
- Residual Cu parts "seeing" the crystal: < 1 cm^2

<u>Reduction by :</u>

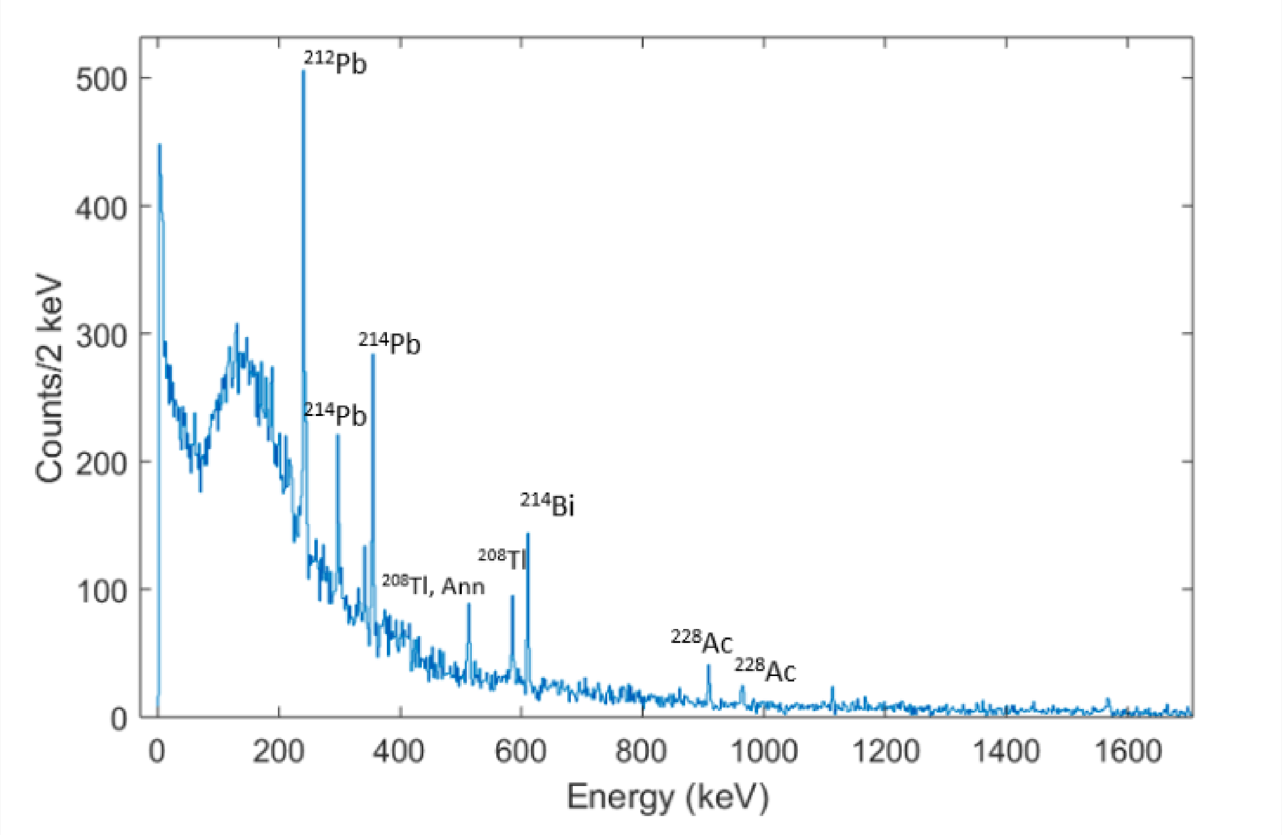
> 1 order of magnitude with respect to CROSS/CUPID-TDR "alternative" structure

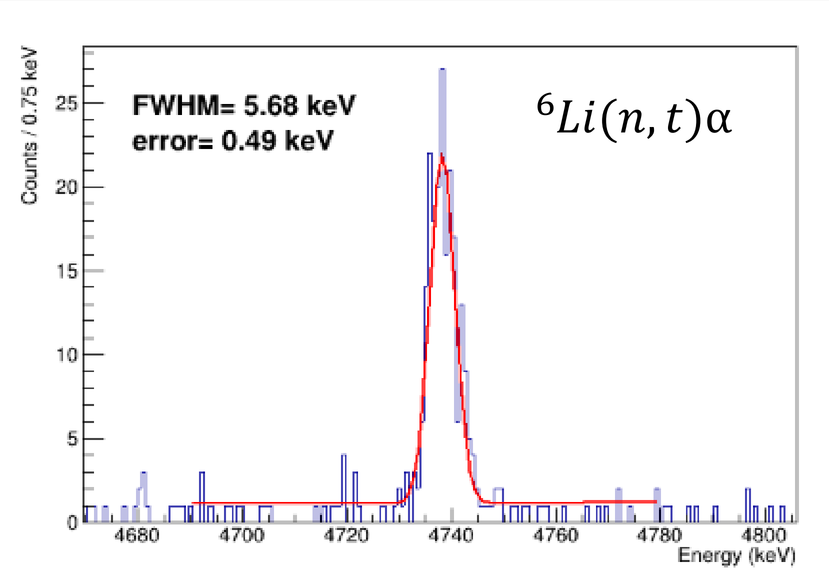
~2 orders of magnitude with respect to CUORE

