BINGO: investigation of the Majorana nature of neutrinos at a few meV level of the neutrino mass scale

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Neutrinoless double-beta decay

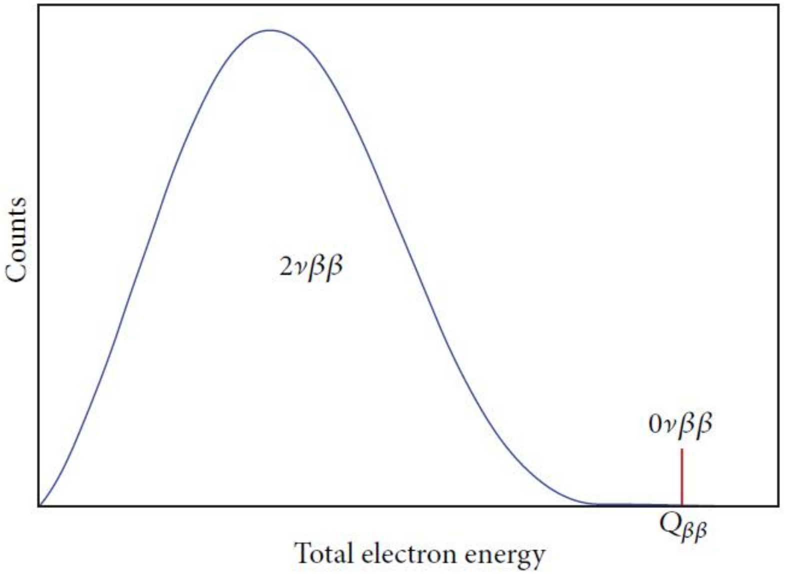
Neutrinoless double-beta decay:

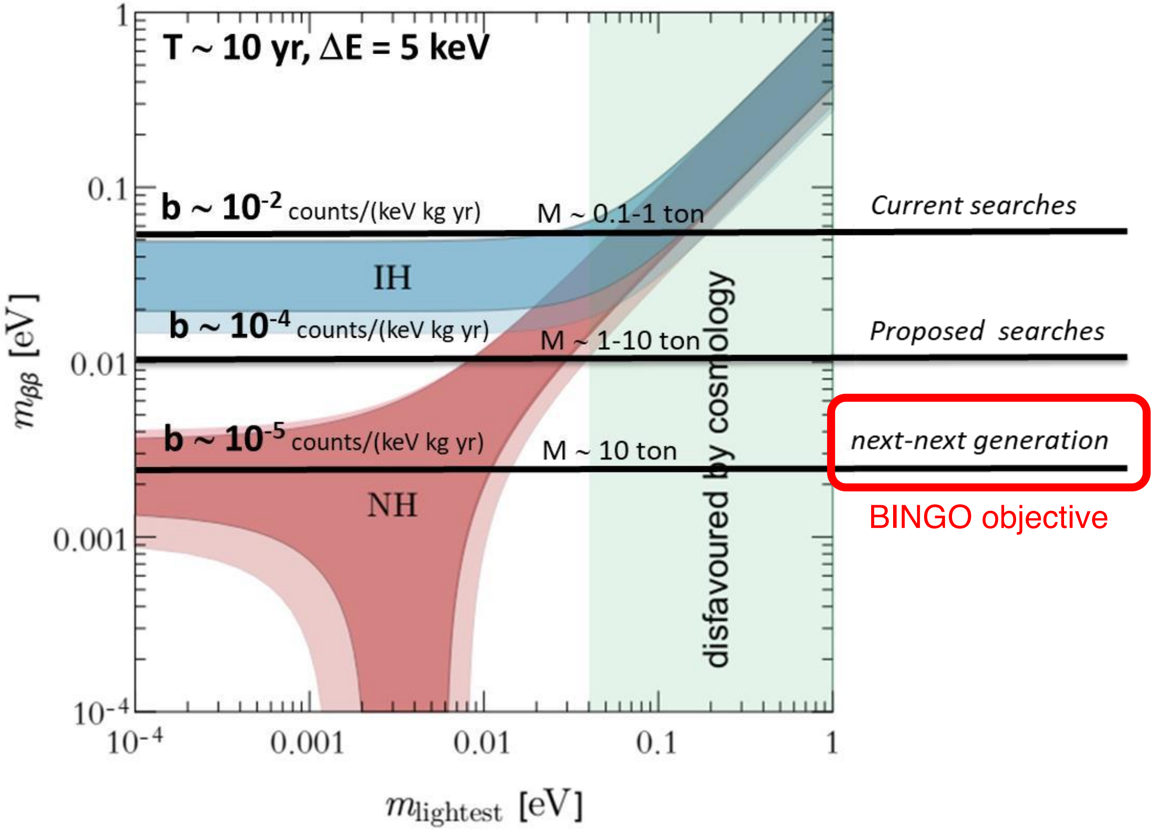
$$(A, Z) \rightarrow (A, Z+2) + 2e^-$$

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

If observed:

