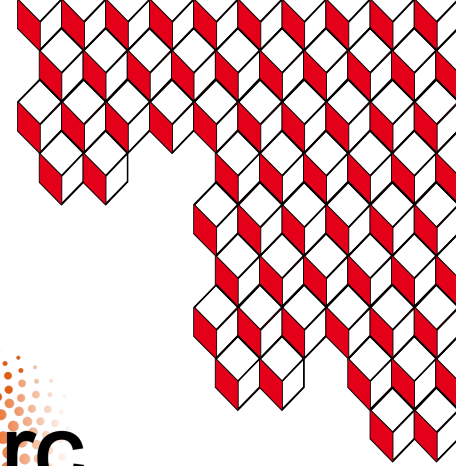
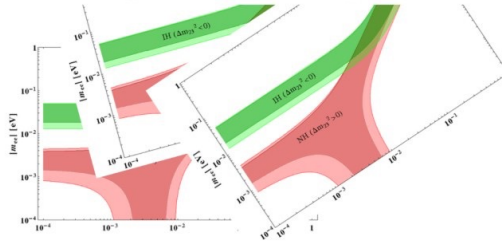




irfu



BINGO: toward a background-free ton-scale bolometric search for Neutrinoless Double Beta Decay

Claudia Nones

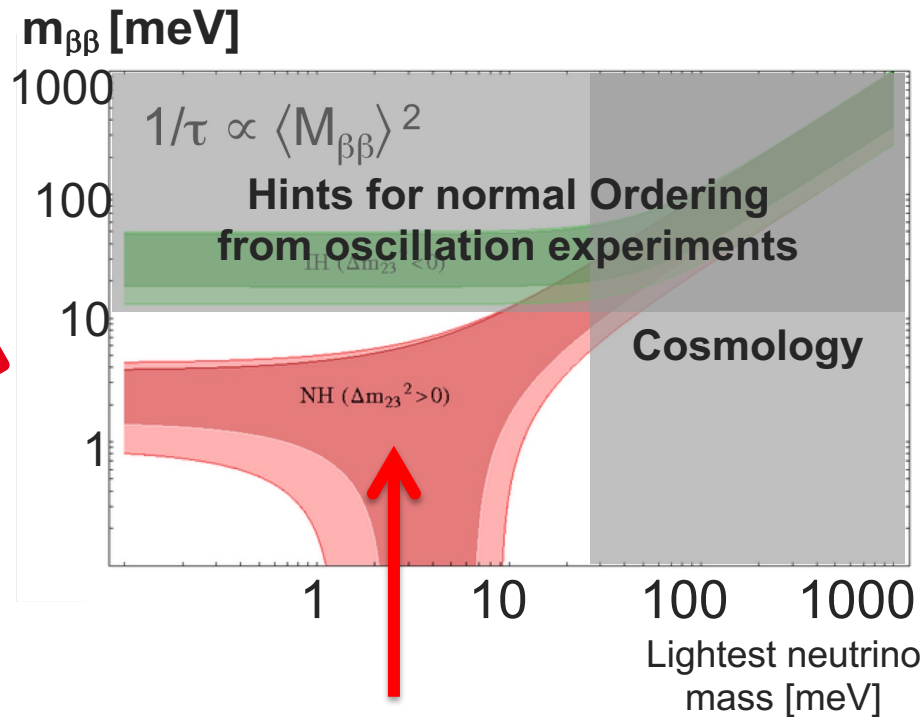
On behalf of the BINGO collaboration



Setting the stage

BINGO (Bi-Isotope $0\nu 2\beta$ Next Generation Observatory) will set the grounds for a large-scale bolometric experiment searching for **neutrinoless double beta decay** ($0\nu 2\beta$) using **innovative technologies** – validated in the **MINI-BINGO demonstrator** – capable of measuring the **neutrino Majorana mass** in the **few-meV** region.

$0\nu 2\beta$ is one of the most important topics in deep underground low radioactivity searches