FIRST TEST ON THE NEW ASSEMBLY SYSTEM

Performances at 15 mK	Sensitivity (nV/keV)	Baseline FWHM (keV)
LMO4	132.9	0.85

LMO4 – Energy spectrum



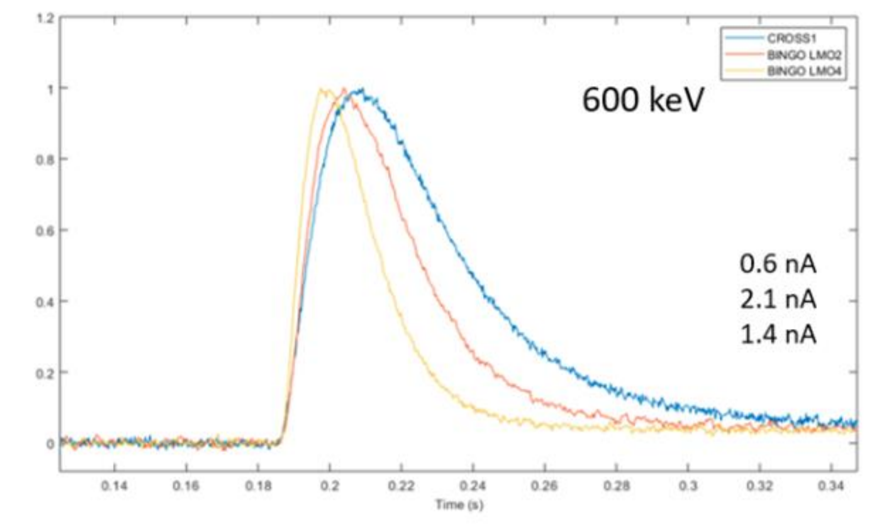


E=4.78 MeV but here thermal quenching
σ=940 barn

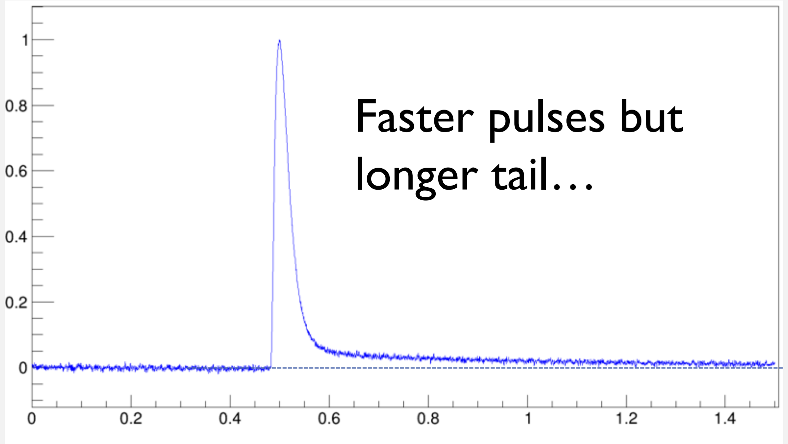
The best energy resolution ever obtained on the Lithium neutron capture peak with bolometers !

Good sensitivity, baseline FWHM (<1keV) and energy resolution ...

FIRST TEST ON THE NEW ASSEMBLY SYSTEM



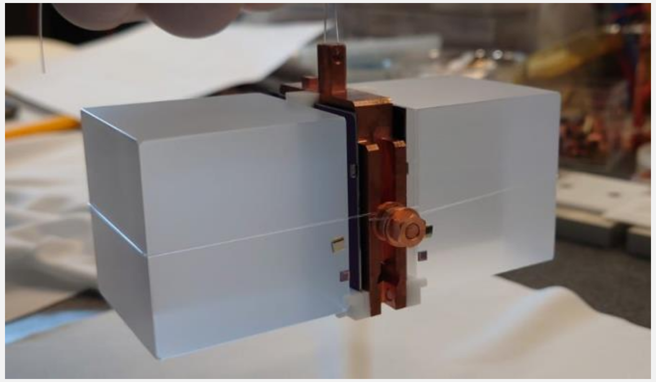
	Rise time	Decay time
LMO2	8 ms	24 ms
LMO4	7 ms	20 ms
CROSS	12 ms	38 ms



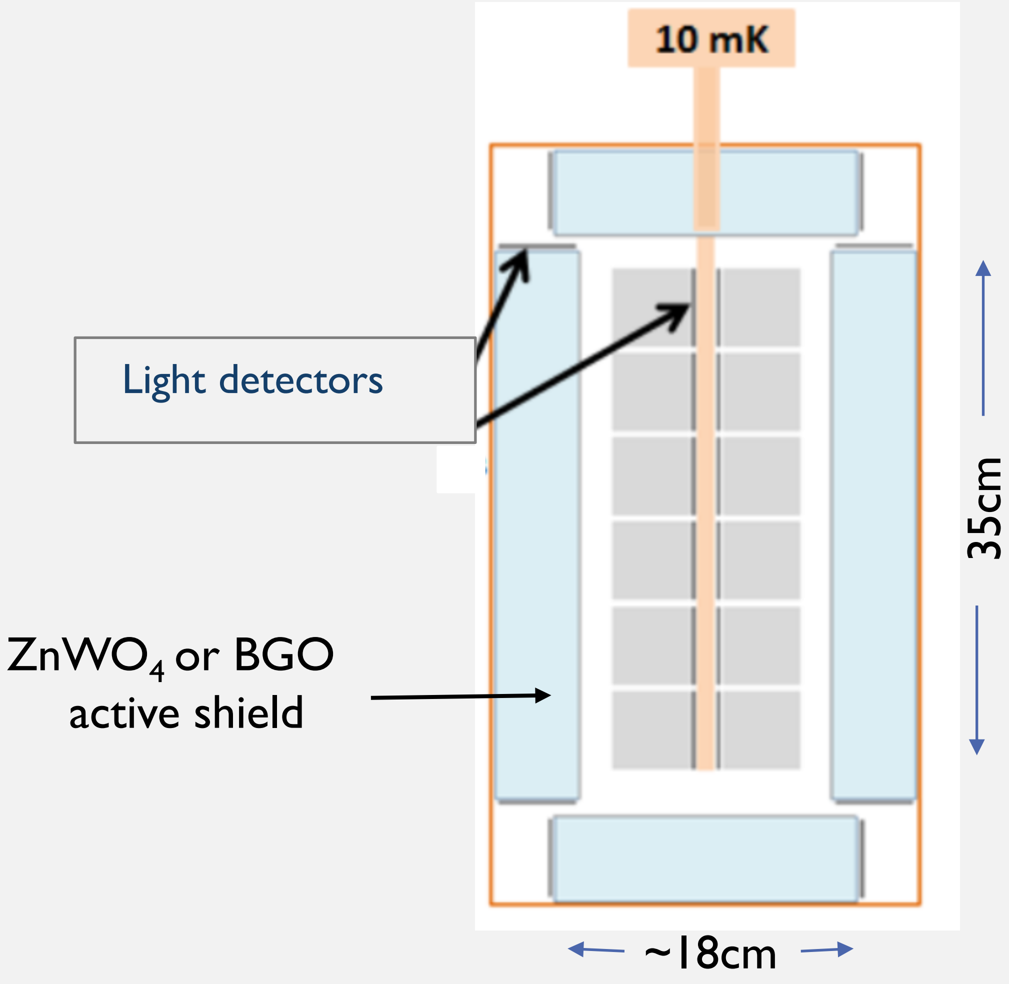
Conclusion :

