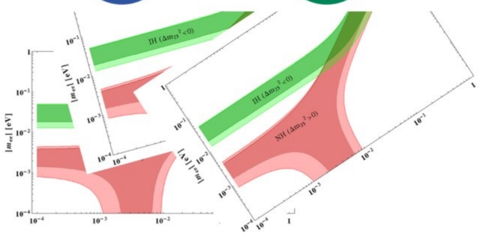


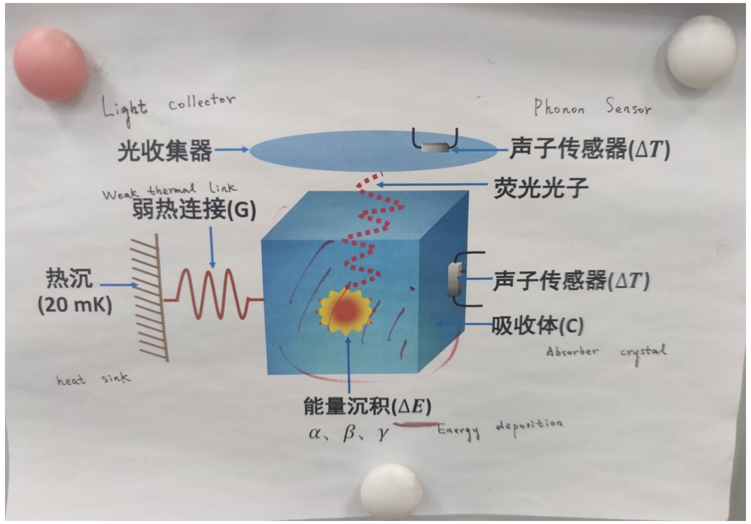
Toward a background-free ton-scale $0\nu2\beta$ bolometric experiment: Status and Prospects of BINGO

Claudia Nones

On behalf of the BINGO collaboration

TAUP 2025

TAUP XICHANG



Setting the stage

BINGO will set the grounds for a large-scale bolometric experiment searching for **neutrinoless double beta decay (0ν2β)** using **innovative technologies** – validated in the **MINI-BINGO demonstrator** – capable of measuring the **neutrino Majorana mass** in the **few-meV** region.

Neutrinos: who are they?

- the most abundant fermions in the Universe
- messengers from cosmology and astrophysics
- initially assumed to be massless in the Standard Model
- now we know they are massive but with the smallest masses of all known particles (< 1eV)
- door to new physics beyond the Standard Model

? important **unanswered** key question ?

Dirac or **Majorana** particle

$\nu = \nu^C$

If **Majorana** : the only fermion ≡ its antiparticle

- Natural explanation of the **smallness of neutrino mass**
- Give a clue for the **dominance of matter over antimatter** in the Universe

0ν2β is one of the most important topics in deep underground searches

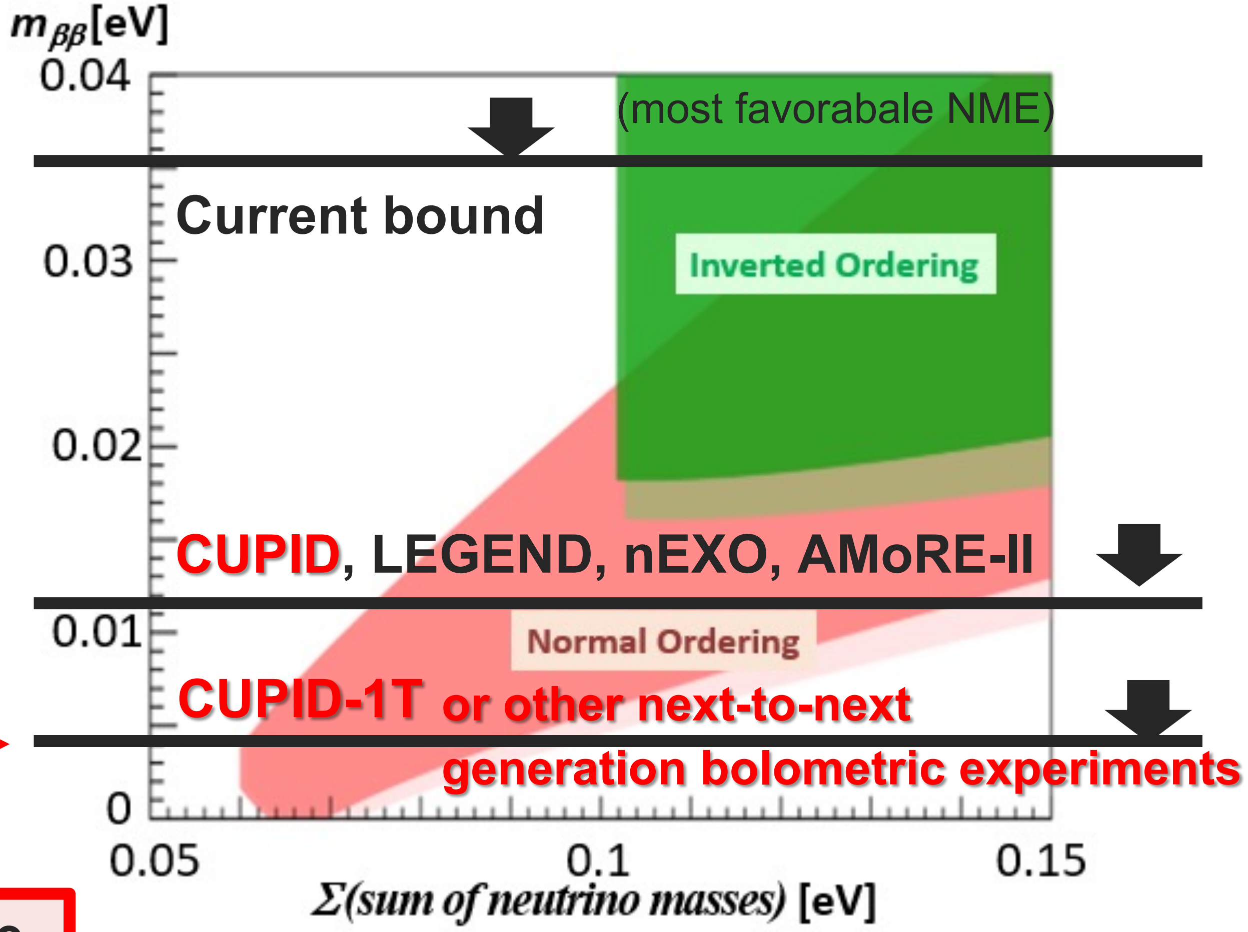
Physics and background targets

How to move forward?
Background is the key concept

Assuming detector mass scaling, physics goals are related **to background index** reduction