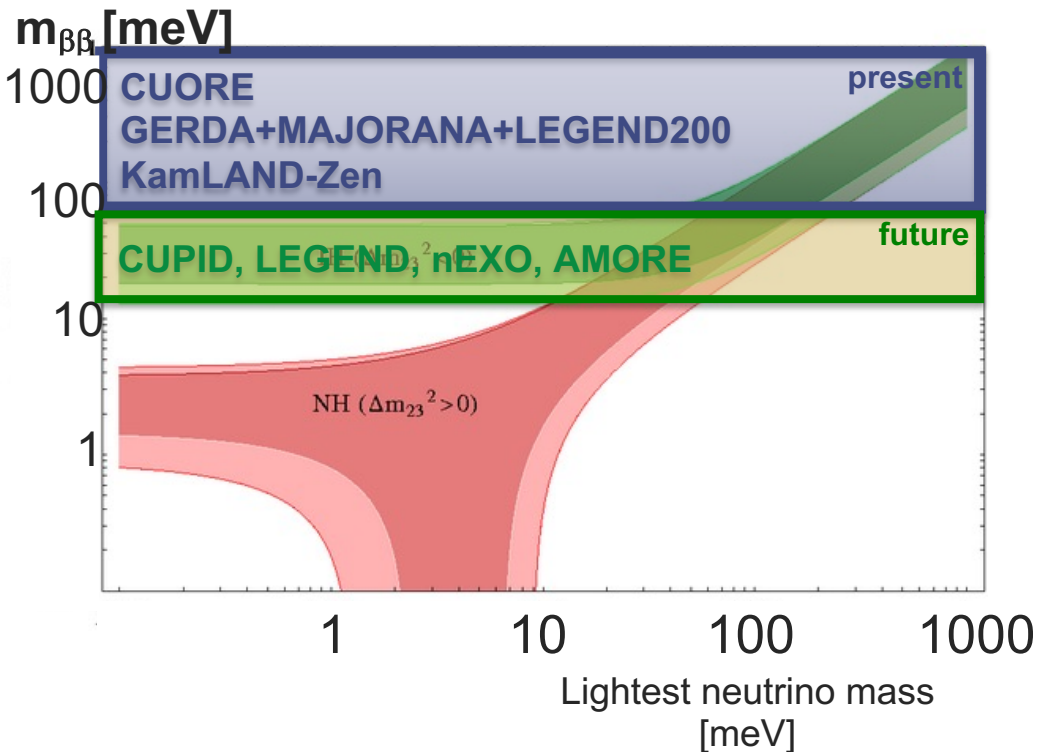
important
unanswered
key question
Dirac or
Majorana
particle



$$\nu = \nu^c$$

BINGO will study new technological solutions on the path towards the meV scale

Where we are now and where we are going in the next decade



Key technologies

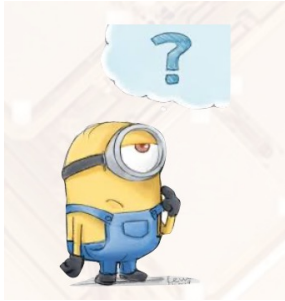
- Xe Time projection Chambers
- Large liquid scintillators
- Ge semiconductors detectors
- Cryogenic calorimeters