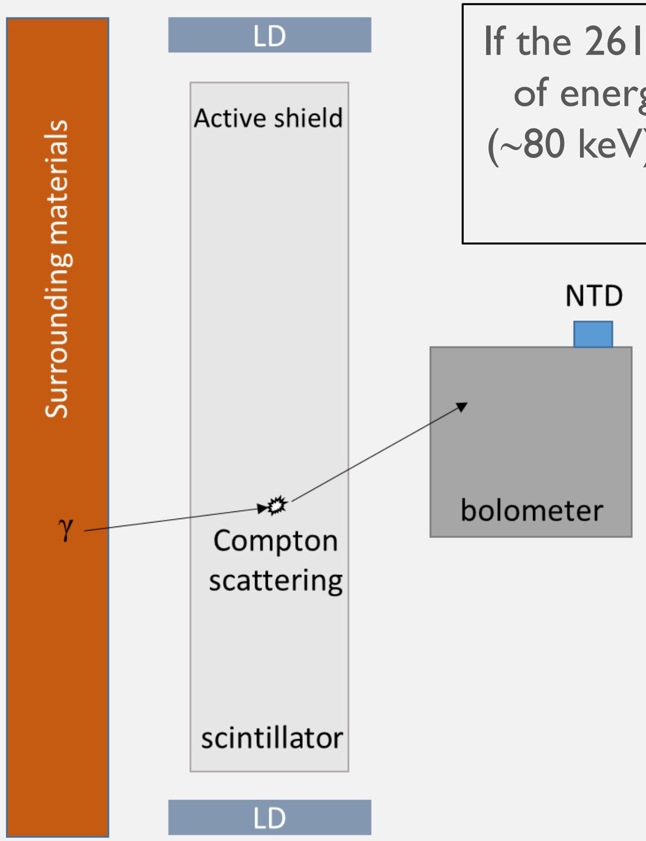
- Good performances for the two LMO crystals and an excellent baseline FWHM (<1 keV)
- It is proved that such an assembly is working at low temperature. Really encouraging !
- Still some things to understand and to confirm.

Next step : A new test will be done with larger LMO crystals (45x45x45 mm^3) in an improved assembly.



THE CRYOGENIC ACTIVE VETO





If the 2615 keV γ deposit a small amount of energy in the surrounding material (~80 keV) and the rest in TeO_2 → bkg in ROI (2527 keV)

Essential requirements to suppress the background from the ROI of TeO_2:

- Very low energy threshold of the light detector → low threshold of ZWO or BGO
- Neganov-Luke LD to increase signal to noise ratio → low threshold
- The nominal BINGO expected threshold is 50 keV (to be confirmed with a devoted MC)

FIRST TEST ON THE VETO CRYSTALS : BGO or ZWO ?

BGO

- Excellent light yield
- Available in large sizes

- Radiopurity to be verified (^{207}Bi)
- Extremely slow to cool down

ZWO

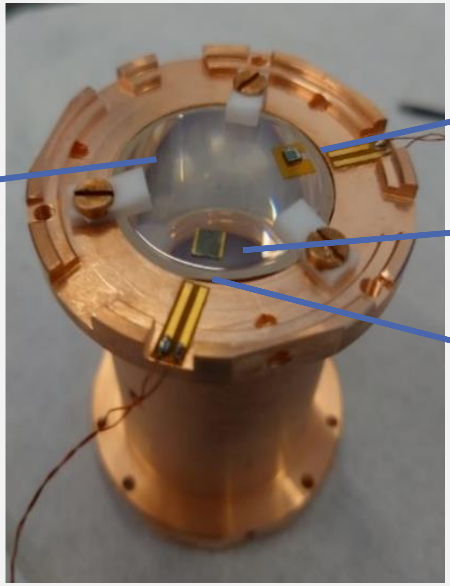
- Very good light yield
- Extremely radiopure (<0.17 uBq/kg in ^{228}Th)

- Large sizes to be demonstrated
- Alpha contamination to be measured

It was possible to grow ZWO crystal with mass of 8 kg and a size of ∅8x20 cm. A possibility to grow a crystal with double the lenght is foreseen.