B.I. ~ 10^{-4} counts/(keV kg y) →

B.I. ≤ 10^{-5} counts/(keV kg y) →

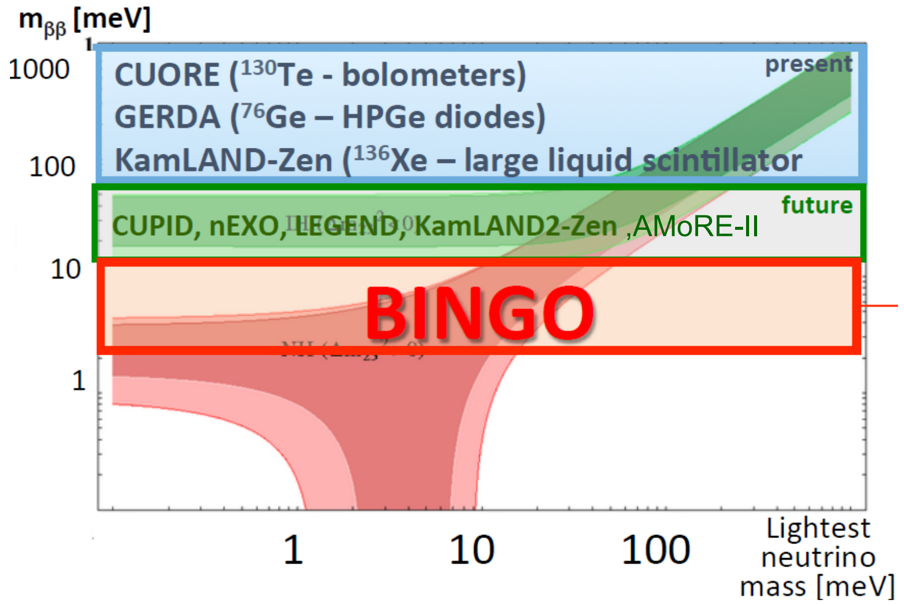


BINGO technologies will play a major role

BINGO in a nutshell

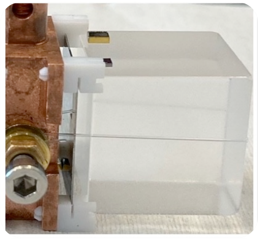
Bi-Isotope 0ν2β Next Generation Observatory

→ **Investigation of the Majorana nature of neutrinos at a few meV level of the neutrino mass scale**



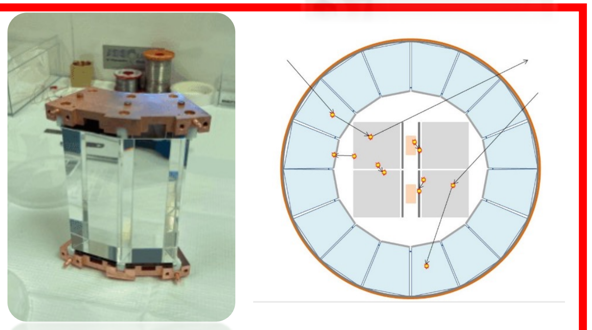
- **Main tools:**
  1. Scintillating bolometers (TeO_2 / Li_2MoO_4)
  2. Very low radioactivity for all the selected materials
  3. Small amount of copper in the holder
  4. Cryogenic active veto
  5. Neganov-Luke based light detectors

1)

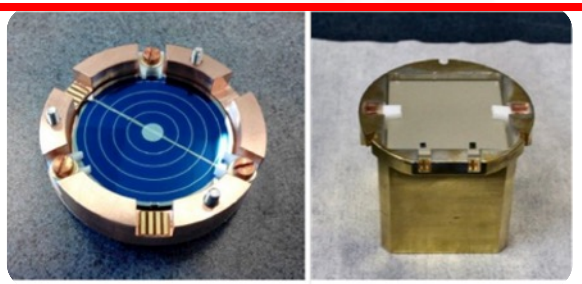


2-3)

4)

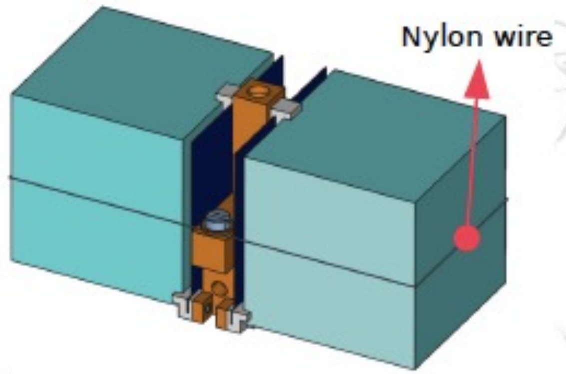


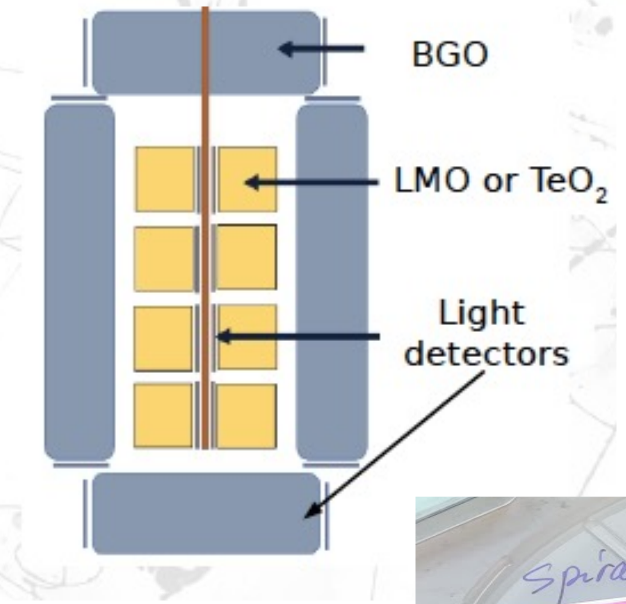
5)



The 3 main BINGO pillars

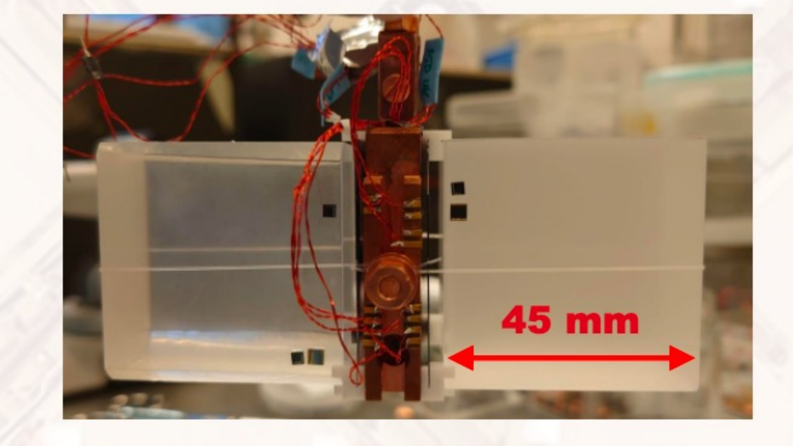
- **Innovative detectors assembly:**
  Minimisation of the amount of passive materials surrounding detectors to reduce α and β background from surface radioactivity
- **Active cryogenic veto:**
  Suppression of background from high energy γ's surrounding detectors volume by a scintillator (BGO) operating at the base temperature
- **Neganov-Luke light detectors:**
  Alpha background rejection (especially for TeO_2), pile-up rejection for LMO, lowering the cryogenic veto threshold