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

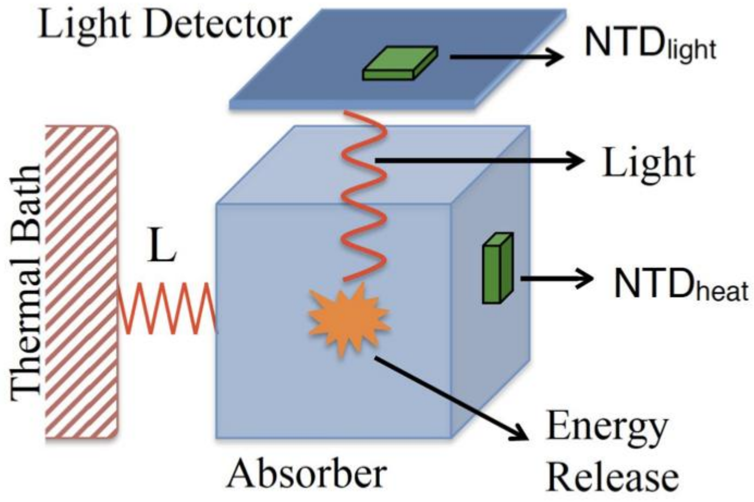




$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}(Q,Z)|M^{0\nu}|^2 \frac{m^2_{\beta\beta}}{m^2_e}$$

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

Scintillating bolometers



- Scintillating crystals allow to detect simultaneously heat and light produced by the same particle

- Using the difference in the light production between gamma and alpha particles we can reject more then 99% of alpha background in the ROI with high enogh energy resolution of the light detector

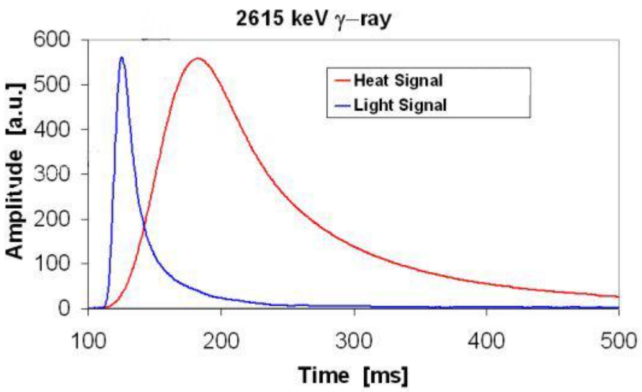
- The deposited energy is measured as a temperature change in a crystal

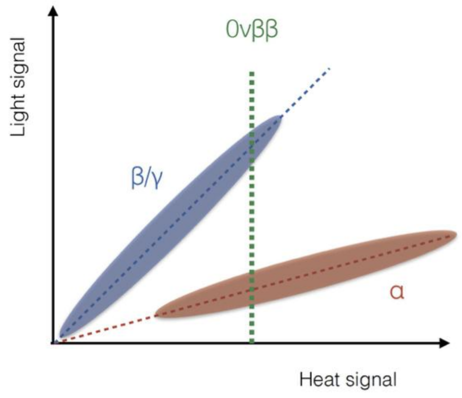
- Detectors are operated at temperature ~10-20 mK

- Source=detector approach → High detection efficiency (~90%)

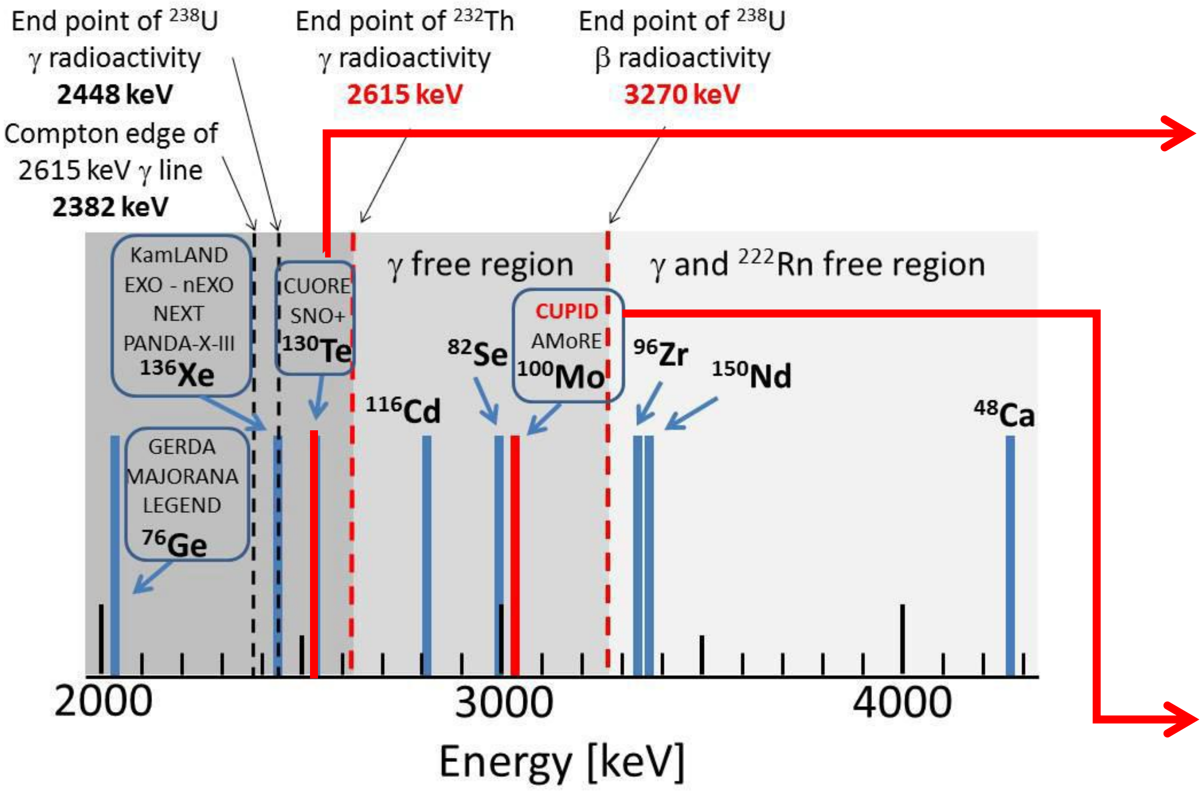
- Excellent energy resolution (~5 keV in the ROI)

