BINGO, towards the meV level of the neutrino mass scale

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Neutrinoless double beta-decay

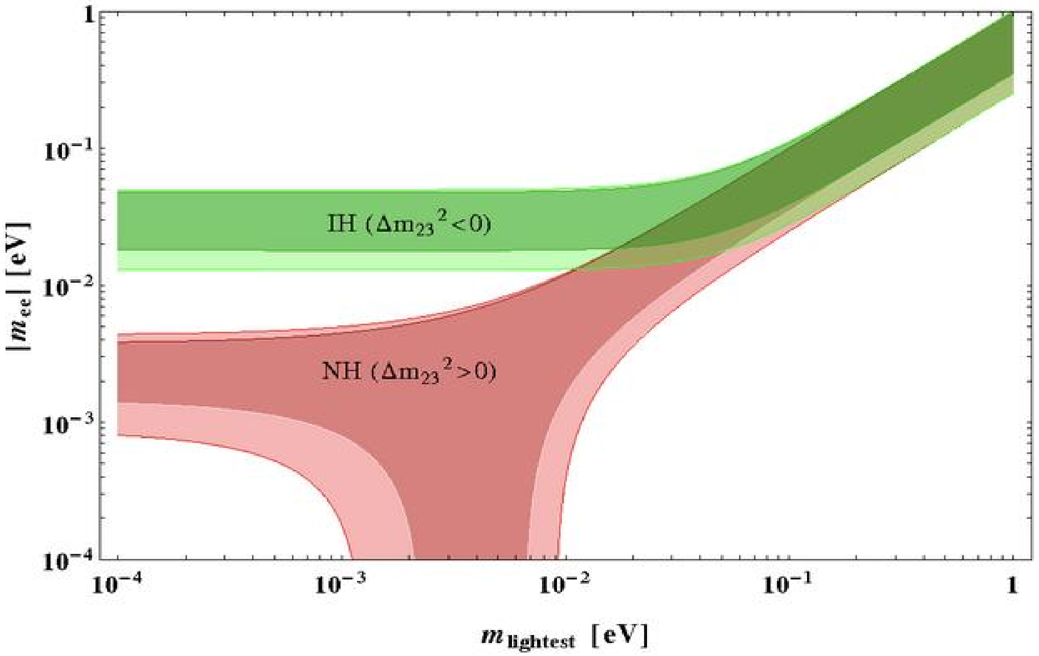
Neutrinoless double-beta decay:

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

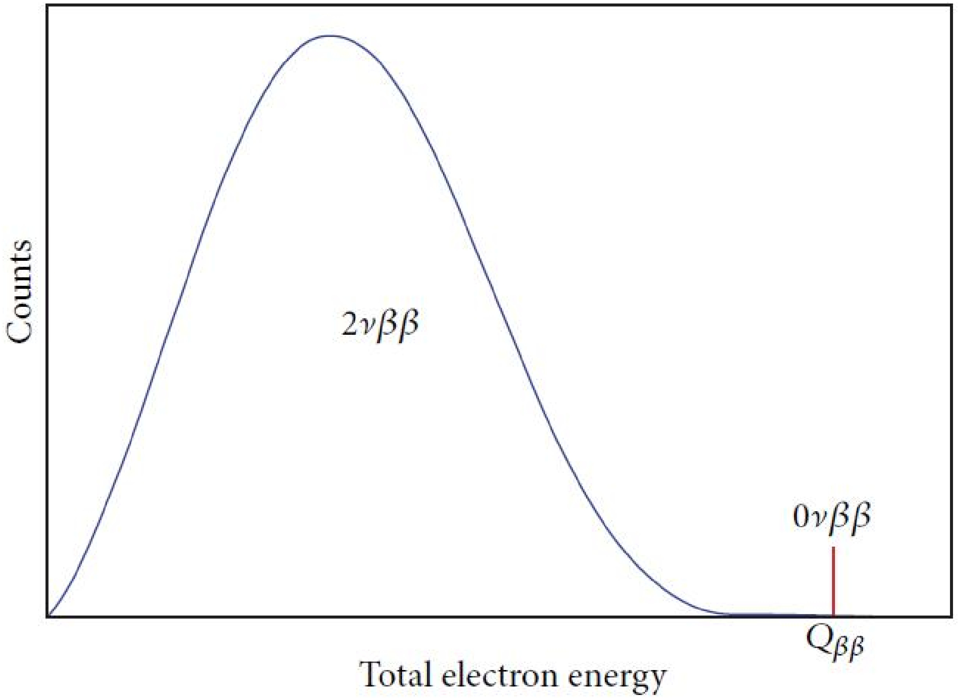
An extremely rare decay: $\boldsymbol{T_{1/2} > 10^{25}\,yr}$

If observed:

- neutrino is Majorana particle
- confirmation of lepton number violation
- fix the neutrino mass scale



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



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

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

Neutrinoless double beta-decay

Neutrinoless double-beta decay:

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

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

If observed:

- neutrino is Majorana particle
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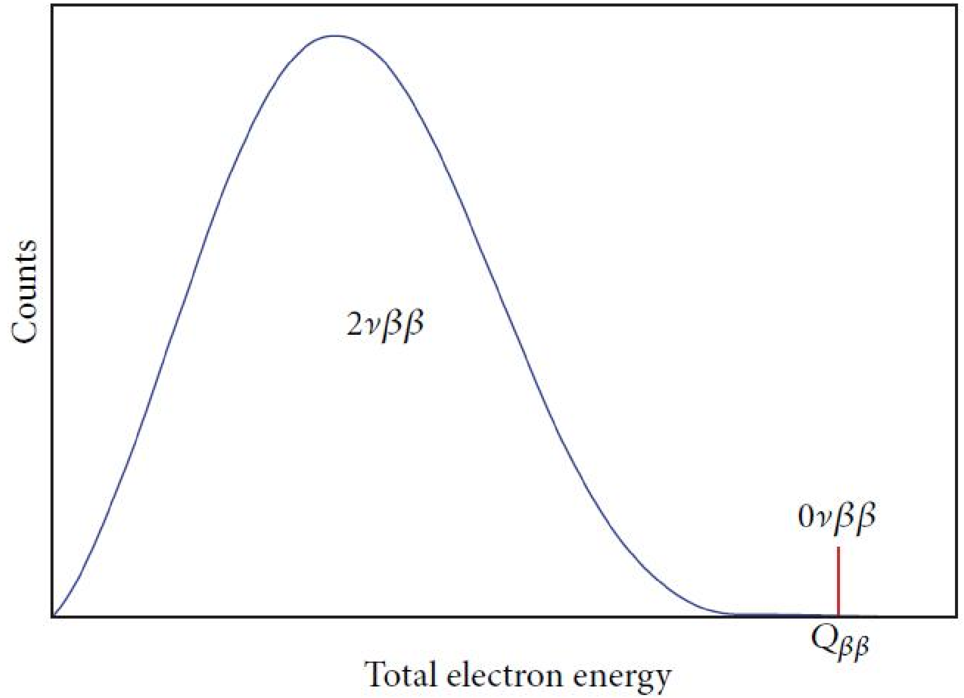