Different isotopes under study

- ^{136}Xe
- ^{76}Ge
- ^{100}Mo & ^{130}Te

Vibrant international competition

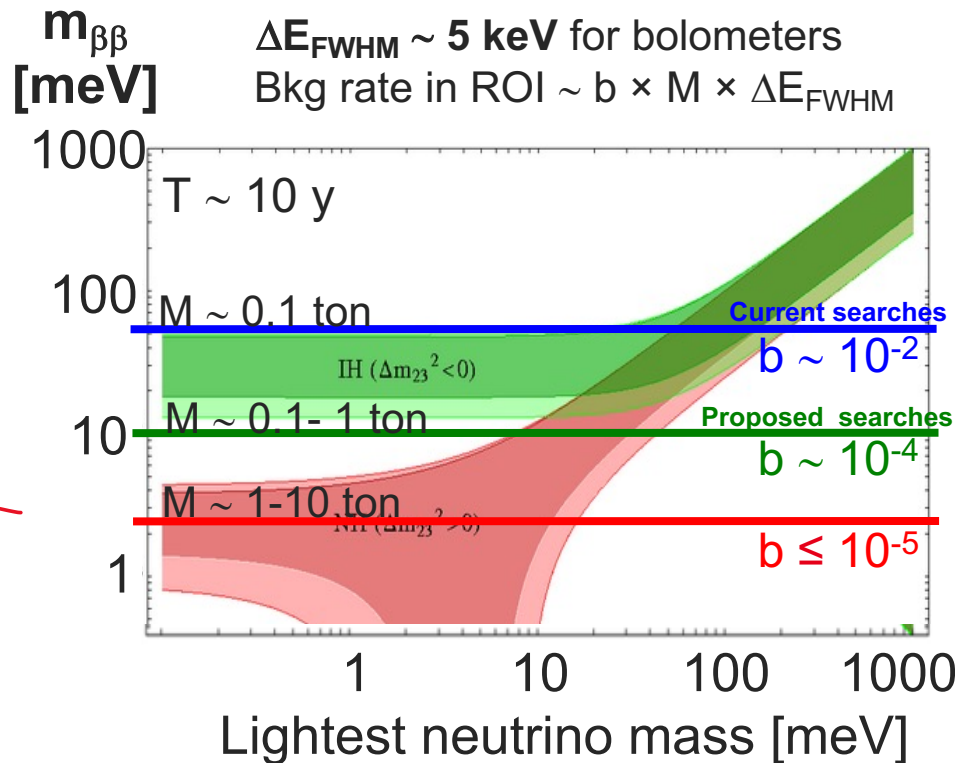
How to move forward with bolometers



Background is the key concept

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

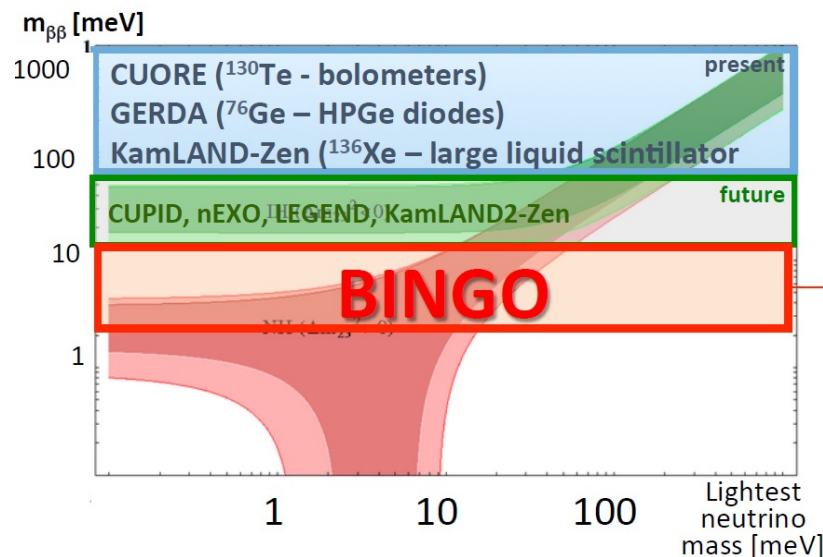
$$b = \frac{\text{number of background counts}}{M \times t \times \Delta E}$$



BINGO technologies can play a major role

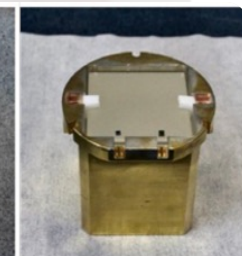
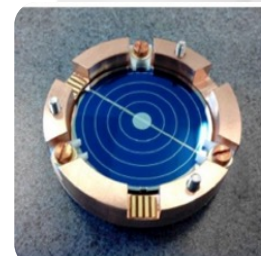
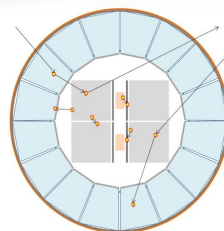
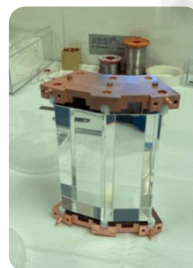
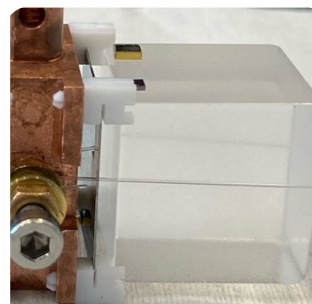


BINGO: the leap towards meV level



Main tools to reach $b \sim 10^{-5}$

- Two isotopes (^{100}Mo & ^{130}Te)
- Scintillating bolometers (TeO_2 / Li_2MoO_4)
- Very low radioactivity for all the selected materials
- Small amount of copper in the holder
- Cryogenic active veto
- Neganov-Luke based light detectors



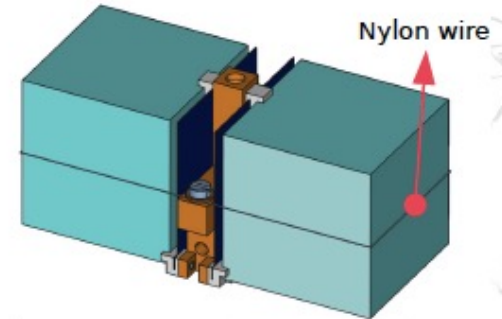
The 3 main BINGO background reduction techniques



3 main remaining backgrounds in CUPID

- Holders
- Crystals Th + U
- $2\nu\beta\beta$ pile-up

B. Schmidt's talk



- **Innovative detectors assembly:**

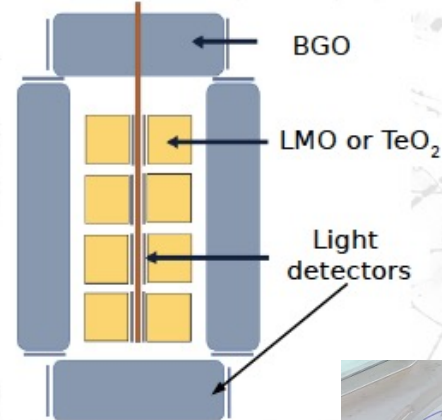
Minimisation of the amount of passive materials surrounding detectors to reduce α and β background from surface radioactivity