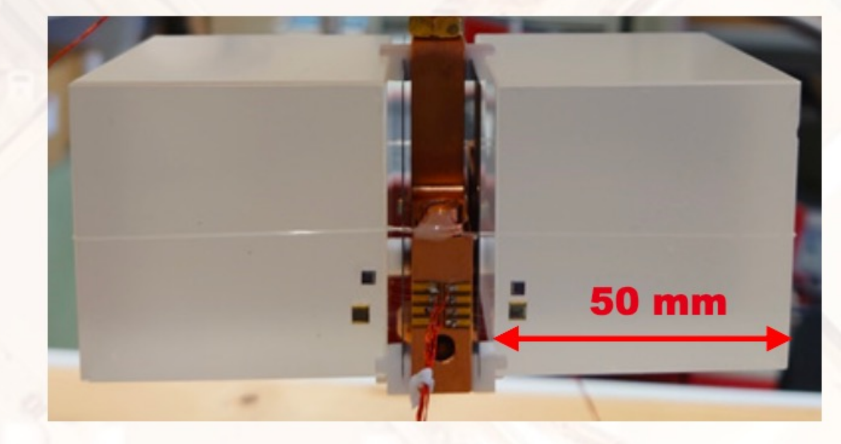




The nylon wire assembly

https://doi.org/10.1016/j.nima.2024.169936



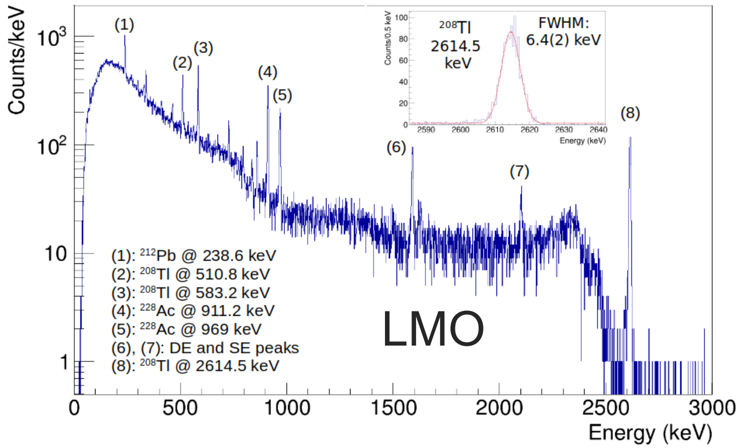


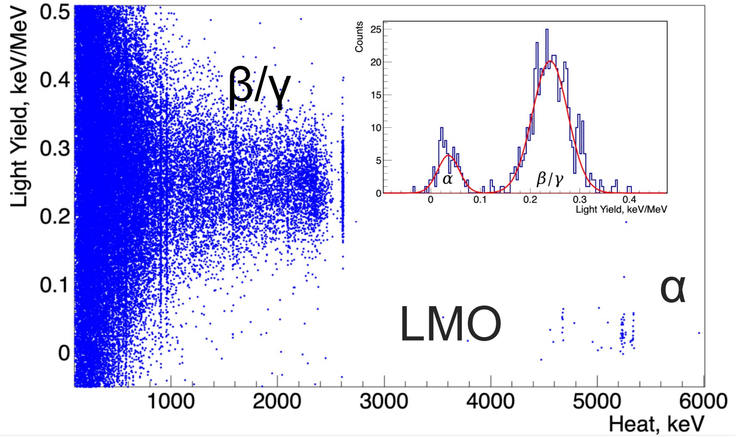
Assembly upgrade:

- Less passive materials: reduction of the total surface radioactivity contribution
- Compact assembly: background reduction through anticoincidence cuts

Two modules of Li_2MoO_4 have been tested and validated at LSC:

- Achieved good bolometric performance, with an average resolution of 6.3 keV FWHM at 2.6 MeV (comparable to CUPID-Mo)
- Sufficient discrimination between α and β/γ to achieve 99.9% of α rejection





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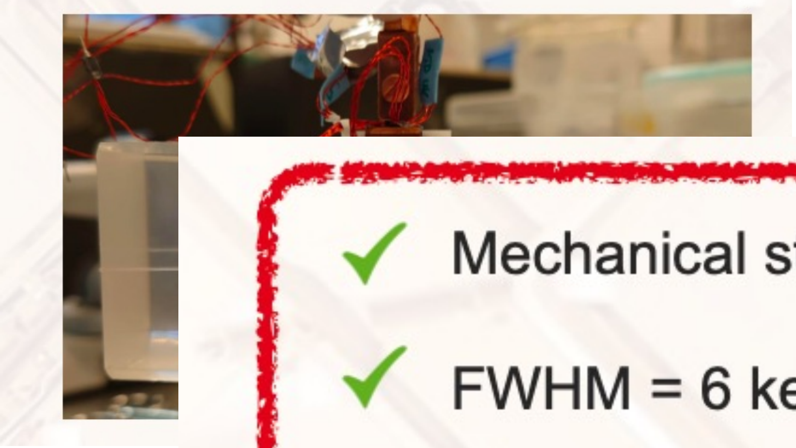


Assembly upgrade:
- Less passive materials: reduction of the total surface radioactivity

cuts

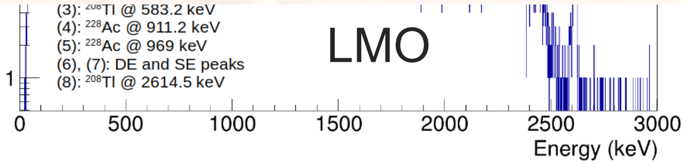
:

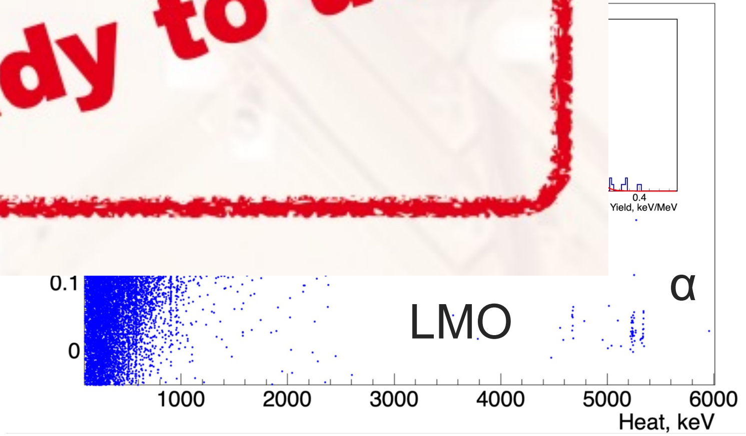
of 6.3

ejection

- ✔ Mechanical structure works at 10 mK for both LMO and TeO_2 crystals
- ✔ FWHM = 6 keV at the 2615 keV peak for LMO
- ✔ Baseline energy resolution comparable to reference light detectors
- ✔ Light yield comparable to reference detectors
- ✔ >95% particle identification efficiency

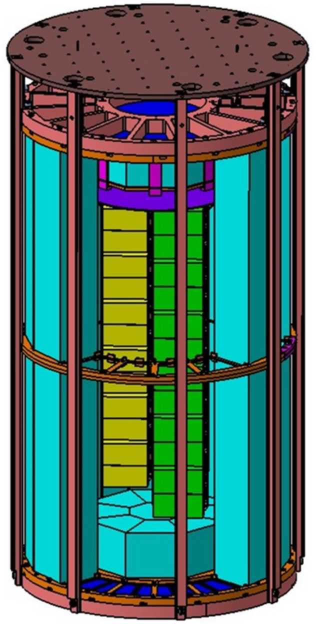
Ready to use!