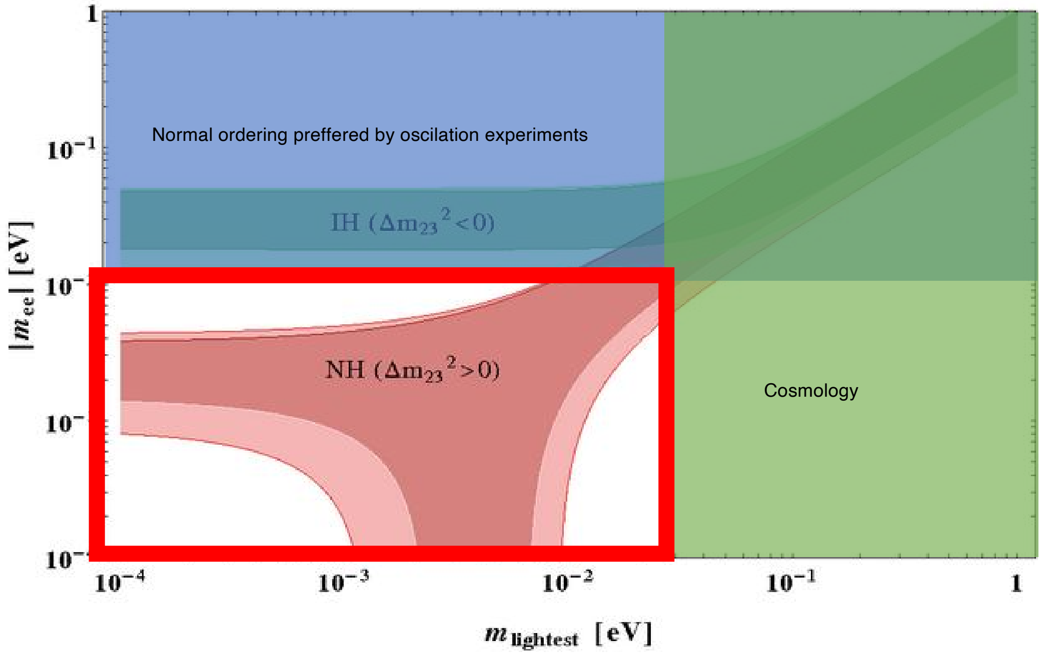

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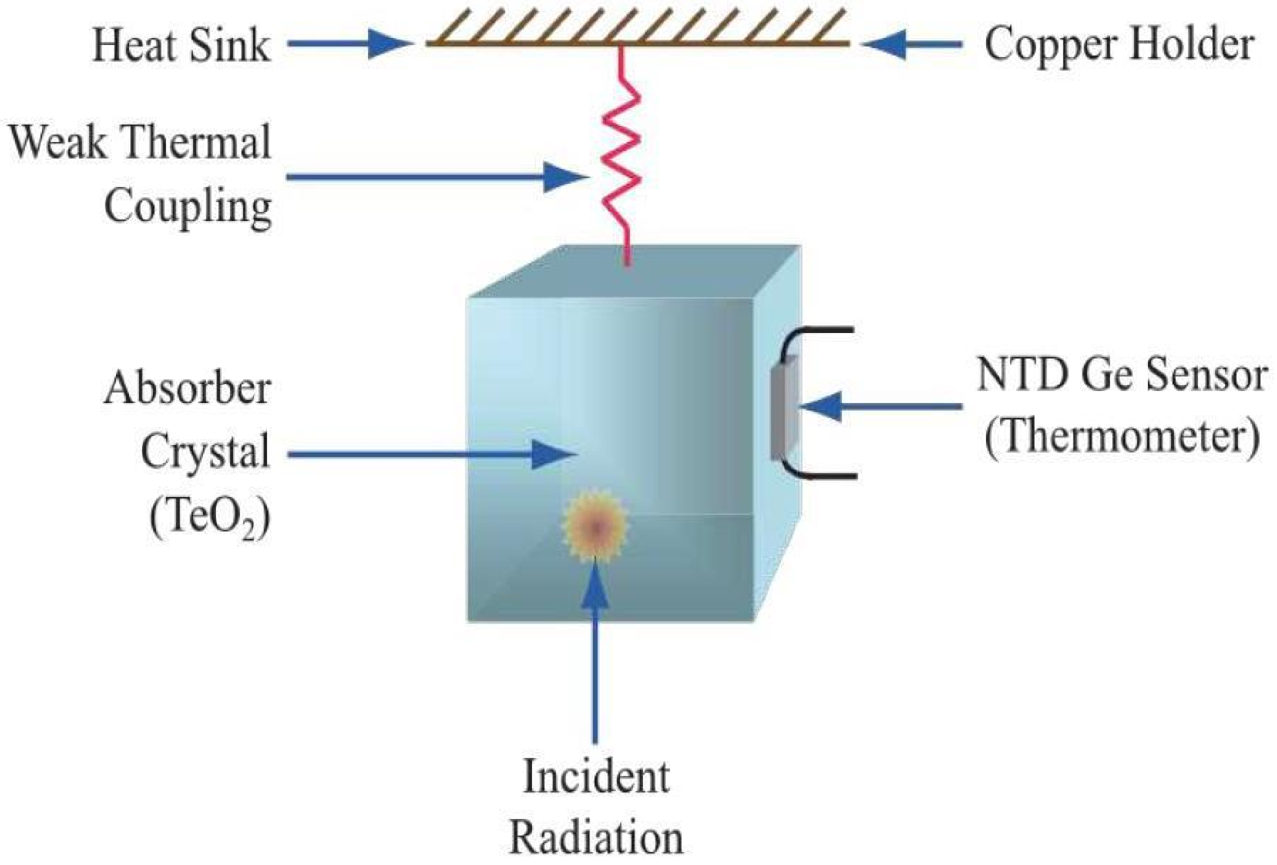
Bolometers

- The deposited energy is measured as a temperature change in a crystal
- Detectors are operated at temperature ~10-20 mK

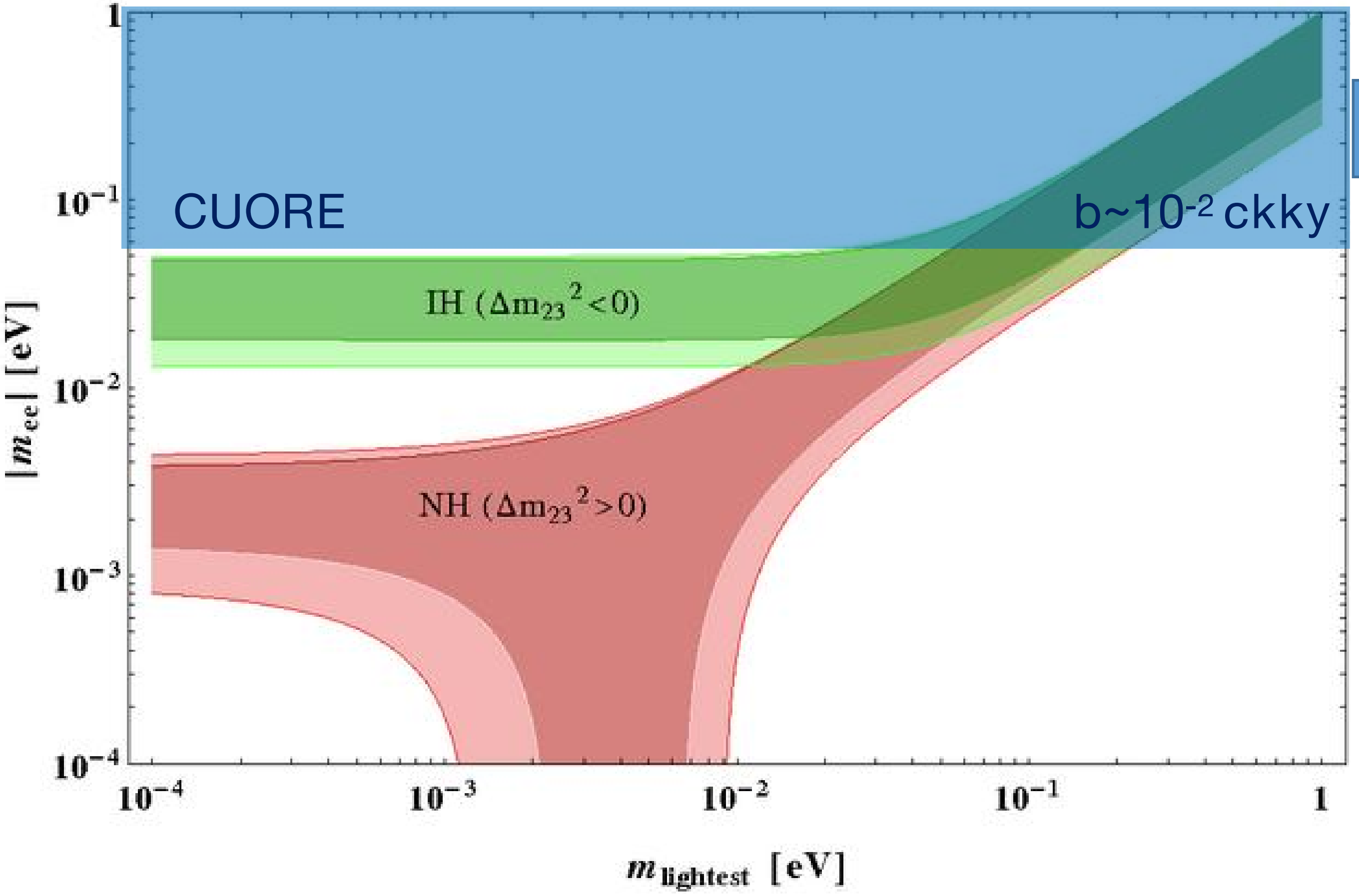
Advantages of bolometers

- Source=detector approach → High detection efficiency (~90%)
- Excellent energy resolution (~5 keV in the ROI)
- Large masses achievable using arrays of crystals