- **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

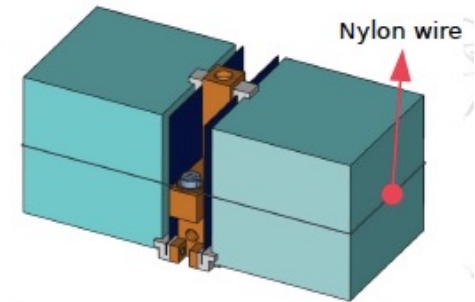


The innovative nylon-wire assembly

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

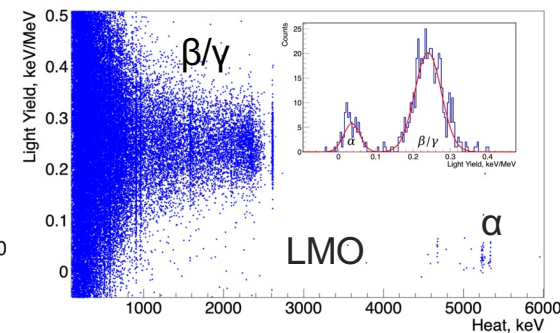
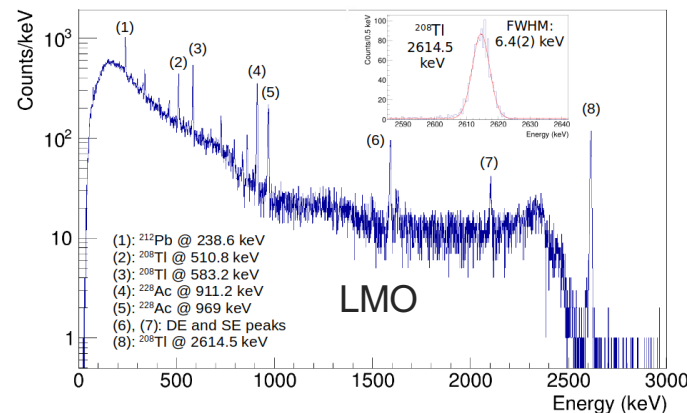
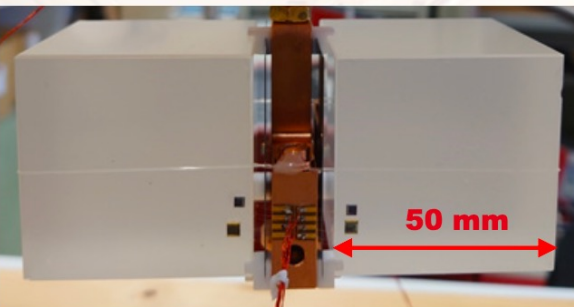
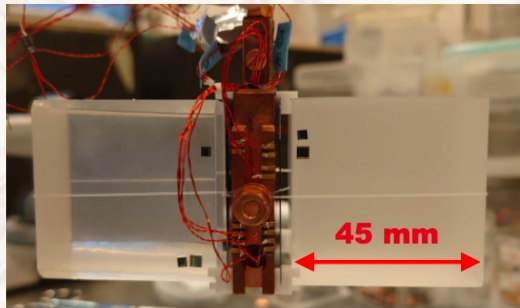
Assembly upgrade:

- Less passive materials: reduction of the total surface radioactivity contribution
- Crystals held in place by nylon-wire
- Compact assembly: background reduction through anticoincidence cuts



Several modules have been tested and validated at LSC and LSM:

- 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

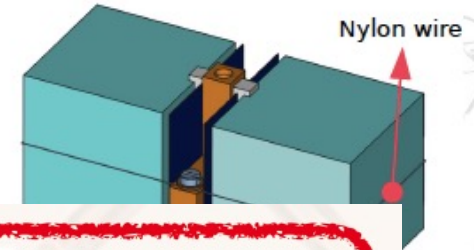


The innovative nylon-wire assembly

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

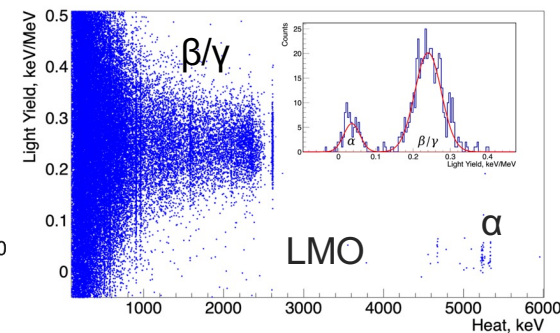
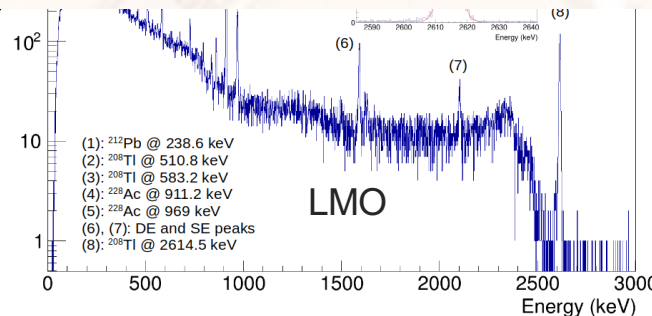
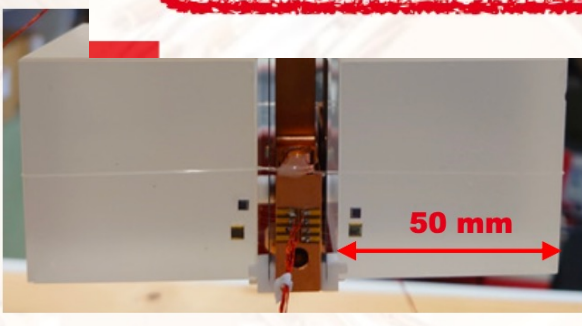
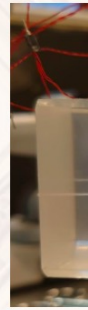
Assembly upgrade:

- Less passive materials: reduction of the total surface radioactivity contribution
- Crystals held in place by nylon-wire
- Compact assembly: background reduction through



- ✓ 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

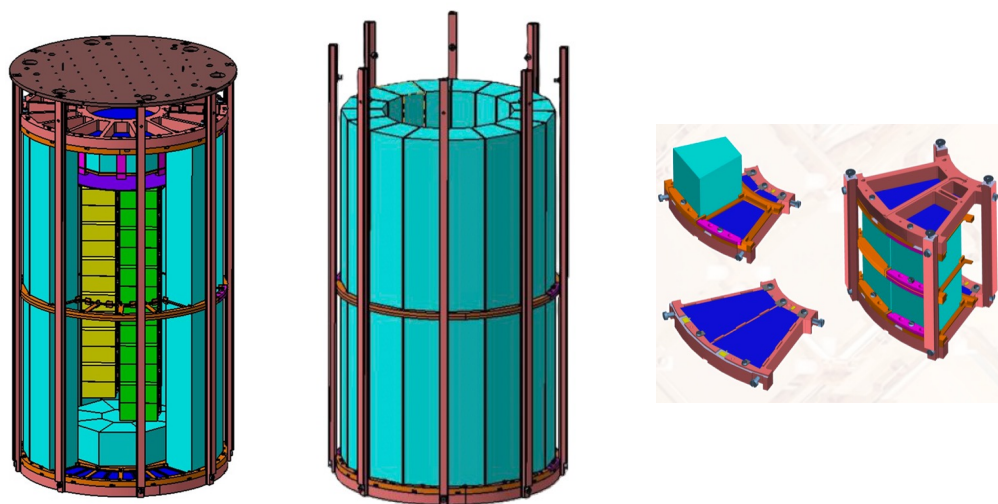
Ready to use!



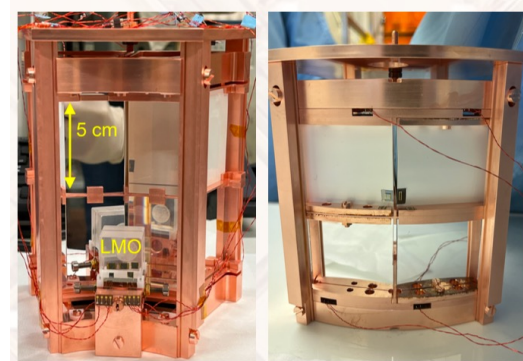
The cryogenic active veto

Main goals

- Suppress external gamma background – relevant for TeO_2 crystals
- Reject surface contamination events (α/β) for peripheral 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



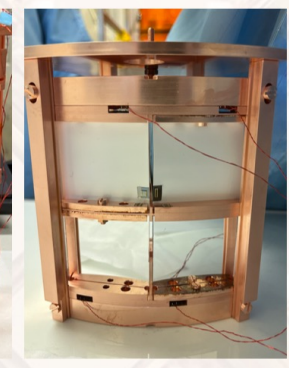
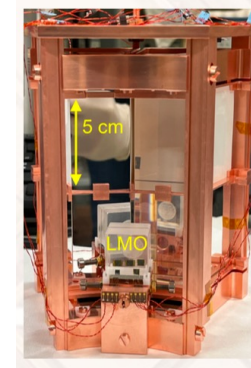
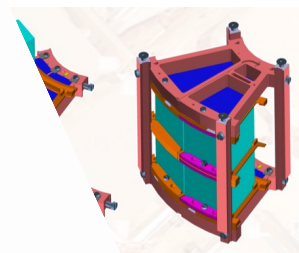
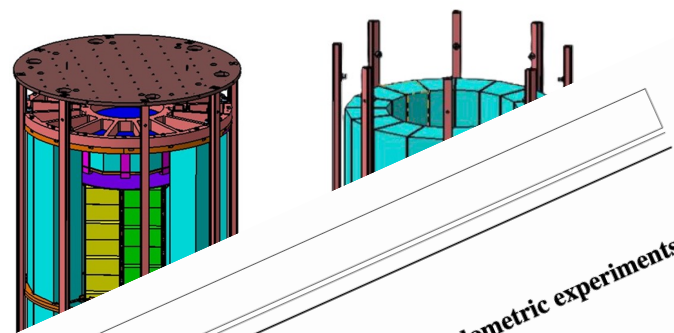
- ✓ Mechanical structure successfully validated at cryogenic temperatures
- ✓ Demonstrated capability to tag surface alpha particles
- ✓ Aluminium coating does not degrade veto efficiency
- ⚠ External gamma rejection potential to be confirmed (requires improved light detectors to achieve a lower BGO detection threshold)
- 🕒 Next step: integration of trapezoidal light detectors with enhanced sensitivity