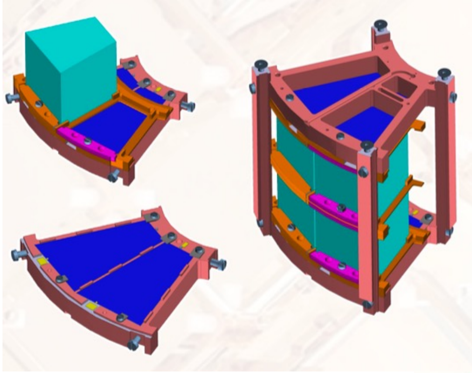


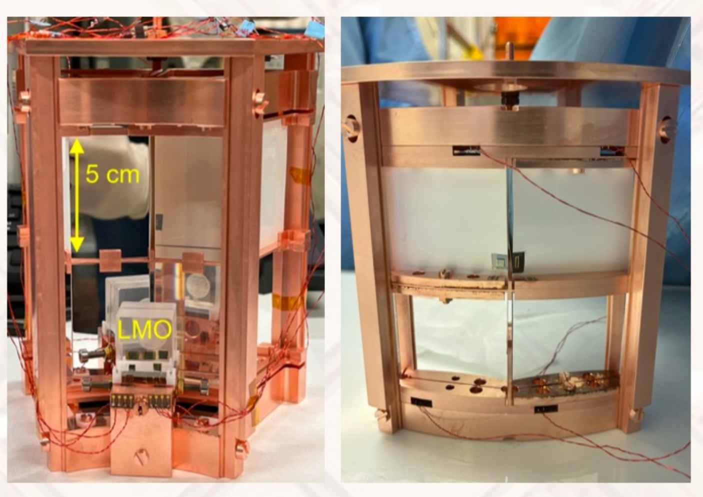


The cryogenic active veto

Main goals
- Suppress external gamma background – relevant for TeO_2 crystals
- Reject surface contamination events (α/β) for peripherical crystals facing the veto







- Uses radiopure **BGO crystals** as active scintillating veto elements
- Coupled to **cryogenic light detectors** for detection of the scintillation
- Crystals form an optically segmented **shield around the main detector**
- The **reflective material** is required from the outer side of the crystal to improve the light collection and lower energy threshold
- Inner side **aluminum coating** will shield the main detector volume from the scintillation light from the veto not preventing the surface contamination rejection

✓ Mechanical structure successfully validated at cryogenic temperatures

✓ Demonstrated capability to tag surface alpha particles

✓ Aluminium coating does not degrade veto efficiency

⚠ External gamma rejection potential to be confirmed (requires improved light detectors to achieve a lower BGO detection threshold)

Next step: integration of trapezoidal light detectors with enhanced sensitivity

NL light detectors

H. Khalife's poster (#77)

- Cerenkov light detection for TeO_2 crystals
- Higher SNR to lower the cryogenic veto threshold
- Pile-up rejection for LMO

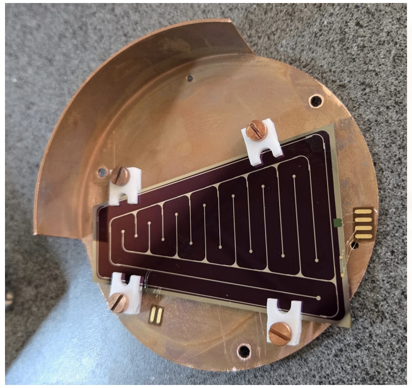
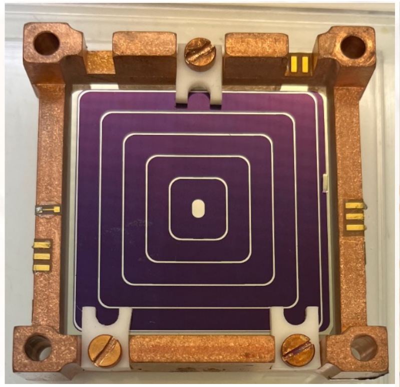
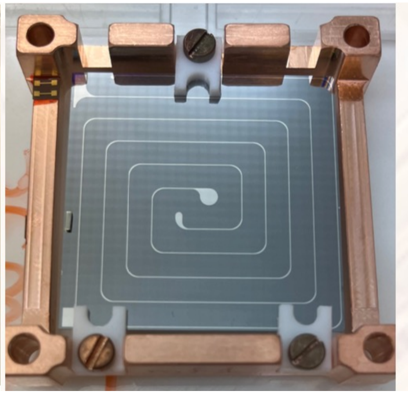
A huge boost on this activity in close synergy with CUPID

Currently obtained performances:
- Avg baseline resolution at 0V < 100 eV RMS
- NTL bias in range 50-100 V, avg baseline ~12 eV RMS
- 0.55 ms rise time
- Surface coverage: 56%

Square LD optimization ongoing with the test of new electrodes geometry increasing the surface coverage

NTL LDs for veto: new masks design received and validated. First production has been done, cryogenic tests after summer break!

BINGO needs:
- 12 (45*45 mm) and 12 (50*50 mm) NTL LDs are required for Li_2MoO_4 and TeO_2 towers
- 32 NTL LDs are required for the veto scintillation light readout and its amplification

MINI-BINGO: a technology demonstrator at LSM

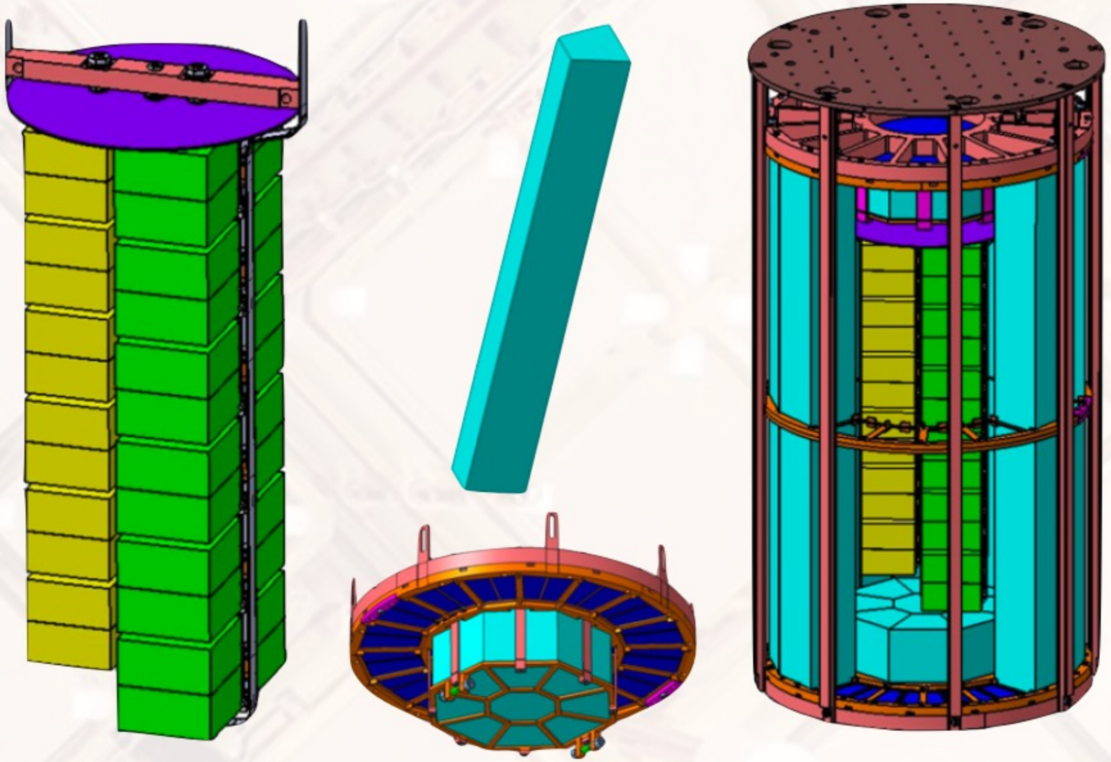
Towers:

- 12 LMO crystals (45×45×45 mm)
- 12 NTL square light detectors (45×45 mm) facing LMOs
- 12 TeO_2 crystals (50×50×50 mm)
- 12 NTL square light detectors (50×50 mm) facing TeO_2

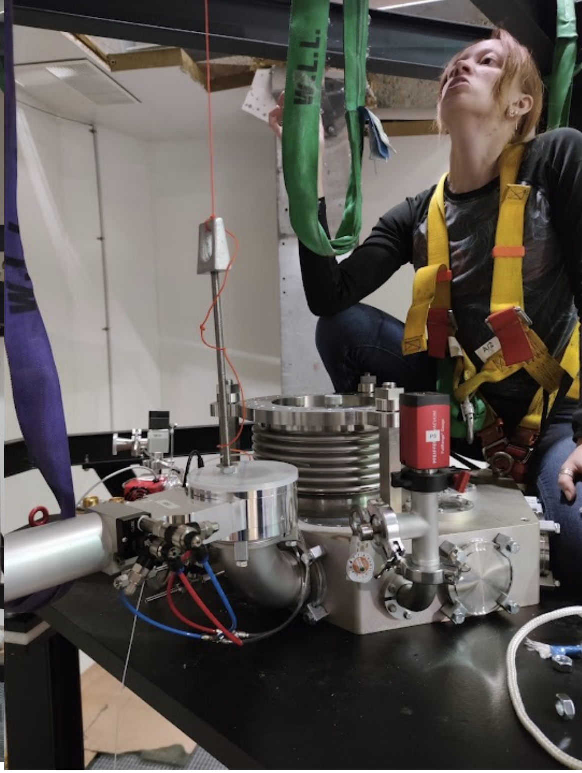
Cryogenic veto:

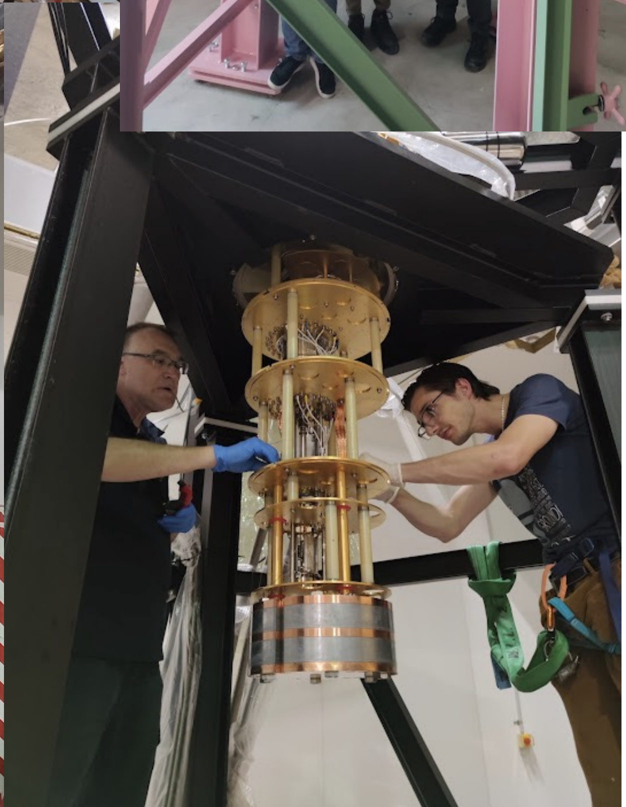
- 32 long trapezoidal BGO crystals (23cm length)
- 32 NTL trapezoidal light detectors
- 16 short trapezoidal BGO crystals (5cm length) for the top and bottom veto part
- 2 octagonal BGO crystals

Goal: demonstrate background index $<10^{-3}$ ckky



Total demonstrator mass ~170kg





BINGO 9.5 mK


MC Temperature [K]
110m
100m
90m
80m
70m
60m
50m
40m
30m
20m
10m
0
2024-09-05 02:00:00
2024-09-07 02:00:00
2024-09-09 02:00:00
2024-09-11 02:00:00
2024-09-13 02:00:
Latest _value _field _measurement type
9.53m MC_Full_Range DilutionRefrigerator_T PLC_log

MINI-BINGO at LSM

- A new low-background cryogenic infrastructure is available at LSM
- Clean room surrounding the facility
- Pulse-tube based dilution refrigerator – 30x70 cm^3 experimental volume
- Base temperature: 9.5 mK

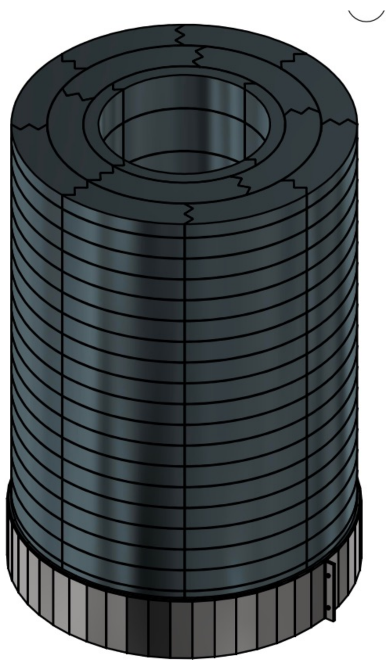
The passive Pb shielding

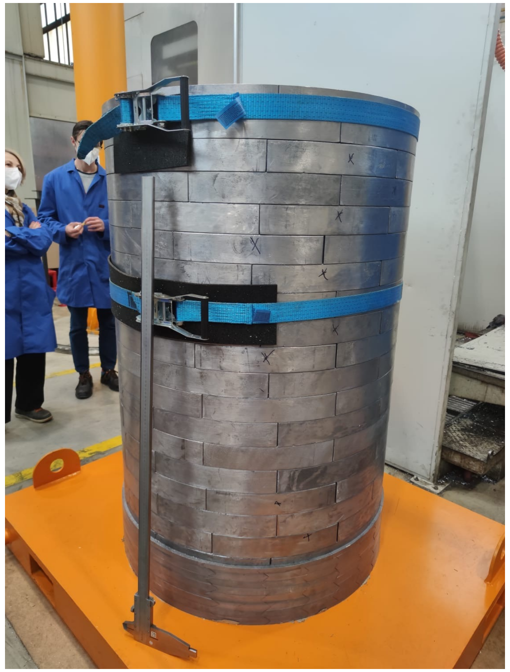
The external lead shield consists of two separate cylinders with total thickness of 230 mm:

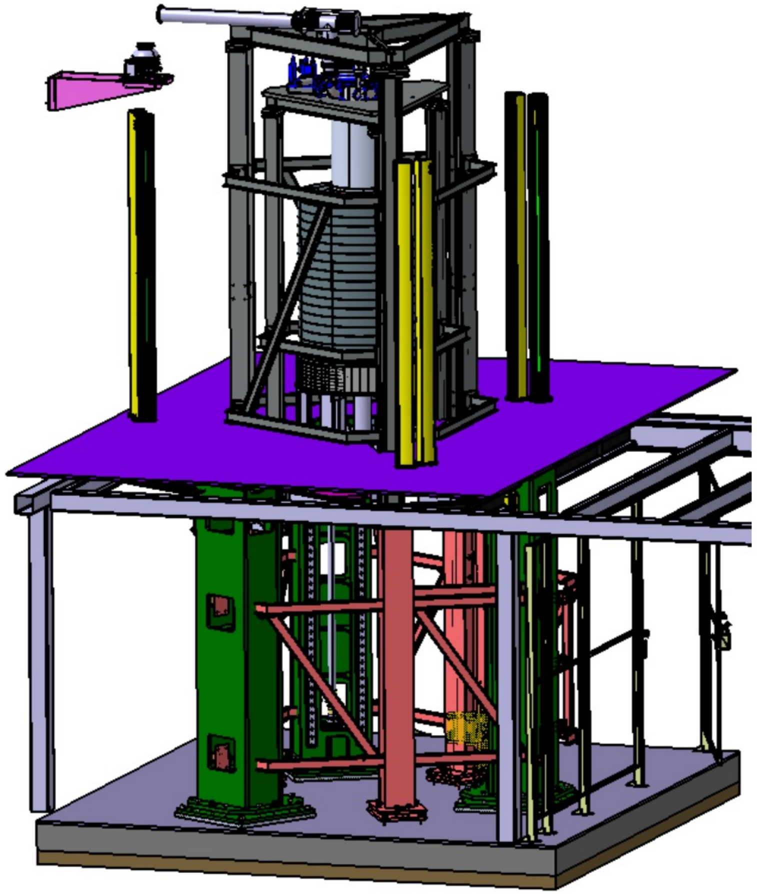
- 5 cm of Pb < 10 Bq/kg
- 18 cm < 50 Bq/kg

The Pb has been melted and delivered to LSM

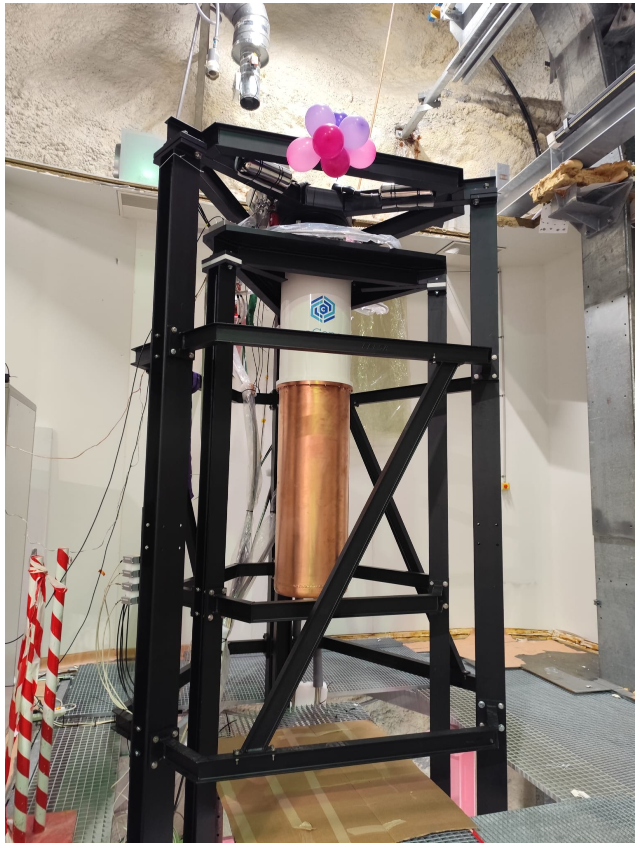
New custom lifting system up top 10 tonnes