- Large masses achievable using arrays of crystals





BINGO Isotope selection



^{130}Te

- Embeds 130 Te with a $Q_{\beta\beta}$ at 2527 keV
- This crystal was validated by the CUORE experiment
- Excellent energy resolution
- High internal radio purity
- Easiness in crystallization
- $Q_{\beta\beta}$ below the end line (at 2615 keV line of 208 Tl) of natural gamma radioactivity
- Very poor scintillator → no alpha background rejection

^{100}Mo

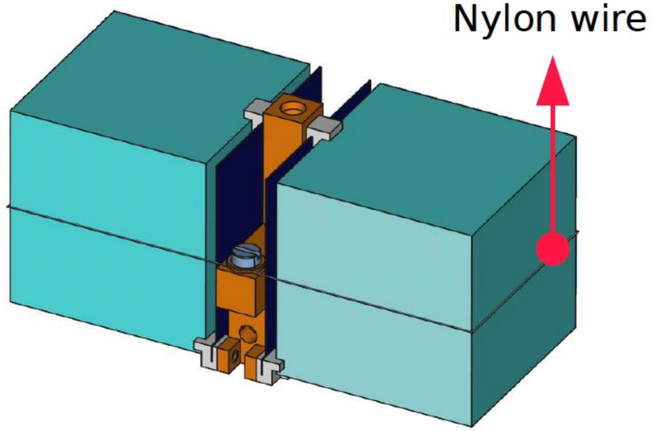
- Embeds 100 Mo with a $Q_{\beta\beta}$ at 3034 keV
- This crystal was validated by the CUPID Mo demonstrator
- Excellent energy resolution
- High internal radio purity
- Easiness in crystallization
- Fast 2ν2β decay → background in the region of interest (ROI) due to 2ν2β random coincidences

BINGO

An innovative detector assembly

- Minimize the amount of passive material
- Active shielding using the light detector position

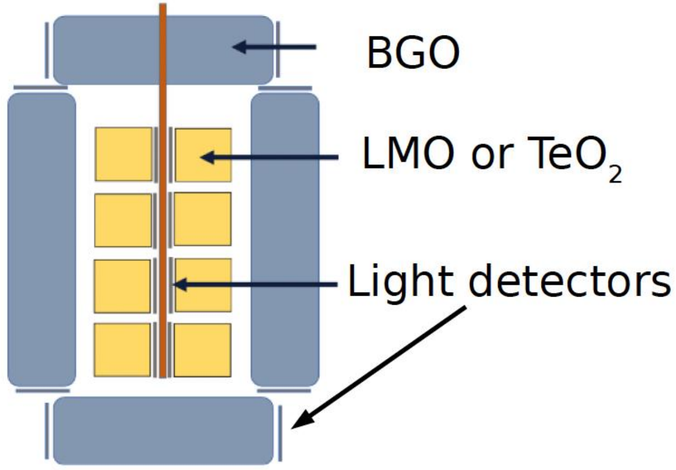
Geometrical reduction of the surface radioactivity + compact assembly for anticoincidence cuts



A cryogenic active veto

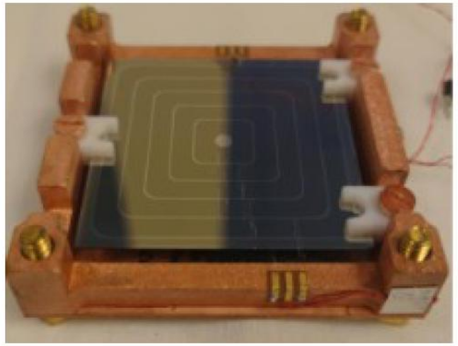
- Made of scintillators (BGO) with a 4π coverage operated at 20 mK Scintillation light read by its own light detectors

Suppress the external γ background and reject surface radioactivity from the crystals facing the active shield using anti-coincidence

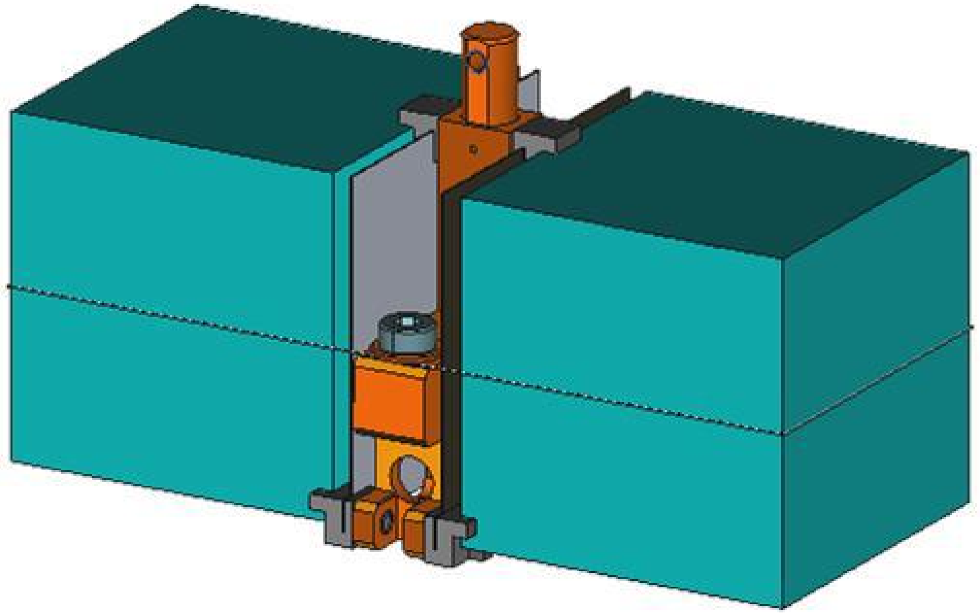


Neganov-Trofimov-Luke light detectors

- **Higher signal to noise ratio**
  → lower energy threshold= efficient suppression of external γ background with the veto
  → Reject the background induced by the $2\nu\beta\beta$ pileup events in LMO
- **Amplification of the tiny Cerenkov signal (TeO_2)**
  → α rejection