The cryogenic active veto

Main goals

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



- ✓ Mechanical structure successfully validated at cryogenic temperatures
- ✓ Demonstrated capability to tag surface contamination events

What's new:

- New paper
- BGO crystals for top/bottom veto are under production
- Issue with new export rules in China: solved
- Crystals expected by fall 2026

Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

BINGO: cryogenic scintillation veto for $0\nu 2\beta$ bolometric experiments

A. Armatol^{1,a}, D. Baudin¹, G. Benato³, V. Berest^{1,b}, M. Buchynska⁴, P. Carniti⁵,
F.A. Danevich^{6,7,8}, M. De Jesus², F. Ferri¹, A. Giuliani⁴, H. Gomez¹, C. Gotti⁵,
Ph. Gras¹, H. Khalife^{1,c}, V.V. Kobychayev⁶, D.S. Kovalenko⁶, M. Lefevre¹, Ph. Mas¹,
E. Mazzucato¹, J.F. Millot¹, C. Nones¹, M.M. Zarytsky⁶, A. Zolotarova¹,
V.I. Tretyak^{3,6,7}, D. Vurpillot¹, M.M. Zarytsky⁶, A. Zolotarova¹

¹IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France
²Univ Lyon, Université Lyon 1, CNRS/IN2P3, IP2L-Lyon, 69100 Villeurbanne, France
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⁴Univ Lyon, Université Lyon 1, CNRS/IN2P3, IP2L-Lyon, 69100 Villeurbanne, France
⁵INFN Sezione di Milano-Bicocca, CNRS/IN2P3, IP2L-Lyon, 69100 Villeurbanne, France
⁶Univ Lyon, Université Lyon 1, CNRS/IN2P3, IP2L-Lyon, 69100 Villeurbanne, France
⁷Institute for Nuclear Research and Applied Physics, Czech Technical University in Prague, 110 00 Prague 1, Czech Republic
⁸Gran Sasso Science Institute, I-67100 L'Aquila, Italy
⁹Univ. Grenoble Alpes, CNRS, Grenoble INP, LPSC/LSM-IN2P3, 73500 Modane, France

- In addition, an aluminum coating will shield the main detector volume from the scintillation light from the veto not preventing the surface contamination rejection

Neganov-Luke light detectors

- 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 CROSS and 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%

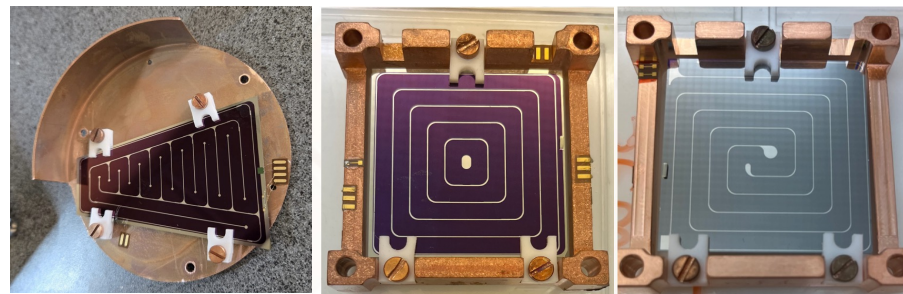
Square LD optimization ongoing with the test of new electrodes geometry increasing the surface coverage

NTL LDs for veto: new masks design received and validated. First production has been done, cryogenic tests on-going!



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



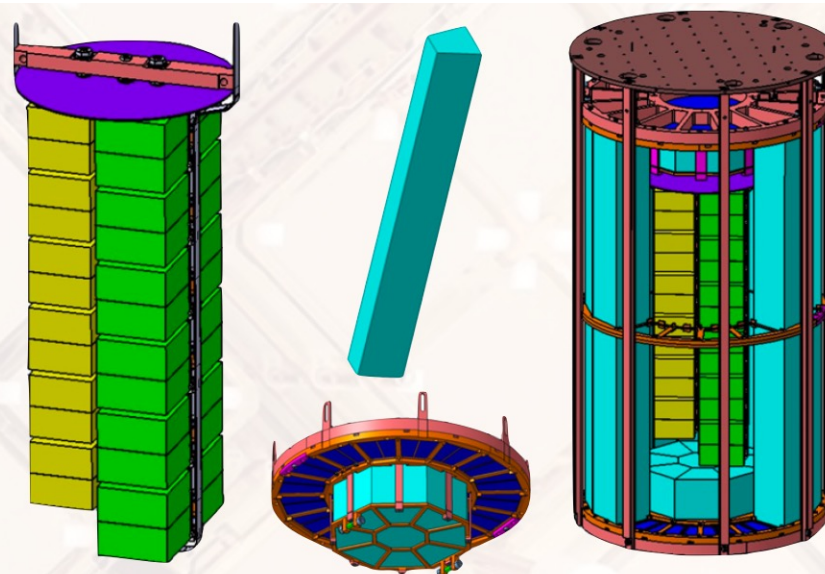
MINI-BINGO: a technology demonstrator at LSM