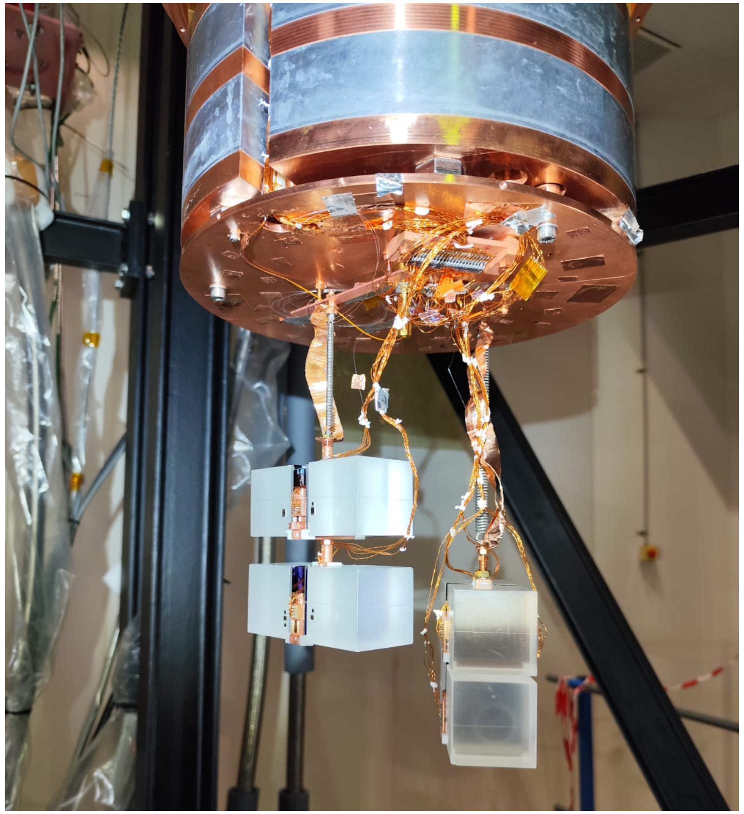






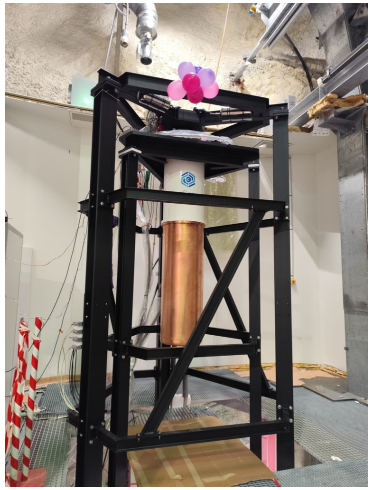
In this moment at LSM

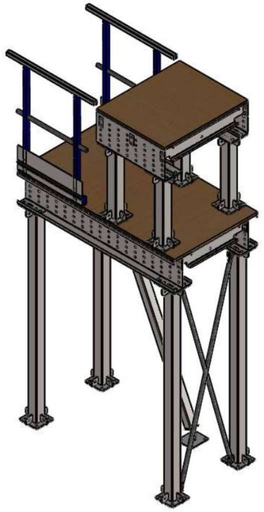


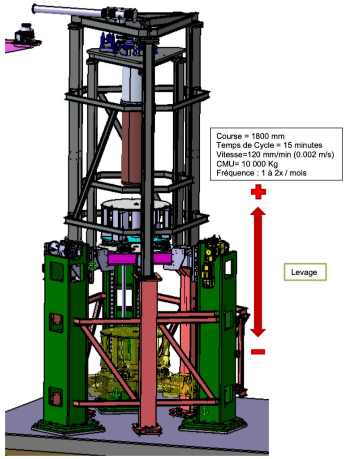


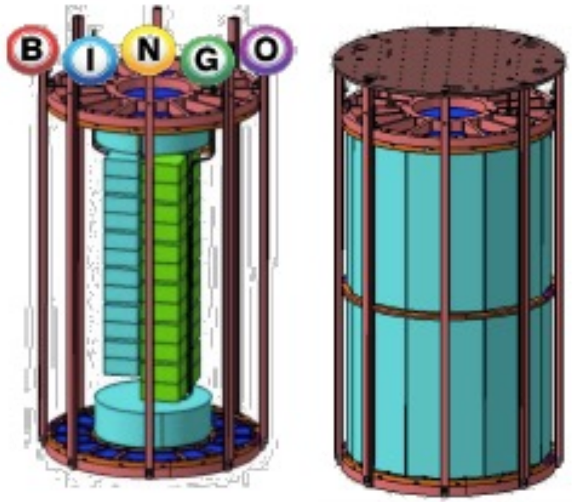
A new run is on-going:
- 2 full-size modules (4 LMO & 4 TEO)
- Temporary Pb shielding
- Full test of the electronic chain & new monitoring on-line system
- Inputs for background simulations

MINI-BINGO at LSM – next steps









Cryostat fully commissioned

Temporary Pb shield installation

Validation of LMO/TEO modules

Lifting system, full Pb shield and clean room installation

Commissioning of the two towers and the BGO cryogenic active veto & Physics run

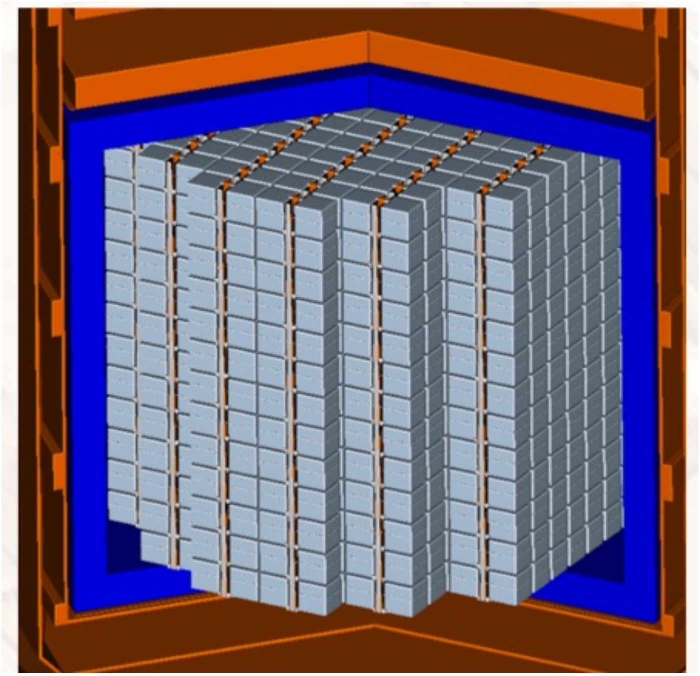
Summer 2025

October 2025

2026

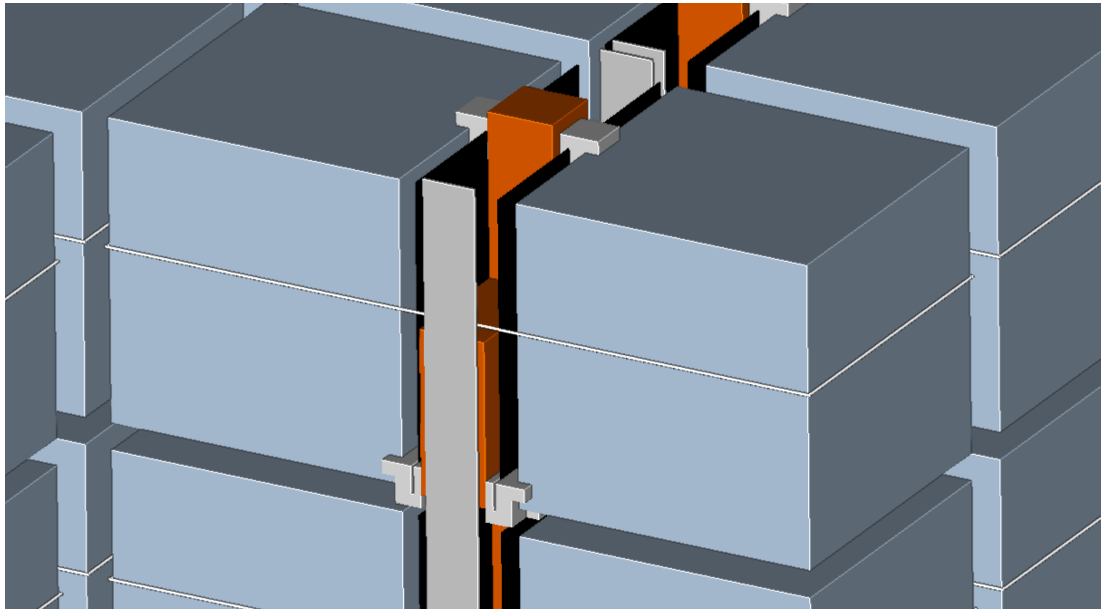
2027

BINGO Simulation
Tower geometry – Li_2MoO_4

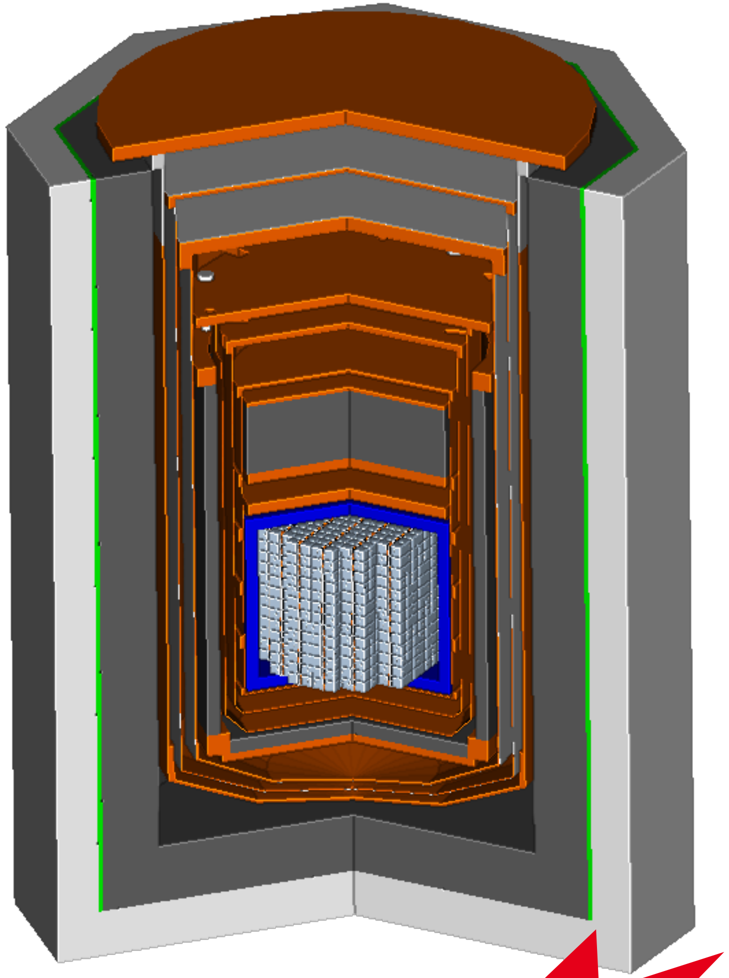


Detailed BINGO-like towers implemented in Geant4
45 mm Li_2MoO_4 cubes / 50 mm TeO_2 cubes