Both tested in the same holder in two different runs :

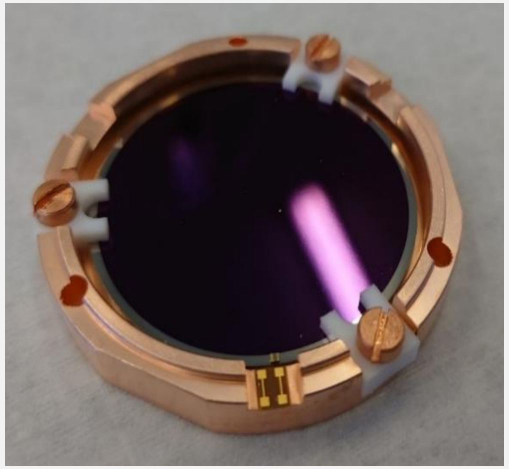
BGO or ZWO (∅3×6 cm)

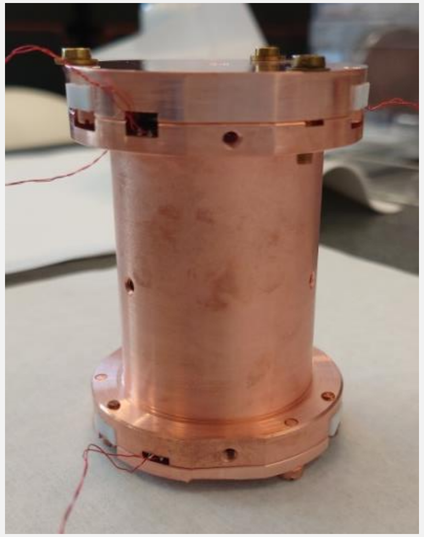


Heater

NTD

Reflecting foil all around the crystal



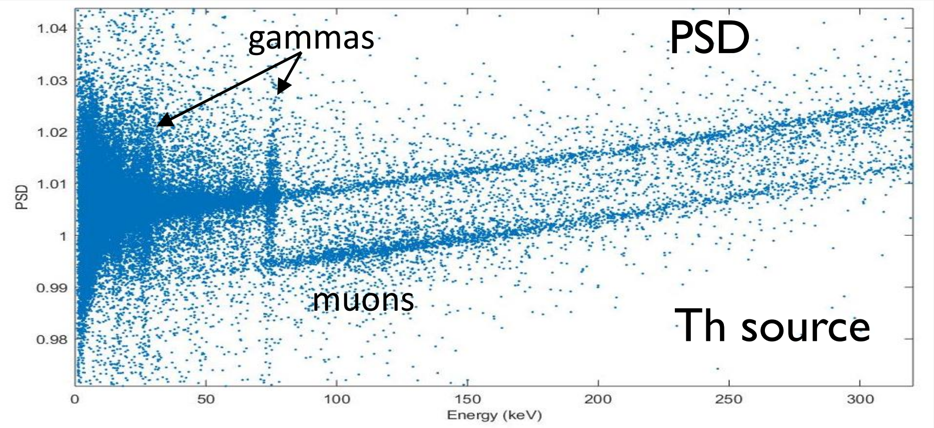


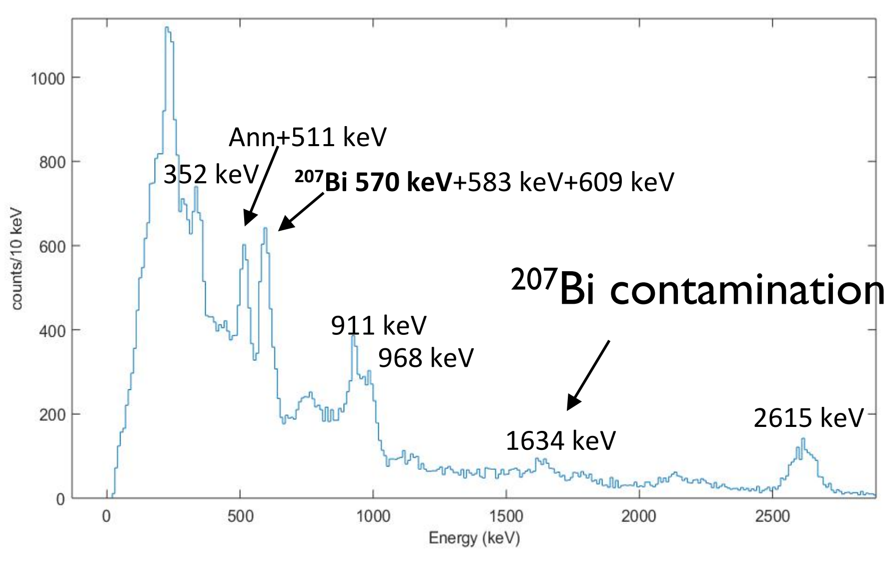
Closed using a piece with a SiO coated Ge LD

LIGHT YIELD RESULTS : BGO or ZWO ?

BGO

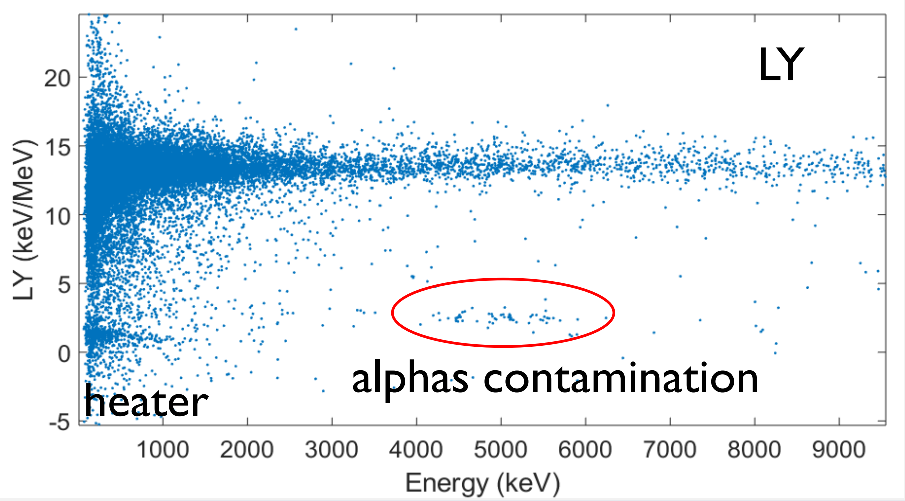
BGO/SiO LD	Sensitivity (µV/keV)	$FWHM_{bsln}$ (eV)	LY (keV/MeV)
15 mK	1.77	127.4	28