Towers:

- 12 LMO crystals (45×45×45 mm)
- 12 NTL square light detectors (45×45 mm) facing LMOs
- 12 TeO₂ crystals (50×50×50 mm)
- 12 NTL square light detectors (50×50 mm) facing TeO₂

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



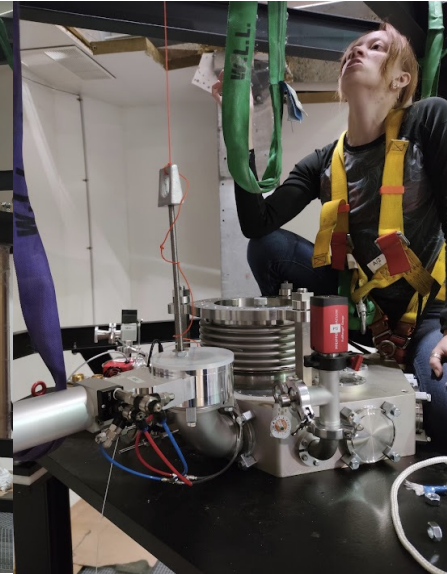
Total demonstrator mass ~170kg

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

BBC NEWS
BREAKING

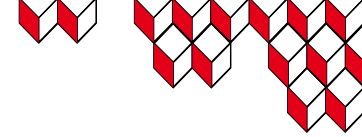
- A new low-background cryogenic infrastructure is available at LSM
- Pulse-tube based dilution refrigerator – 30x70 cm³ experimental volume
- Base temperature: 9.5 mK
- Clean room surrounding the facility

MINI-BINGO at LSM (1)

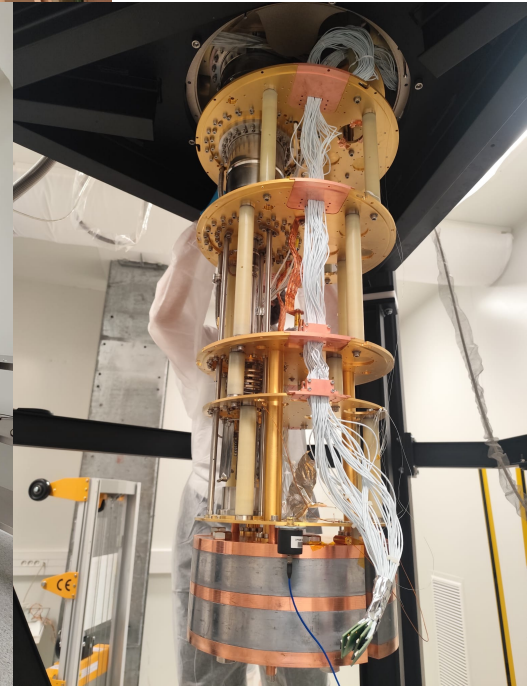
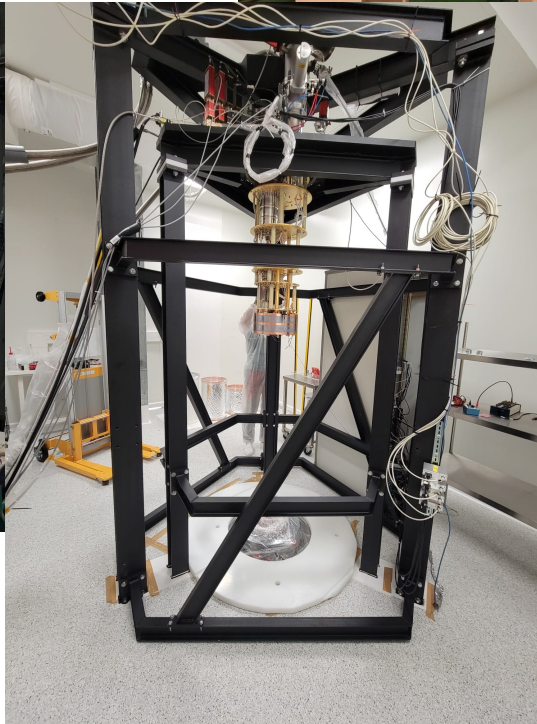