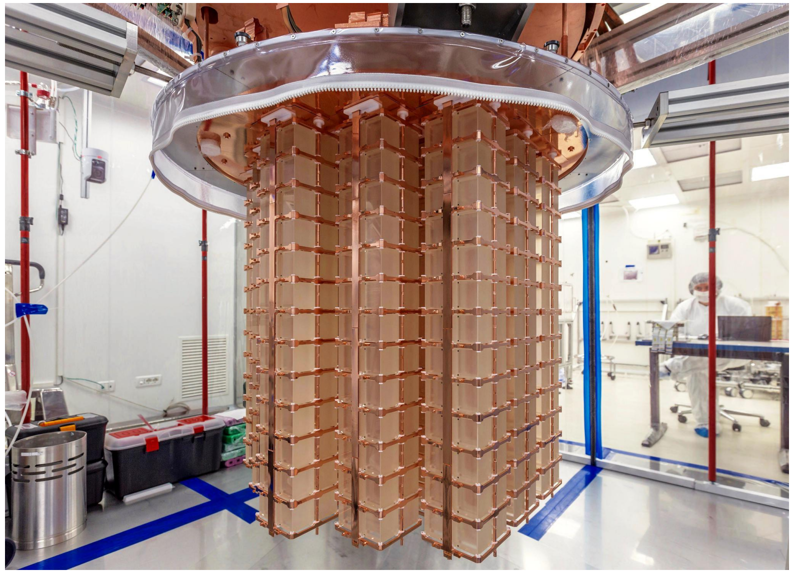


CUORE

CUORE is a first tonne scale array of cryogenic calorimeters (988 TeO_2 crystals) installed in Gran Sasso undergound laboratory



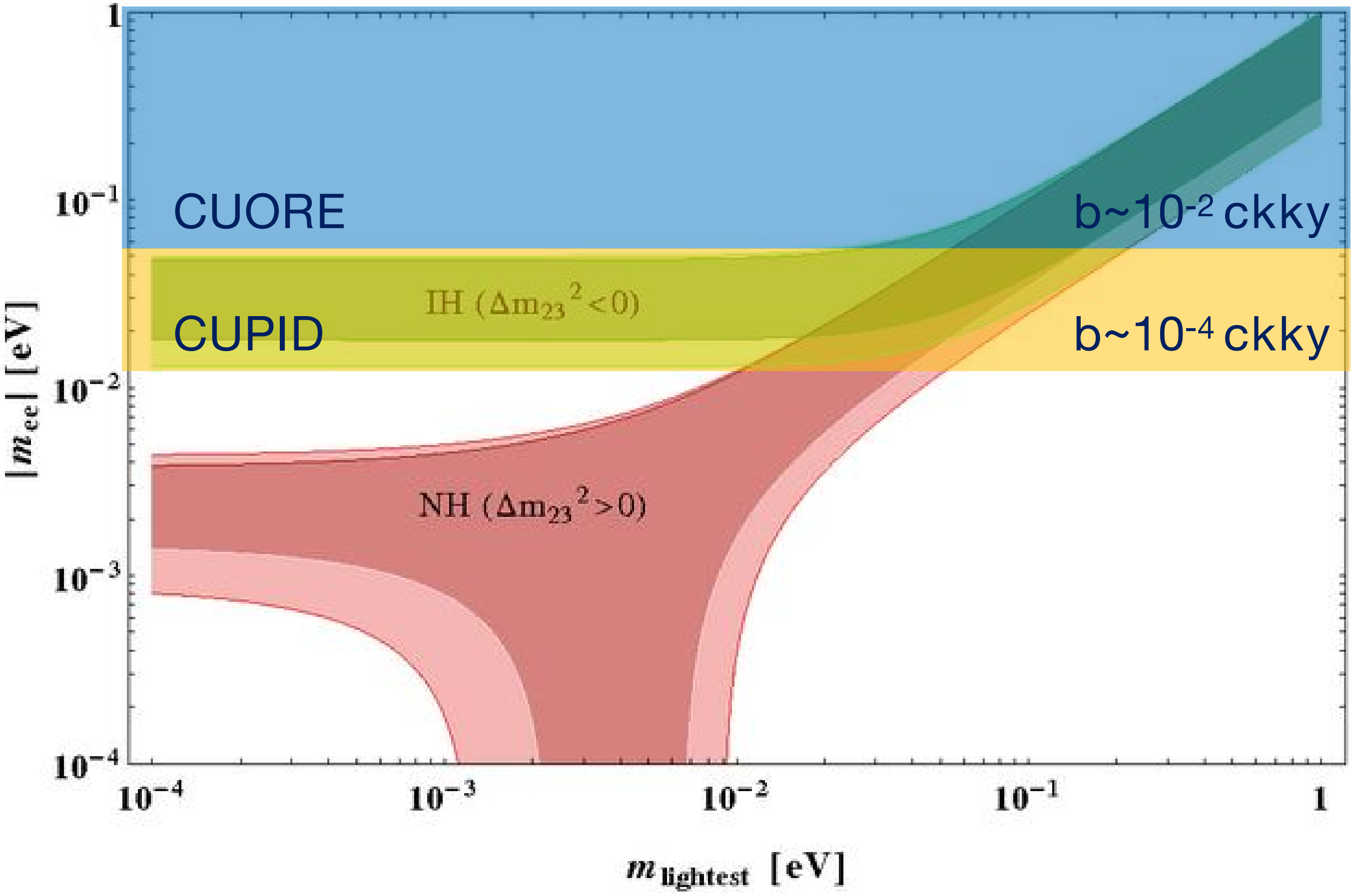
Data-taking is ongoing (started in 2017)

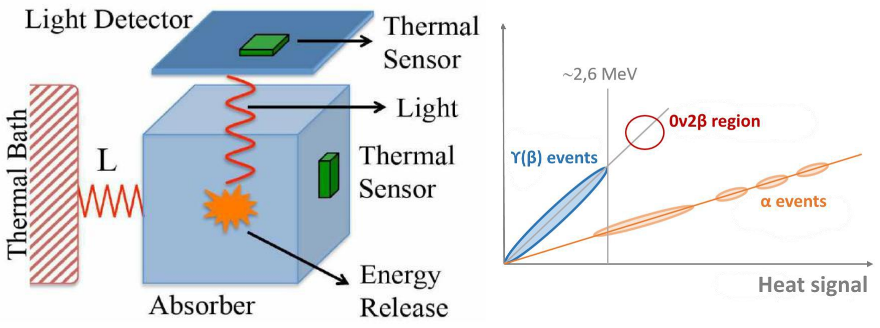


Lessons learned:

- Tonne-scale bolometric detector is feasable
- About 90% of background in ROI is from α particles
- About 10% is from environmental radioactivity