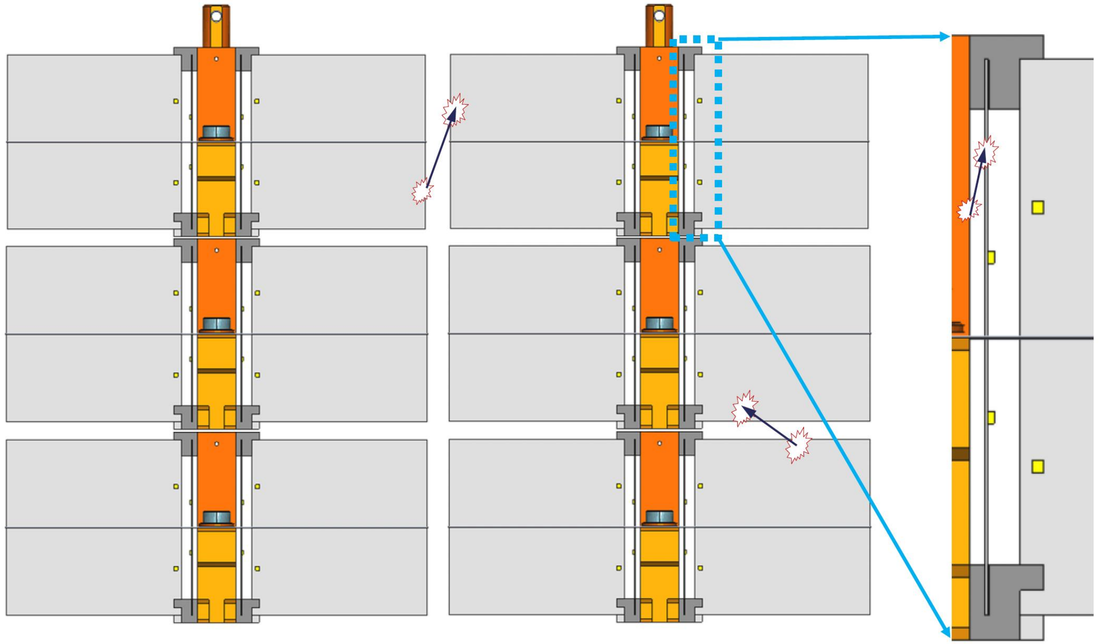


1. Nylon wire assembly



Assembly components:

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

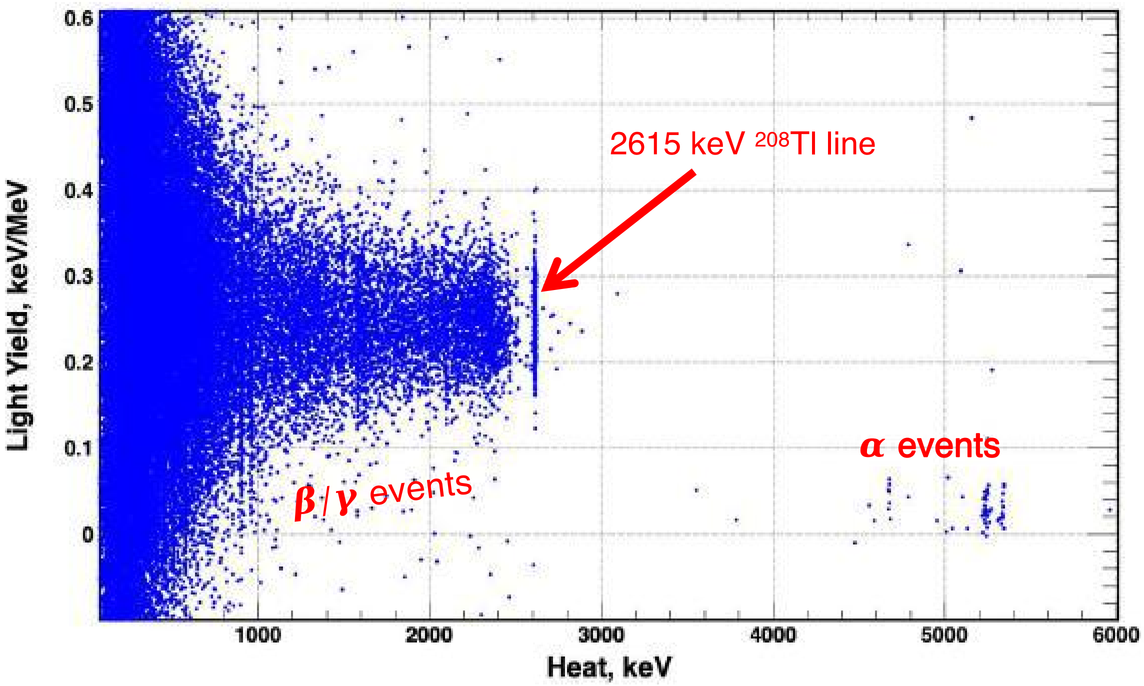


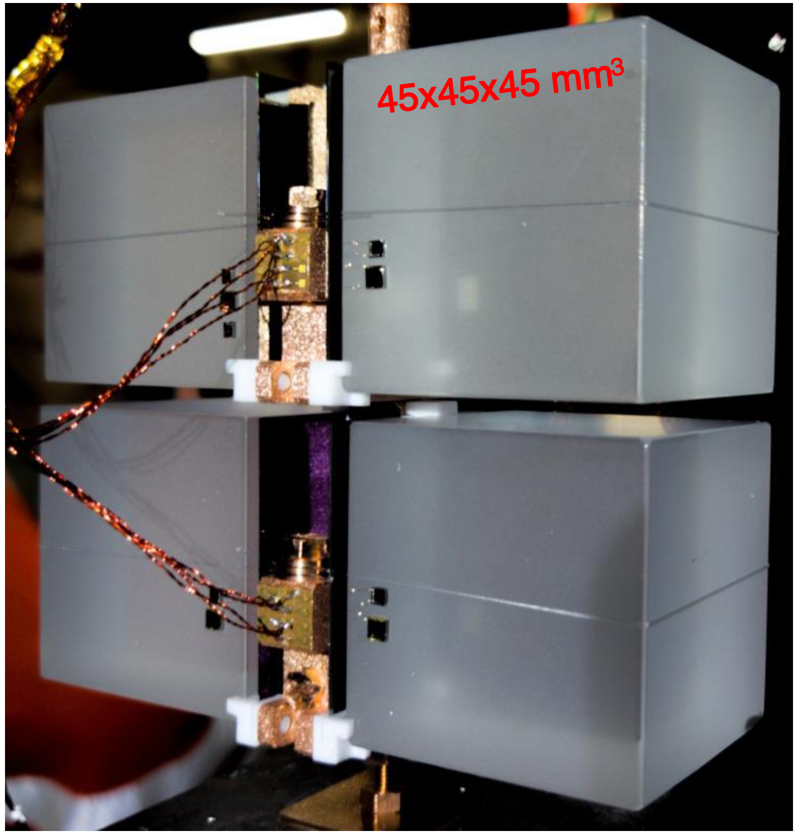
Advantages:

- Crystal sees nothing except LD surface (reduction of total surface radioactivity contribution
- ~1.5 orders of magnitude background reduction with respect to CUPID

1. Nylon wire assembly underground tests

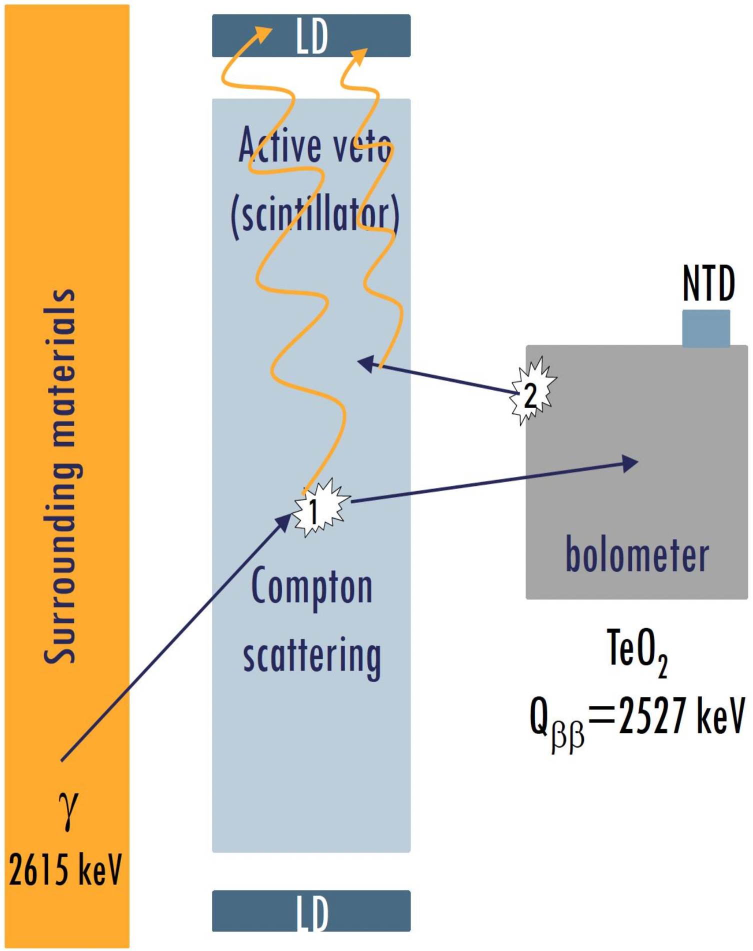
- The assembly was tested in the cryostat at Canfranc underground laboratory
- The measurements showed a good bolometric performance of the assembly
- Any additional noise induced by assembly was not observed