- Detailed assembly with aggressive spacing
  - 450 um diameter Nylon wire (42g)
  - 3x3 mm Teflon clamps (1.6 kg)
  - 300 um x 45 mm x 45 mm Ge LD (5.2 kg)
  - Central copper support structure (74.8 kg)
  - Preliminary CuPEN readout cable strips

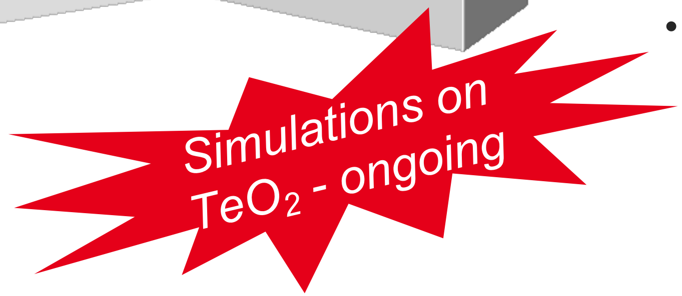


BINGO simulations – Li_2MoO_4

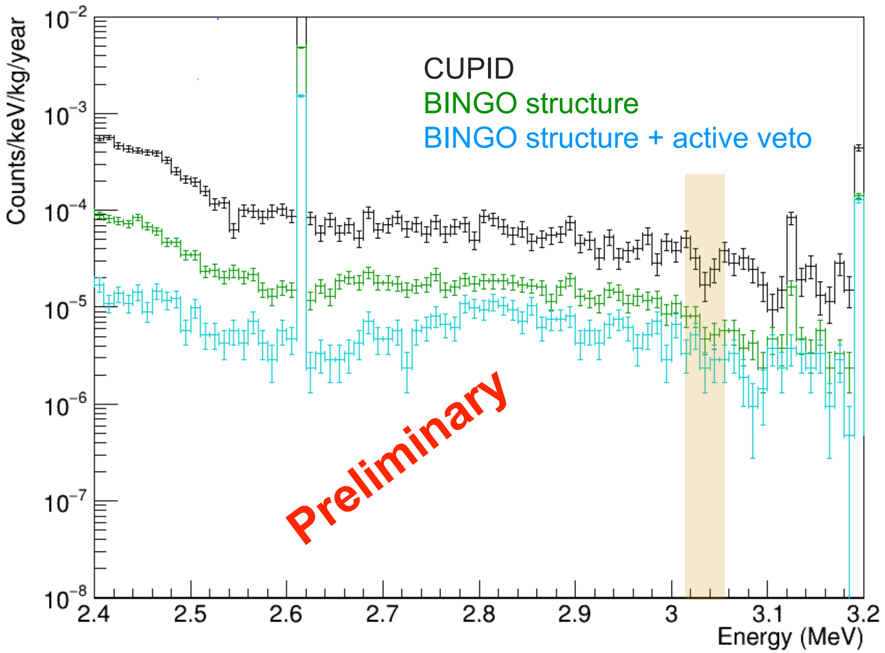


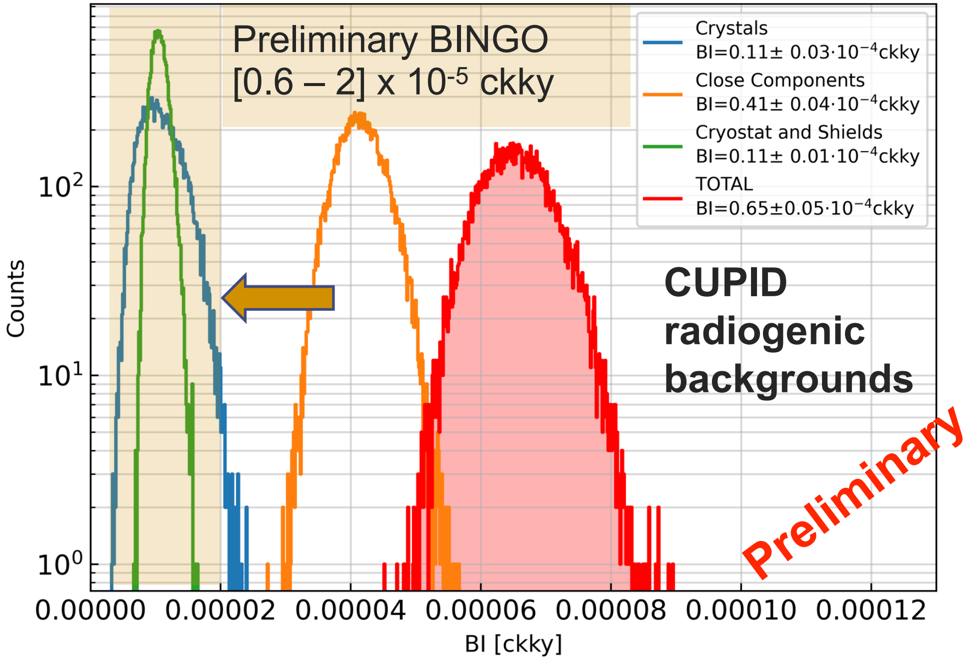
An option for CUPID-1T

- Use CUORE/CUPID simulation (AGATA) with full CUORE cryostat and shielding
- Fits 1612 Li_2MoO4 crystals in 62 towers (236.6 kg ^{100}Mo)
- Simplified/Idealized active veto [5cm thick BGO, no Cu structure]
- Preliminary analysis
- Preliminary: Overall factor ~5 improvement on background from close surface contaminations
- <u>Future work:</u>
  - Simulation of isotopes in all parts of shield & active cryogenic veto (requires U/Th screening)
  - Resolution of ambiguity in CUORE bkg model (New screening campaigr for Cu, PTFE, CuPEN)

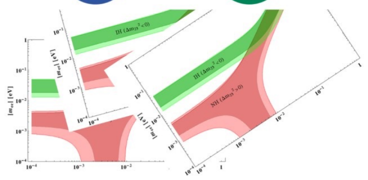


Example: Th-chain, copper surface contamination





Conclusions



BINGO is a promising project towards the meV scale of the effective Majorana mass:

- Original combinations of methods to reach **b~10^{-5}**
- **Technological breakthrough**
- **Future potential** beyond this proposal (i.e. CUPID-1T)
- Several important milestones have been achieved during the last year
- One year of life time is needed to achieve the bkg index goal < 10^{-4}
- Smooth data taking starting by end 2026
- Web site : http://www.bingo-neutrino.eu/

宾果