CUPID

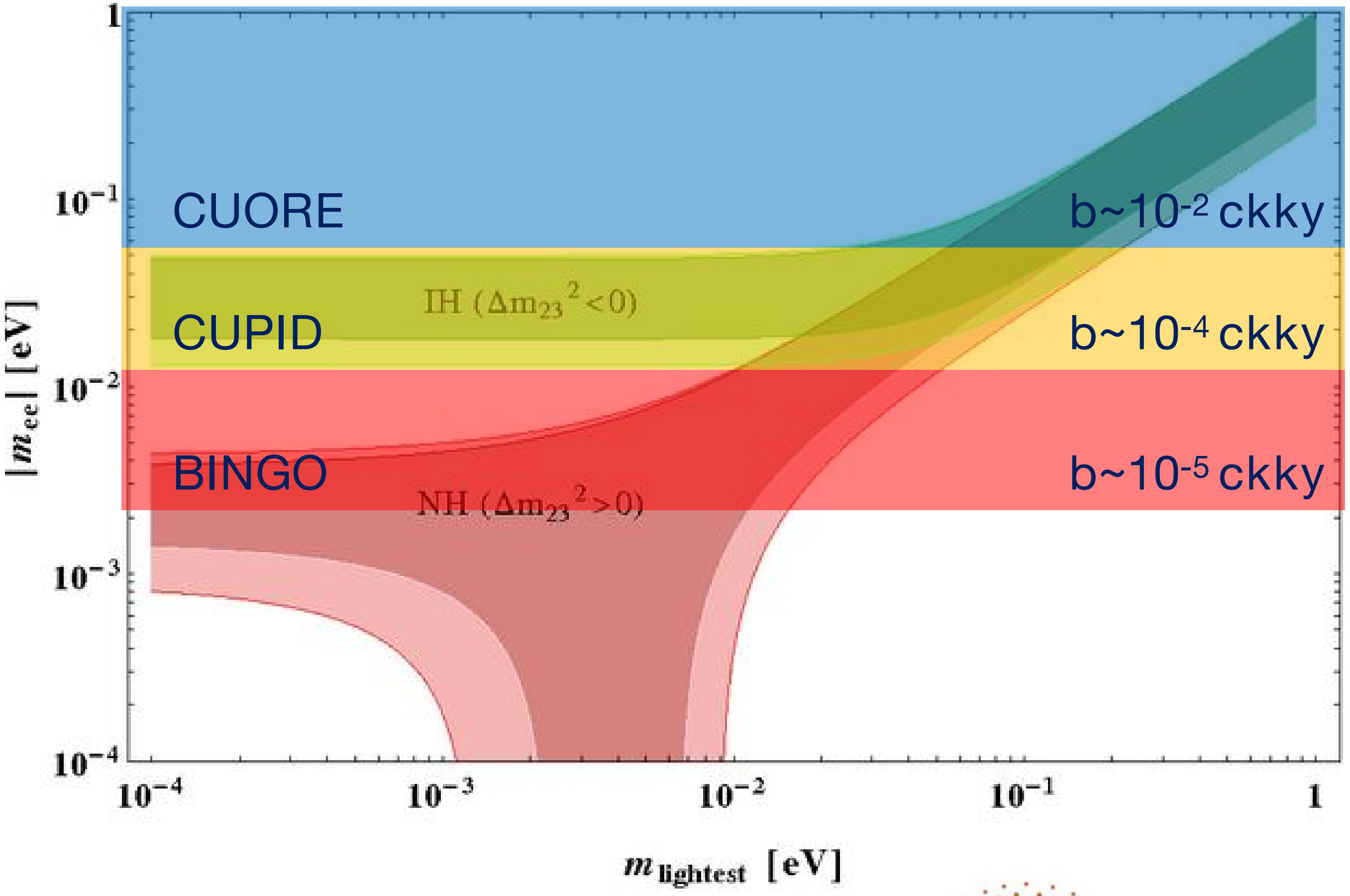




- Use of scintillating bolometer: double heat-light readout = $\boldsymbol{\alpha}$ rejection
- ^{130}Te $\rightarrow$ **^{100}Mo ($Q_{\beta\beta}$ = 3034 keV): automatic gamma backgound mitigation**
- **Most critical source of background is $2\nu\beta\beta$ pileups**
- **Background from surrounding materials**
- **Surface radioactivity of the crystals**

BINGO

BINGO - Bi-Isotope Next Generation Observatory



Project funded by ERC grant

Scintillating bolometer

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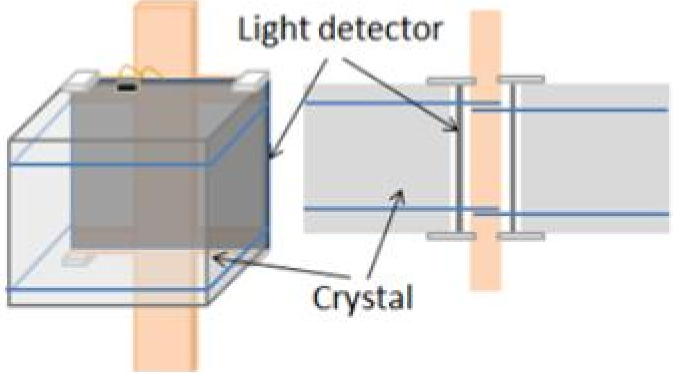
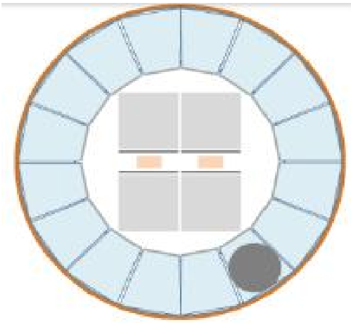
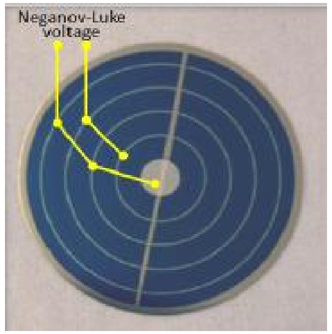
New technologies to reach NH region:

- Innovative detector assembly



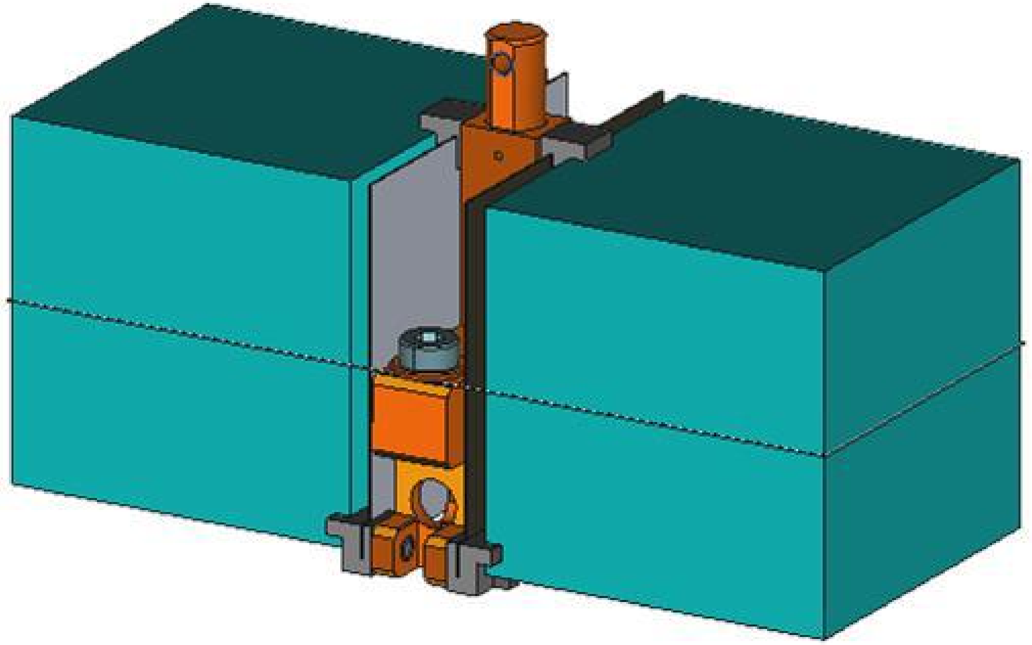
- Active veto





- Neganov-Luke light detectors

Detector assembly



Advantages:

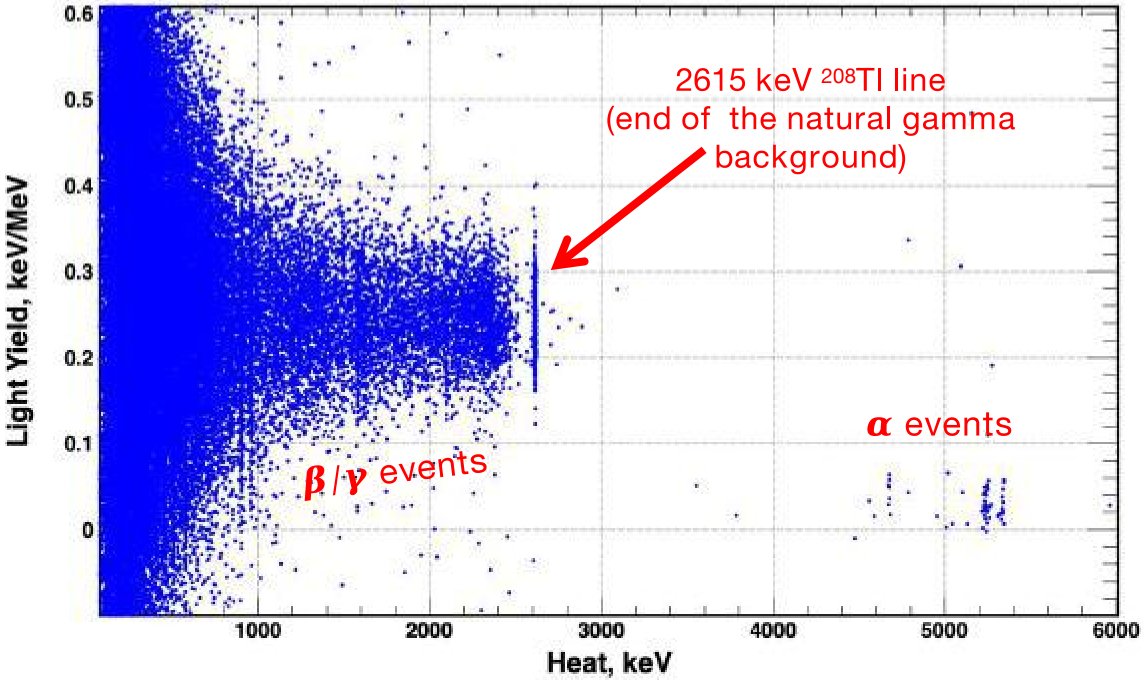
- Crystal sees nothing except LD surface (reduction of total surface radioactivity contribution
- ~1.5 orders of magnitude backgound reduction with respect to CUPID
- Very easy to assemble (2 people, 10-15 min)

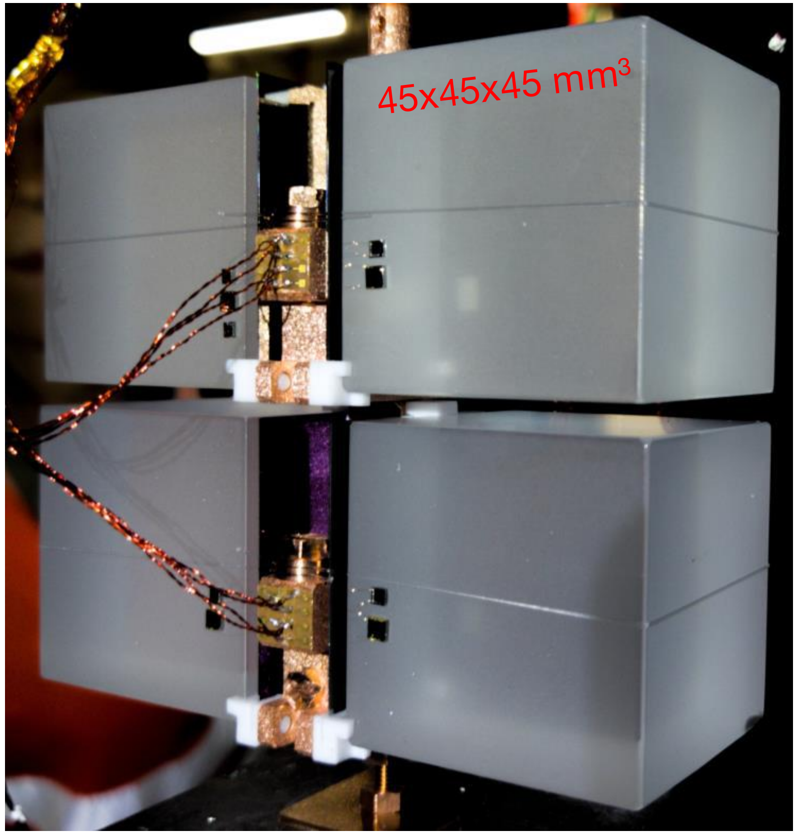
Assembly components:

- Nylon wire
- 2 LMO or TeO_2 crystals
- 2 germanium light detectors
- PTFE/PLA support
- Copper holder

Underground measurements results

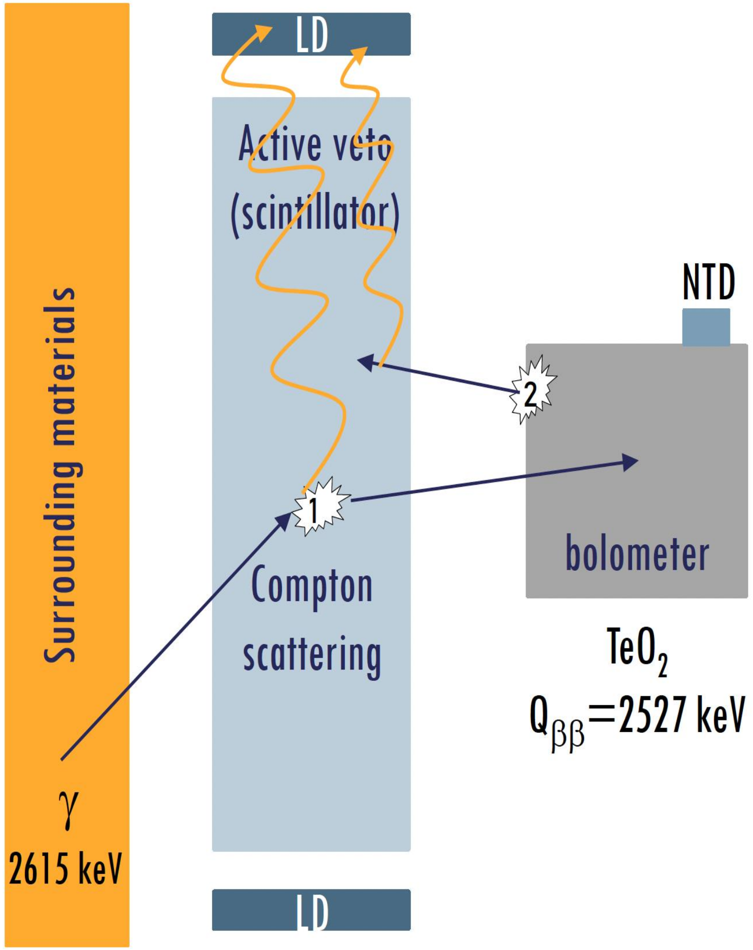
- The assemble was tested in the cryostat in Canfranc underground laboratory
- The measurements showed a good bolometric performance of the assembly
- Any additional noise induced by assembly was not observed





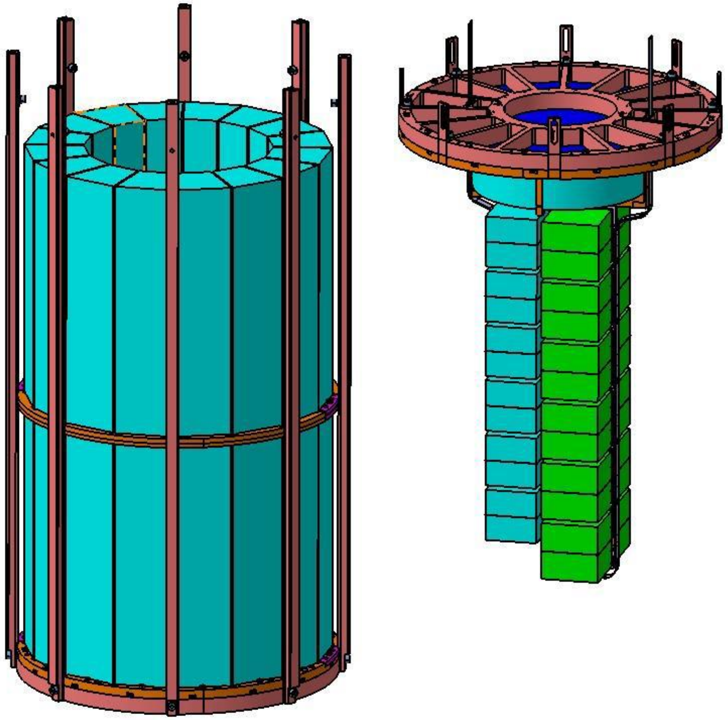
- The average baseline resolution FWHM is ~2.3 keV for heat channels and ~220 eV for light detectors
- Good discrimination between $\boldsymbol{\alpha}$ and $\boldsymbol{\beta/\gamma}$