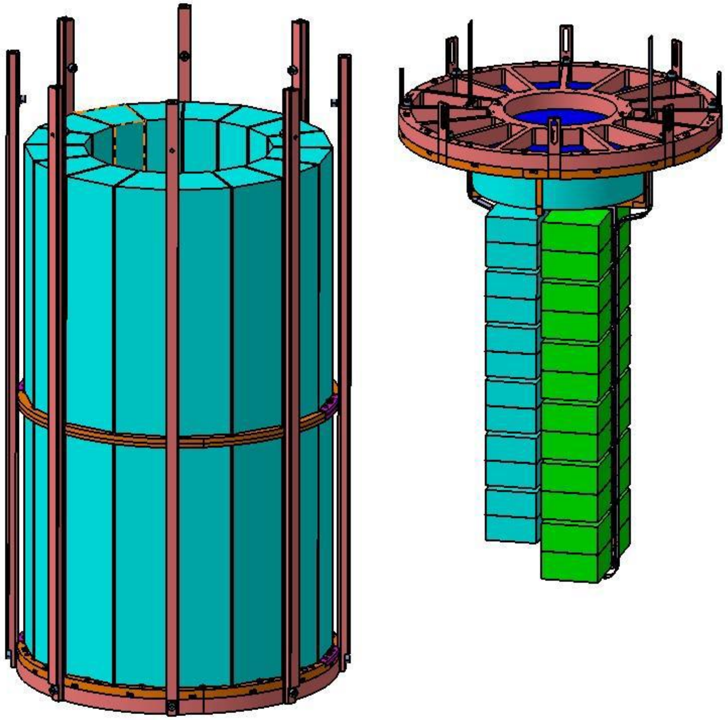
- The average baseline resolution FWHM is ~2.3 keV for heat channels and ~220 eV for light detectors
- Good discrimination between α and β/γ

2. Active cryogenic veto

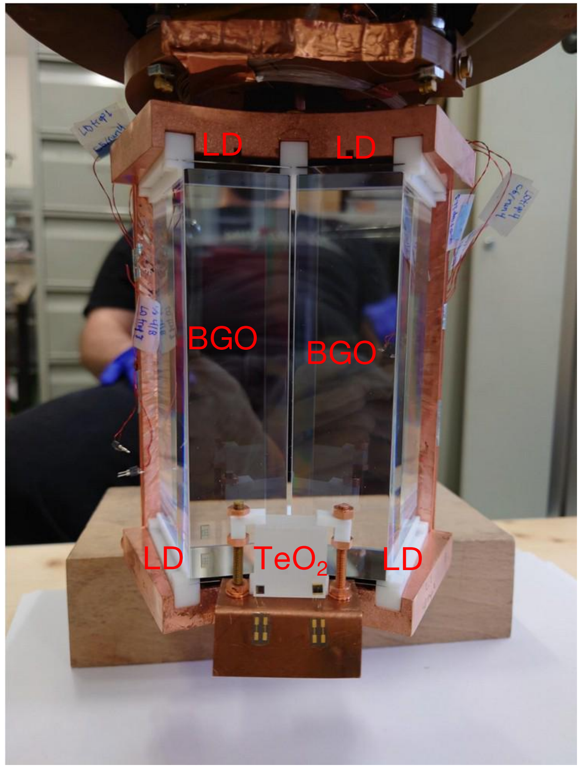


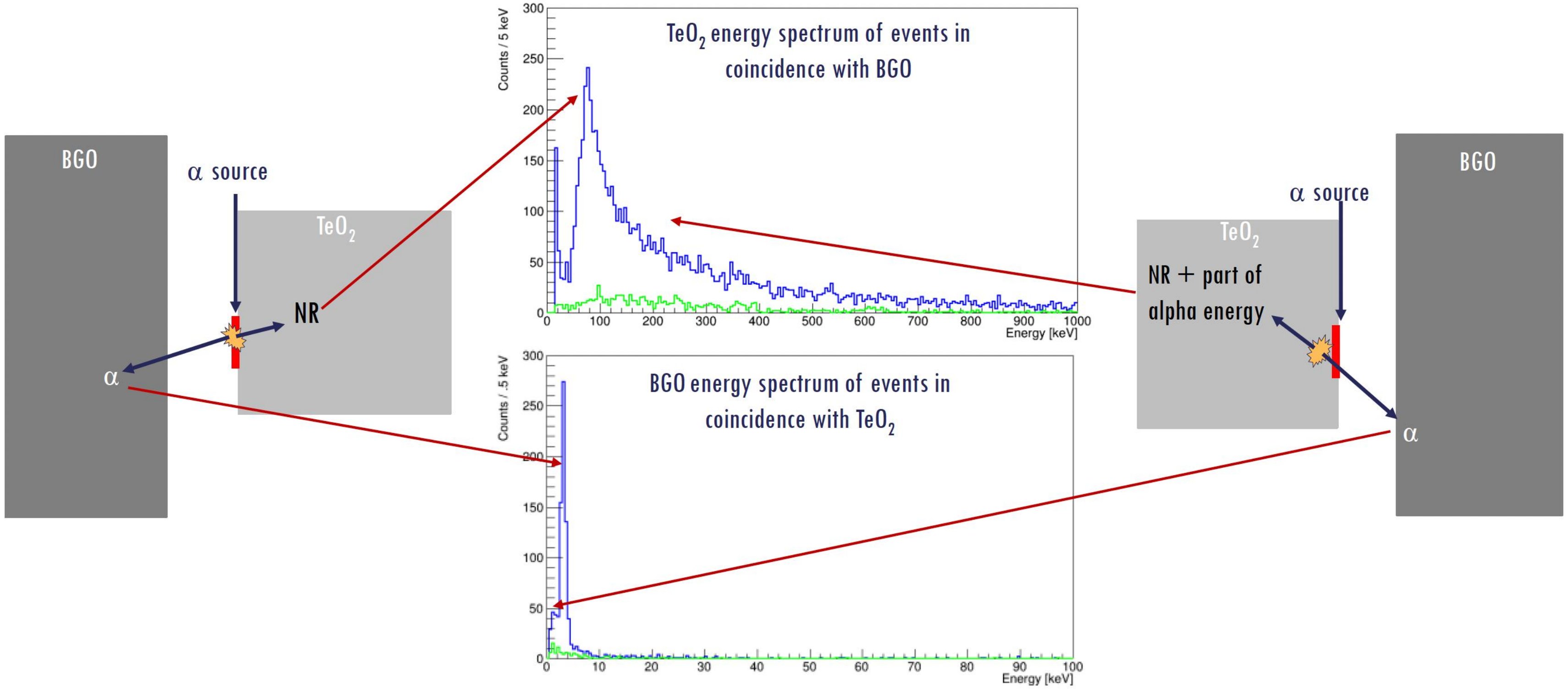
Reject through anti-coincidence with the veto:

- external gamma background, especially in case of TeO_2 (Q_β below 2.6 MeV)
- background from surface contamination of the crystals



2. Active cryogenic veto tests

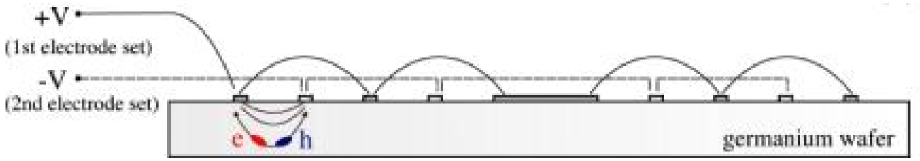




- 2 BGO crystals (1.6kg each)
- 2 LDs facing each BGO
- TeO_2 crystal facing both BGOs
- Uranium alpha source on the TeO_2 to imitate surface contamination

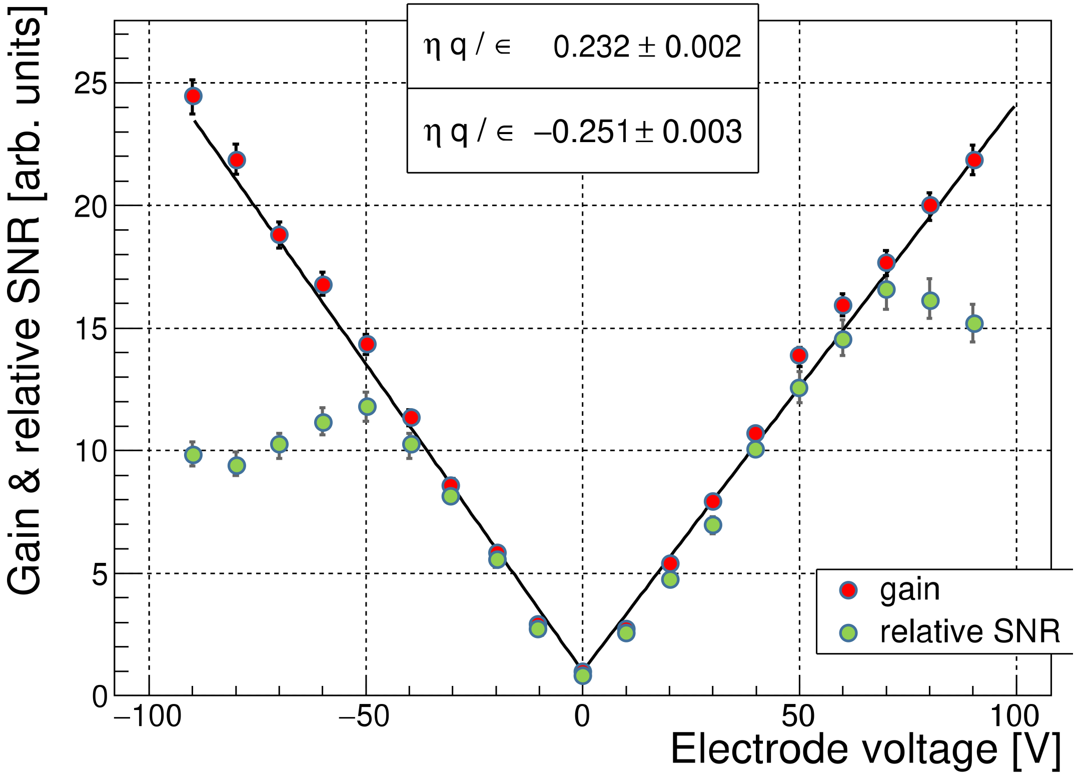
- The required energy threshold for the veto scintillator should be around 50 keV, which corresponds to around 0.3 keV in LD (scaling using the light yield). This level is not reacheable with standard LDs → light detector upgrade is needed

3. Neganov-Luke light detectors



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

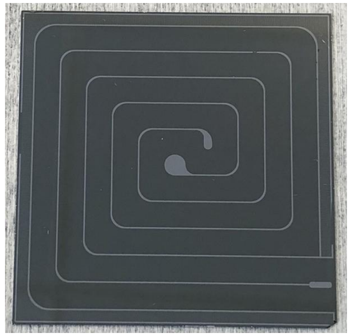
- The light is absorbed in a Ge wafer (< 1mm thick) equipped with a Ge-NTD thermal sensor
- Applied E field in the Ge : electron-hole pairs induced by photons will drift in the Ge and generate Joule heating (NL effect)
- The goal is to have the best S/N at the highest voltage difference value possible.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