ZWO

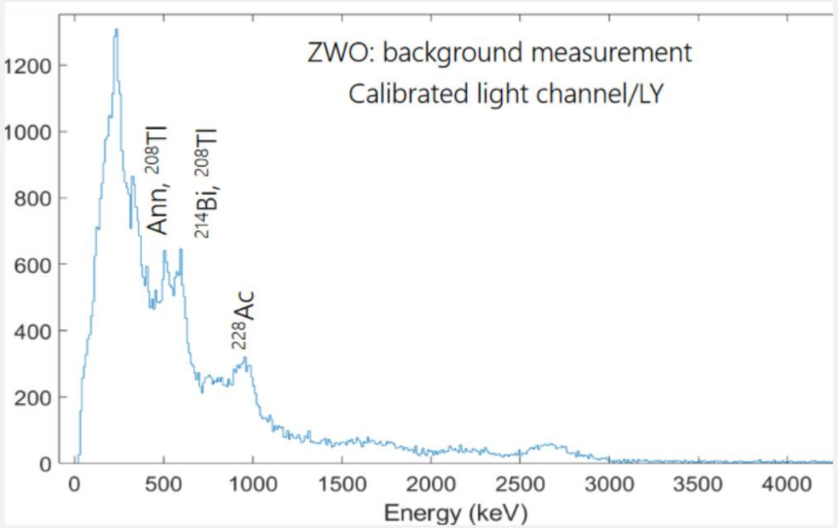
ZWO/SiO LD	Sensitivity (µV/keV)	$FWHM_{bsln}$ (eV)	LY (keV/MeV)
15 mK	1.73	145.5	13.6



$^{238}U : 1.48(11)\ mBq/kg$

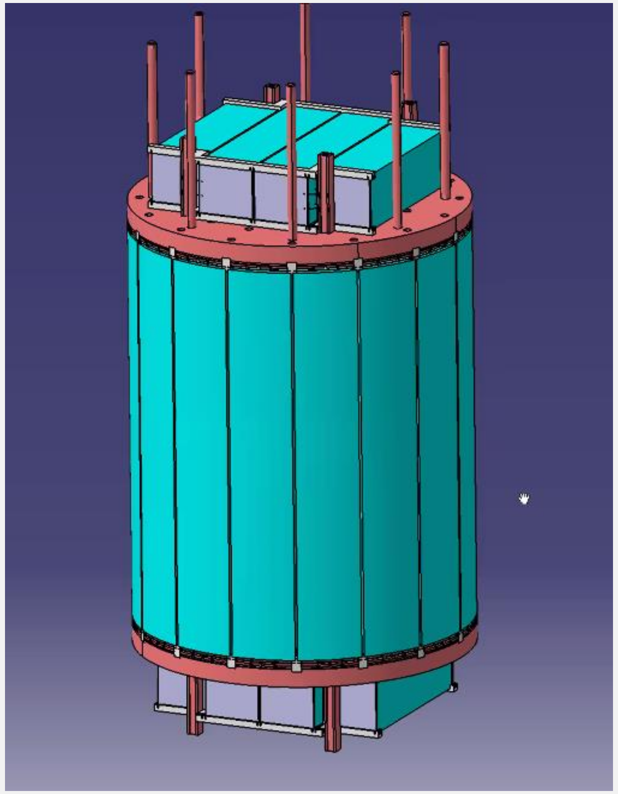
$^{234}U : 1.51(11)\ mBq/kg$

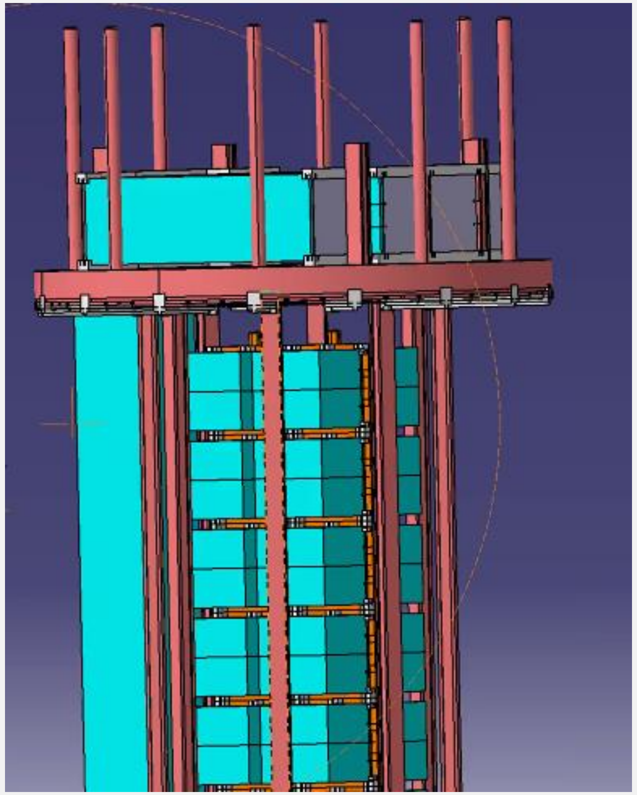
$^{210}Po : 0.85(9)\ mBq/kg$



THE MINI-BINGO DEMONSTRATOR

First mechanical drawings





Placed in a new cryostat at Modane underground laboratory (LSM)