Active veto

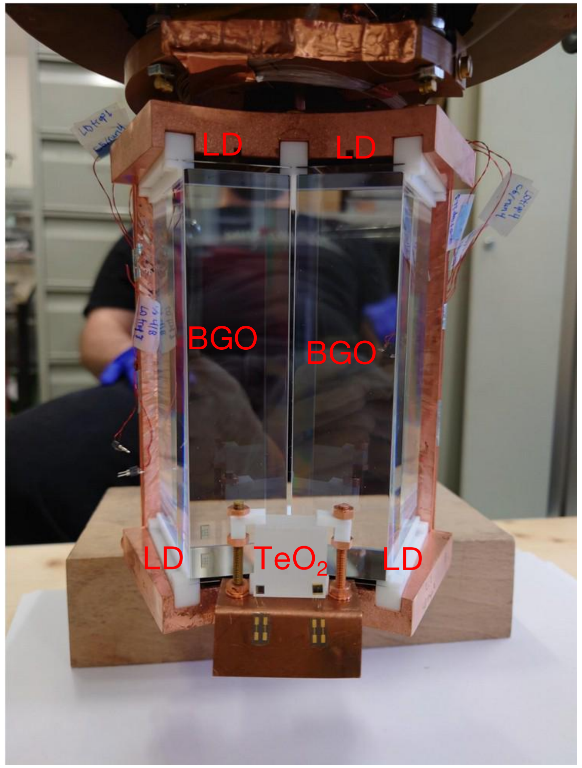


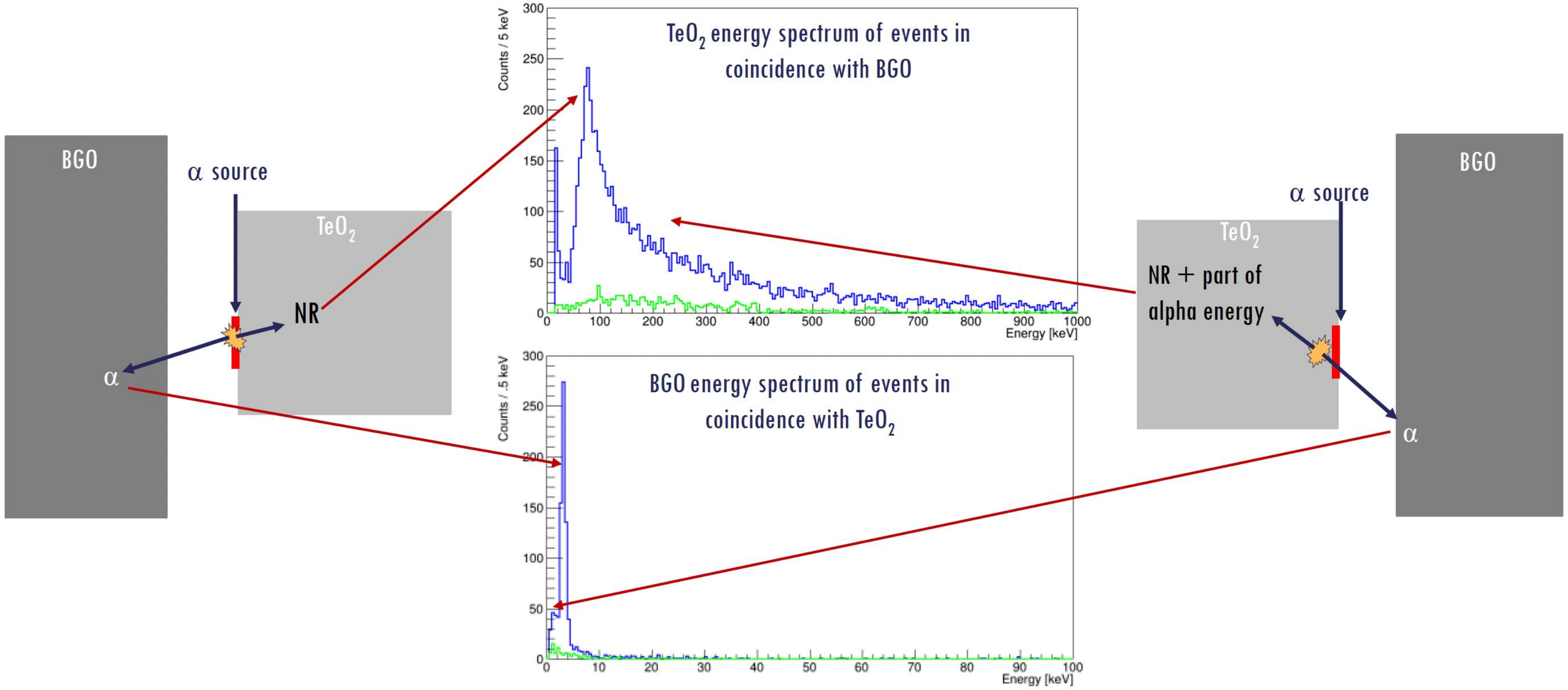
Reject through anti-coincidence with the veto:

- external gamma background, especially in case of TeO_2 ($\boldsymbol{Q_\beta}$ below 2.6 MeV)
- background from surface contamination of the crystals