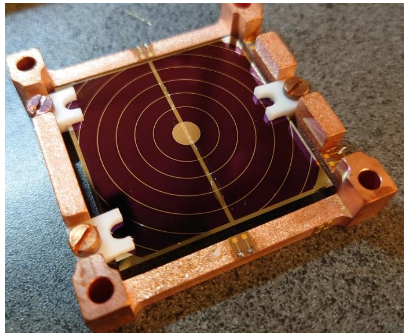
3. Neganov-Luke light detectors tests

- Several different electrodes geometries were tested

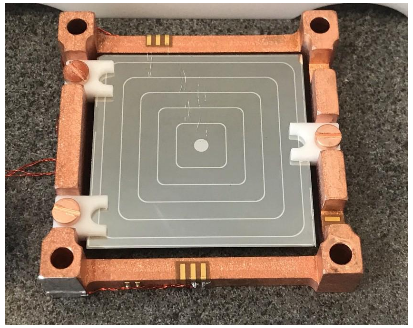
Edge



Meander



Concentric circular



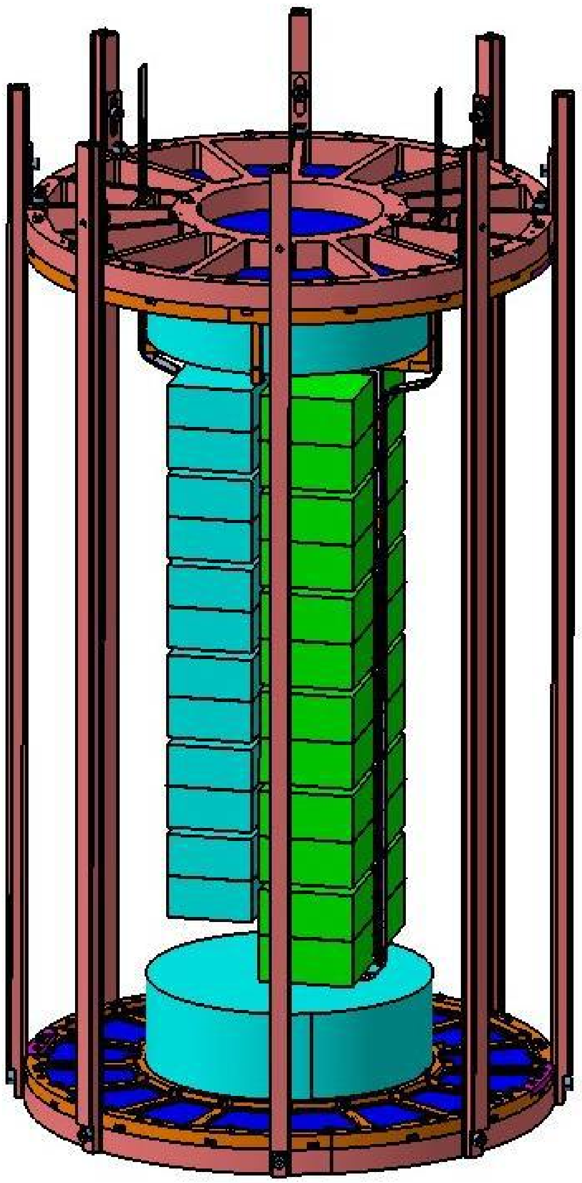
Concentric square

- Concentric circular electrodes geometry showed the best results among others in terms of possible applied voltage and signal amplification. 10 similar light detectors were measured underground in the tower of 6 LMO and 4 TeO crystals

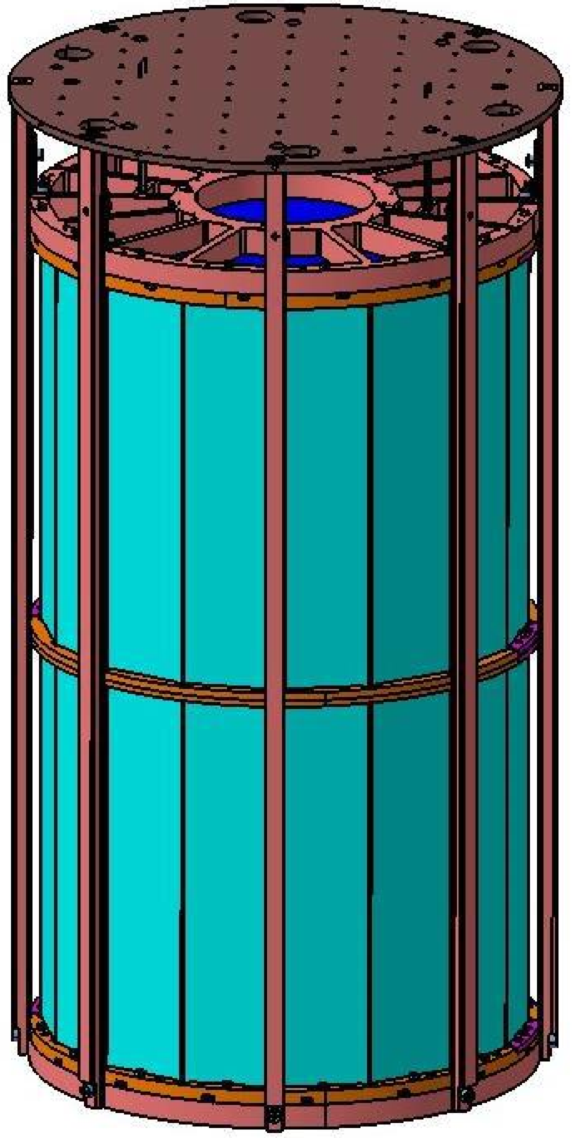
- 9/10 light detectors were able to hold up to 100V bias and demonstrated average signal amplification around 10.8 and baseline resolution 11.6 eV

- Further tests will be aimed at understanding the problems we had with other geometries and at the improvement of Neganov-Luke efficiency moving from circular to square electrodes geometry

Mini-BINGO demonstrator



- The cryostat will be installed in Modane underground laboratory in France
- 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 beginning of 2025
- 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 perspectives

- 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 efficiently reject events coming from the environment and crystal's surface
- We have several 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 evaluate the possibility of implemetation of BINGO technologies to CUPID infrastructure

BINGO

http://www.bingo-neutrino.eu