Bolometers assembly

	Nb of crystals	Mass [kg]	Dimensions	Nb of LD
Li_2MoO_4	12	4	45x45x45 mm^3	12
TeO_2	12	8.5	45x45x45 mm^3	12

Total weight of the crystals ~150 kg

LD: 45×45 mm^2 and a thickness of 0.2 mm

Two towers of 12 crystals each

TO VALIDATE THE TECHNOLOGY AND THAT b~10^{-5} CKKY IS REACHABLE WITH THE RIGHT EXPOSURE

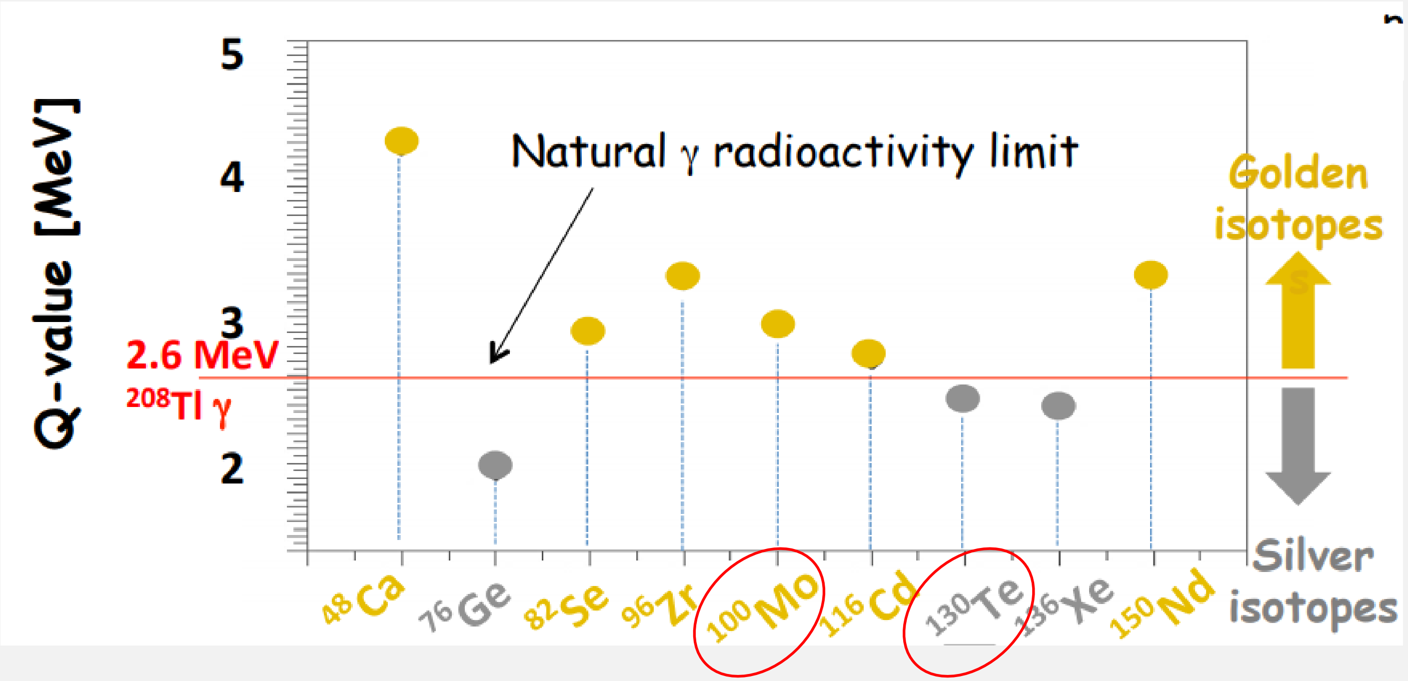
Active shield		nb of crystals	Mass [kg]	dimensions	Nb of LD
$ZnWO_4$ [BGO]	lateral	16	110 [99.8]	$25cm^2 \times$ **35 cm**	**32**
	cap shield (1)	4	11.7 [10.7]	$25cm^2 \times$ **15 cm**	**8**
	cap shield (2)	4	14 [12.8]	$25cm^2 \times$ **18 cm**	**8**

SUMMARY AND CONCLUSION

- BINGO proposes innovative methods to reach a background index of b~10^{-5} ckky and start the exploration of the normal hierarchy in the next-next generation of bolometric experiments.
- We have shown that the new assembly system is working well and obtained really interesting results. We will do a new test with bigger crystals (of the size of CUPID crystals)
- We have done first tests on the two candidates for the veto scintillators : BGO and ZWO in order to compare their results.
- It is too soon to make a choice and we need to do new measurements and Monte Carlo simulations (to determine precisely if BGO Bi contamination or ZWO alpha contamination are harmful).
- Work is ongoing also on Neganov-Luke light detectors. We need to confirm their performances, study new geometries for electrodes, make a fabrication protocol suitable for large scale production…
- The final goal of this work is to build a demonstrator « MINI-BINGO » which will be operated underground at LSM in a new cryostat to prove the BINGO improved performances.