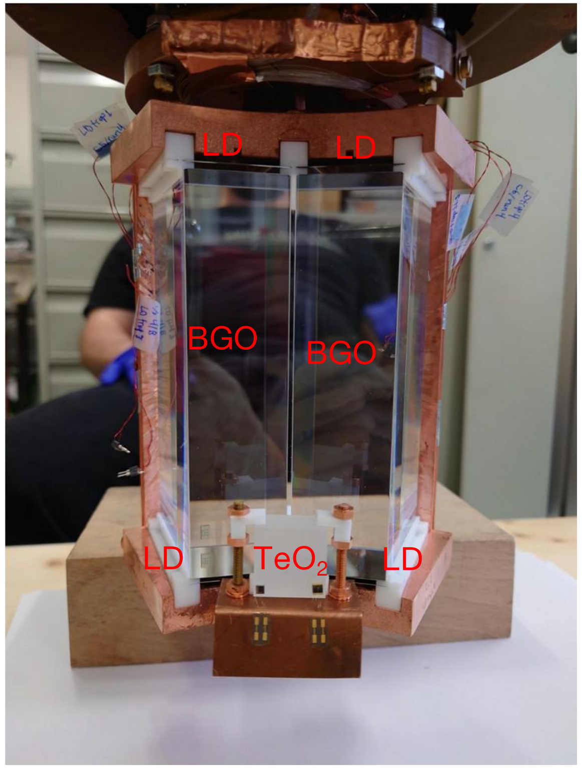
Veto test in aboveground cryostat

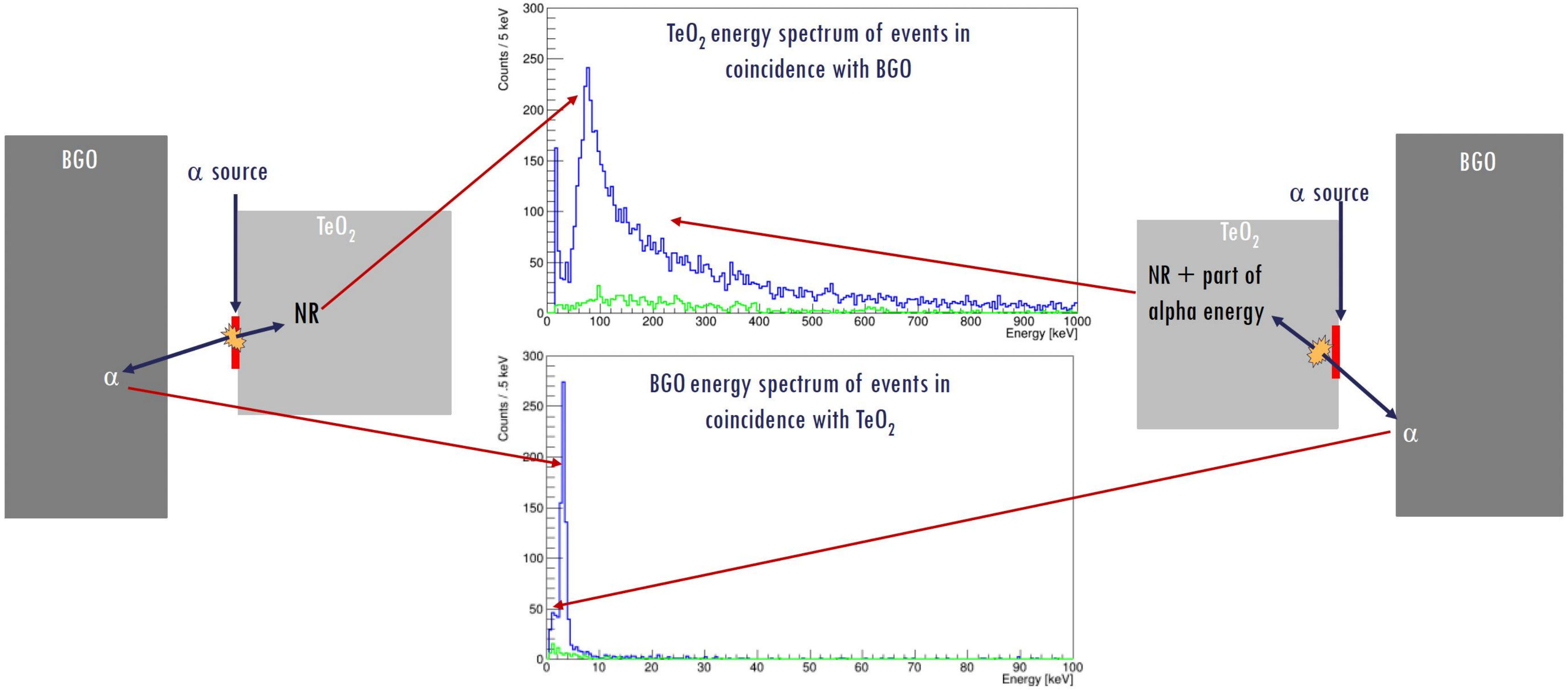




- 2 BGO crystals (1.6kg each)
- 2 LDs facing each BGO
- TeO_2 crystal facing both BGOs
- Uranium alpha source on the TeO_2 to immitate surface contamination

Veto test in aboveground cryostat





- 2 BGO crystals (1.6kg each)
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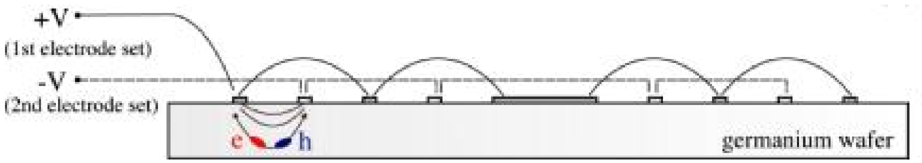
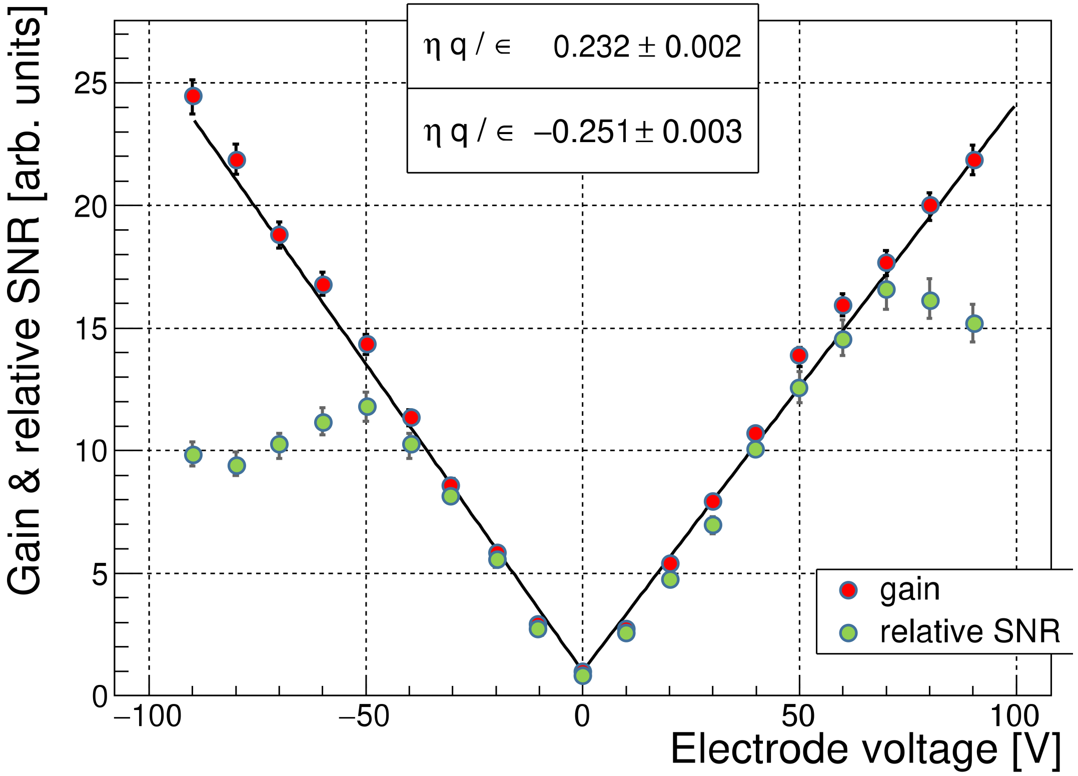
- The required energy threshold for the veto scintillator should be around 50 keV, which corresponds to around 0.3 keV in LD (scaling using the light yield). This level is not reacheable with standard LDs → **light detector upgrade is needed**

Neganov-Luke light detectors

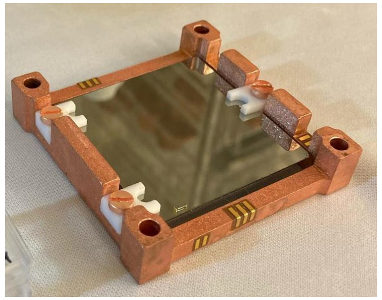


$$E_{tot} = E_0 \left(1 + \frac{q \cdot V_{el} \cdot \eta}{\epsilon}\right)$$

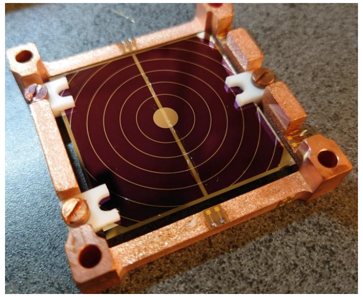
- The light is absorbed in a Ge wafer (< 1mm thick) equipped with a Ge-NTD thermal sensor
- Applied E field in the Ge : electron-hole pairs induced by photons will drift in the Ge and generate Joule heating (NL effect)
- The goal is to have the best S/N at the highest voltage difference value possible.
- In addition, with NL LD we can get a lower energy threshold thanks to higher signal to noise ratio



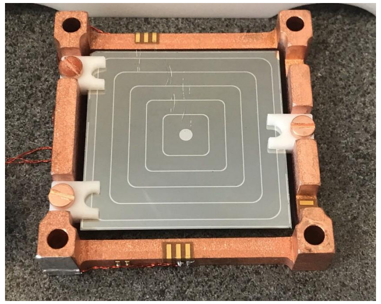
NL light detectors cryogenic test



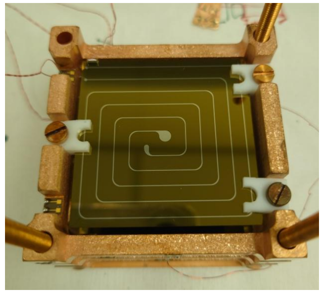
LD with electrodes on the edges



Concentric circle electrodes on a square LD

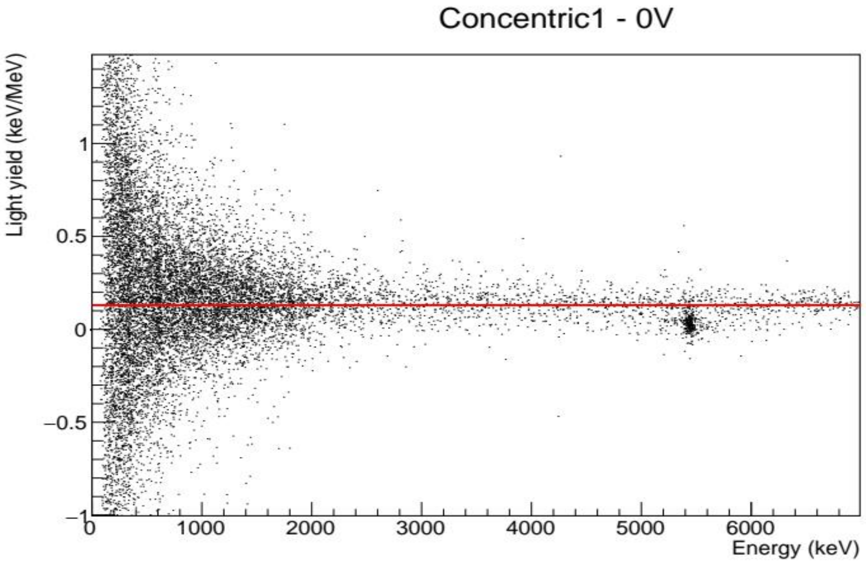


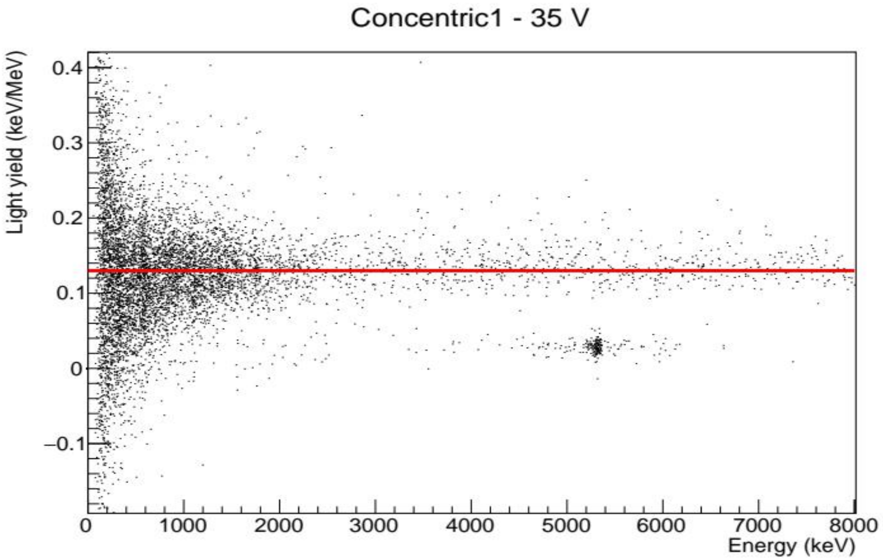
Concentric square electrodes on a square LD



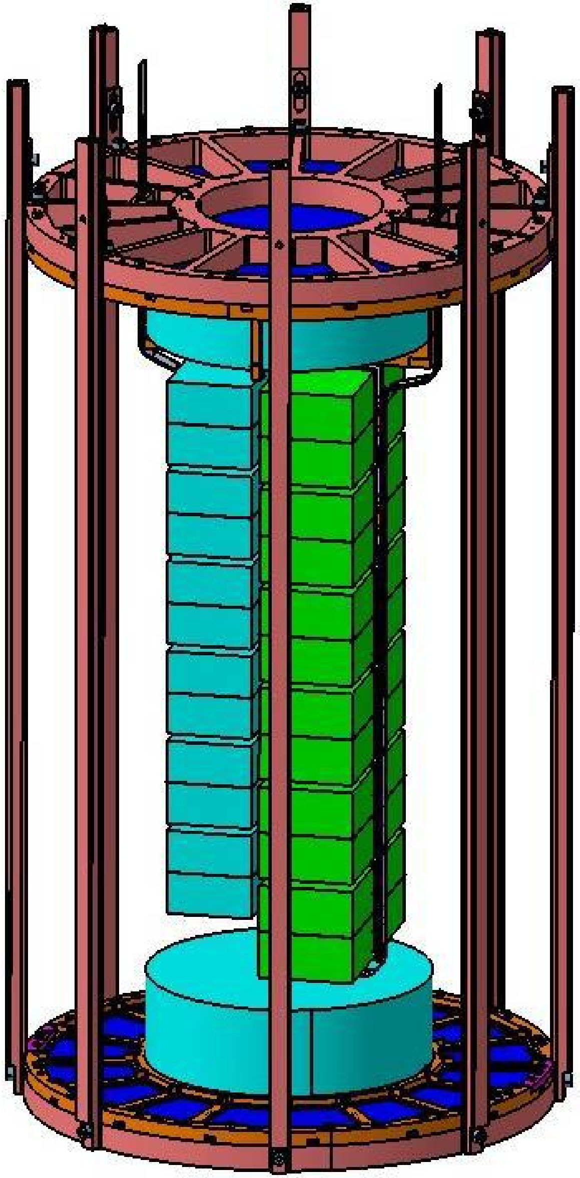
Meander (spiral) electrodes

LightHeat plots for LMO crystals and LD with concentric electrodes

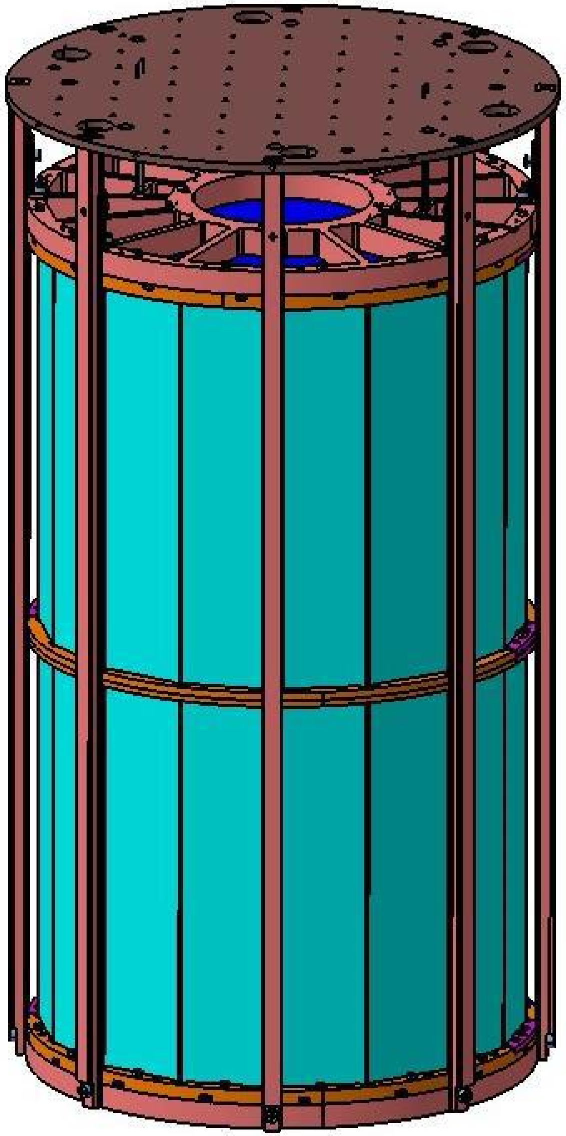




MINI-BINGO demonstrator



- The cryostat will be installed in Modane underground laboratory in France before summer 2023
- 12 cubic LMO scintillating crystals (45x45x45 mm), each coupled to a Neganov-Luke light detector (45x45x0.3 mm)
- 12 cubic TeO_2 crystals (50x50x50 mm), each coupled to a Neganov-Luke light detector (50x50x0.3 mm)
- 32 trapezoidal shape + 2 disc scintilators (BGO), each coupled to LD
- Start of data-taking in the end of 2024
- Such demonstrator scale is enough to reach background level below 10^{-3} c/keV*kg*yr and possible to go down to 10^{-4} c/keV*kg*yr



Conclusion and outlooks

- BINGO proposes innovative methods to start the exploration of the normal hierarchy region to reach a background index of b~10^{-5} ckky
- Innovative detector assembly have been tested in the underground cryostat and shown good performance
- We have done the aboveground test of active cryogenic veto and confirmed that using anticoincidences in the light detector we can cut a lot of events coming from the environment and crystal's surface
- We have some working designs of Neganov-Luke light detectors. Tests are ongoing
- The goal is to build the MINI-BINGO demonstrator to prove the detectors performance we planned to obtain
- Work in progress in simulations to see the possibility of implemetation of BINGO technologies to CUPID infrastructure