BACK UP SLIDES

BINGO ISOTOPES



Isotope	$Q_{\beta\beta}$	Crystal	Isotopic abundance	Defaults
^{130}Te	2527 keV	TeO_2 (CUORE)	34 %	- $Q_{\beta\beta}$<2.6 MeV - Only Cherenkov light
^{100}Mo	3034 keV	Li_2MoO_4 (CUPID-Mo)	9.6 %	- Fast 2ν2β

Bi-Isotopic approach: observation in 2 candidates → discovery + confirmation

The CUORE experiment in LNGS

- $2\beta 0\nu$ candidate : $^{130}\boldsymbol{Te}$ $(\boldsymbol{Q_{\beta\beta}} = \boldsymbol{2527\ keV})$

- The LARGEST bolometric experiment ever :
988 5x5x5cm crystals of TeO_2 arranged in 19 towers
Total mass : 742 kg (206 kg of ^{130}Te)

- One of the MOST SENSITIVE current experiment :
Current limit : $T_{1/2}^{0\nu} > 2.2 \times 10^{25}\ yr$
$\rightarrow m_{\beta\beta} < 90 - 305\ meV$
Expected limit after 5 years : $T_{1/2}^{0\nu} > 9 \times 10^{25}\ yr$
$\rightarrow m_{\beta\beta} < 60 - 280\ meV$

«High sensitivity neutrinoless double-beta decay search with one tonne-year of CUORE data», CUORE Collaboration, arXiv:2104.06906v1 [nucl-ex] 14 Apr 2021

- CUORE has proven that a ton-scale experiment is technically possible using bolometers.
- The cryostat holding the experiment shows excellent performances and a really good stability overtime.
- An energy resolution of ~7 keV FWHM is reached in the ROI, so really close to the objective.

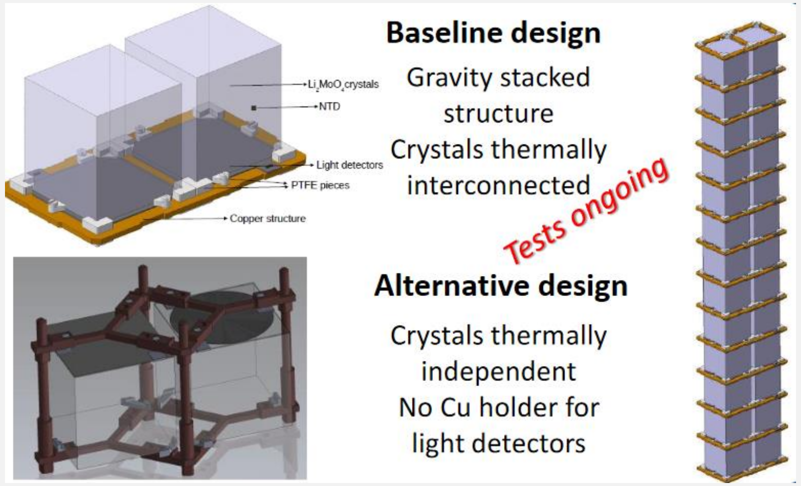
- BUT ~50 background counts/year in the ROI, corresponding to b~$10^{-2} ckky$
- Dominated by surface α events + $Q_{\beta\beta}$ of ^{130}Te < 2615 keV
- = Sensitivity limited by the background index

CUPID EXPERIMENT

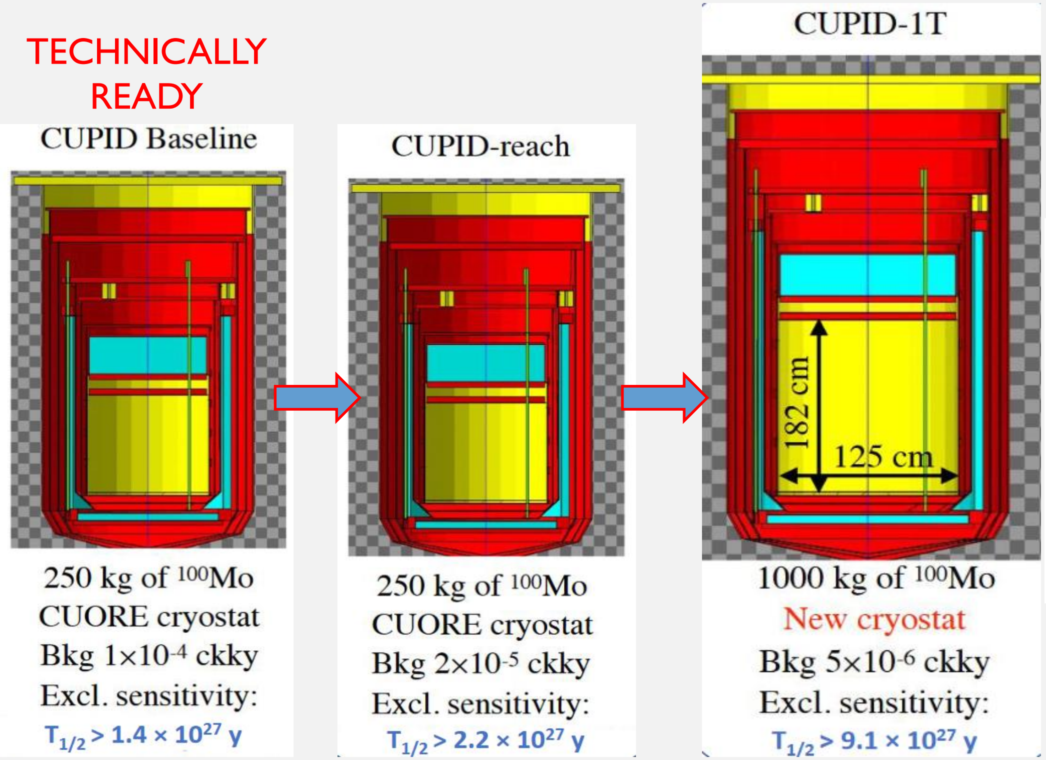
- Use of the CUORE cryostat at LNGS (available in ~2024)

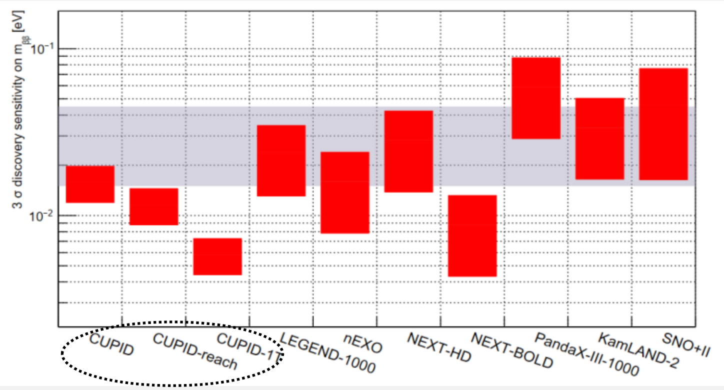
- **1596** 45x45x45mm Li_2MoO_4 crystals of ~280g each
  - Arranged in 57 towers of 14 floors
- Total mass : ~**240 kg** of ^{100}Mo thanks to a >95% enrichment

- SEVERAL TESTS DONE AND ON GOING FOR THE BASELINE DESIGN



TECHNICALLY READY

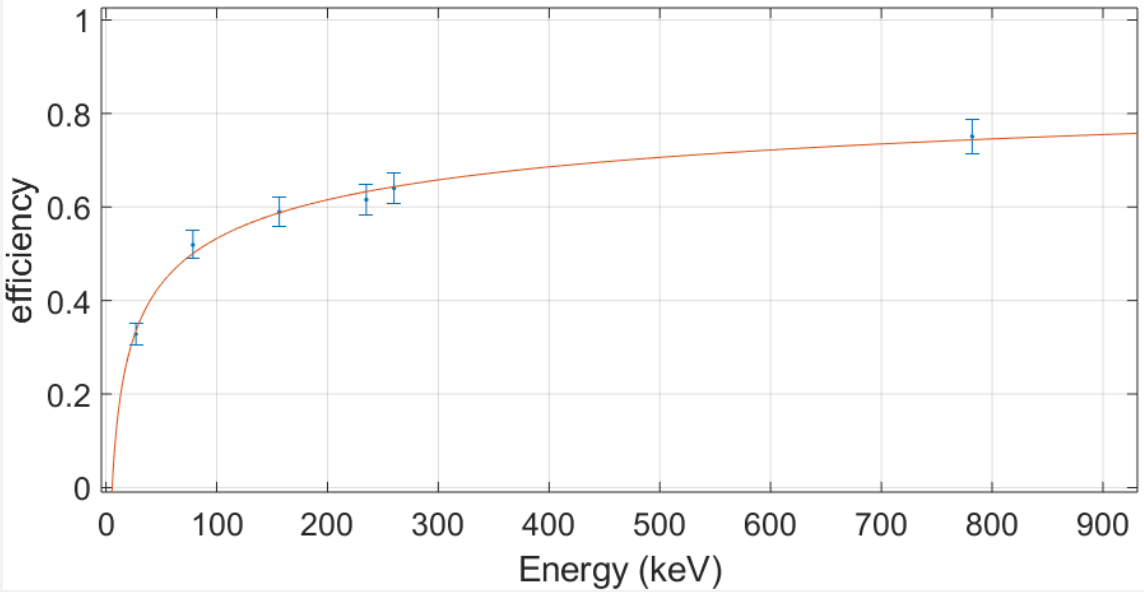




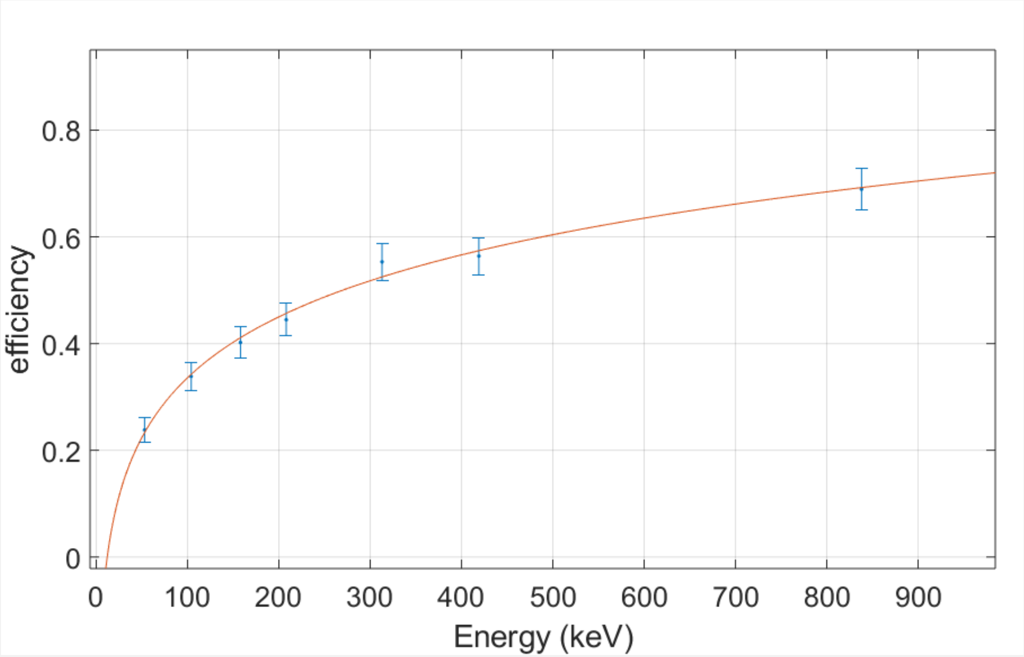
TRIGGER EFFICIENCY : BGO or ZWO ?

Preliminary study : Injection of 570 fake pulses (similar to the mean pulse) at several amplitudes to see how many we can trigger.

BGO



ZWO



Trigger efficiency at high energy is not 100% due to the quantity of events leading a lot of pile up