B I N G O 9.5 mK





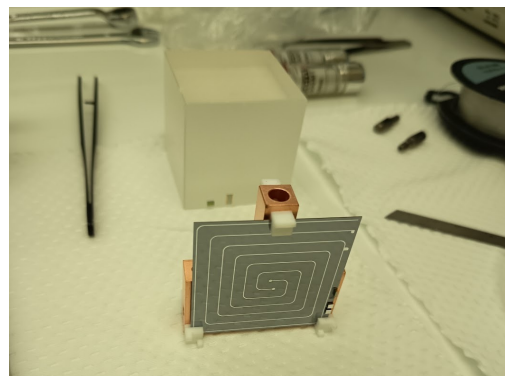
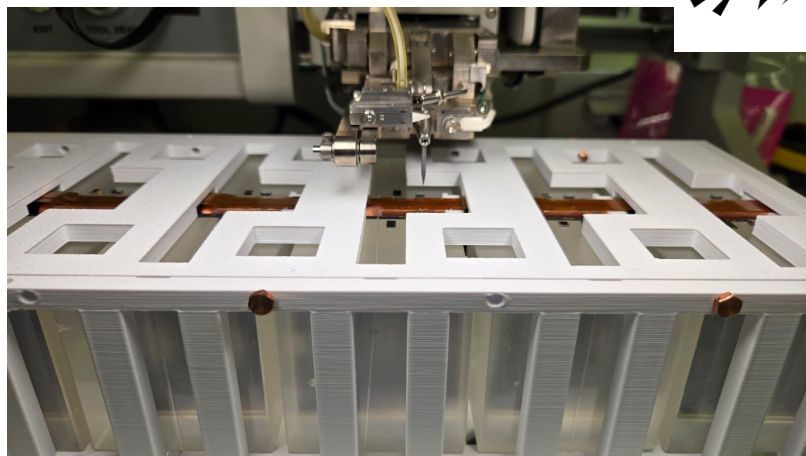
MINI-BINGO at LSM (2)



MINI-BINGO: where we are

Towers:

- 12 LMO crystals & 12 NTL
- 12 TEO crystals & 12 NTL



- The two towers will be installed in the coming weeks in LSM
- No BGO veto for the moment – coming soon



MINI-BINGO background model

With a view to mini-BINGO, an intense **background simulation work** started

Objectives

- Calculate BI in the ROI considering known background sources
- Full demonstration of the BINGO background reduction concepts

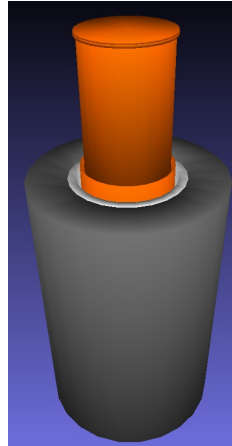
Simulation features

- Simulate events from the various setup volumes by Geant4-based Monte Carlo
- Account for pile-up through a preset time window
- Exploit multiplicity among detectors for background rejection

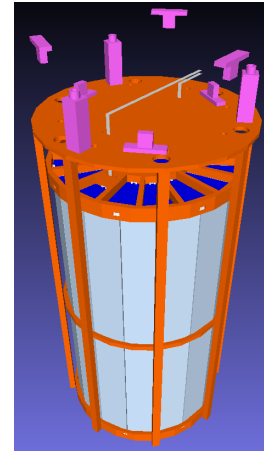
Next steps

- Group background contributions originated in the same volume
- Build spectra from the various contributions and assess BI

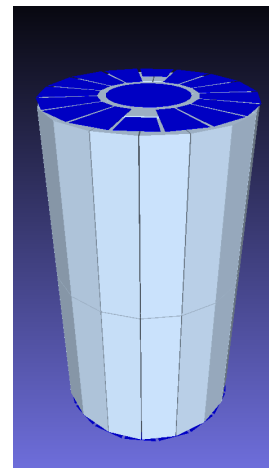
Cryostat +
Shielding



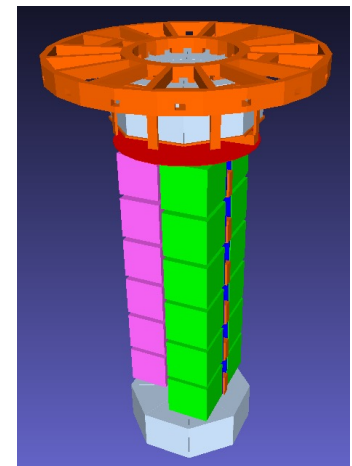
Housing



BGO internal
veto



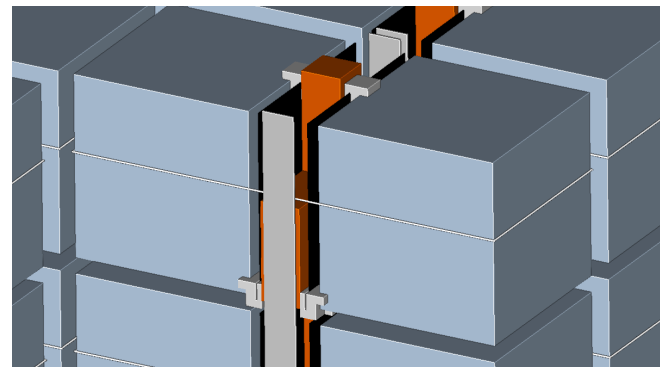
LMO/TeO₂
towers



Beyond MINI-BINGO and towards CUPID-1T

Detailed BINGO-like towers implemented in Geant4

- 45 mm side Li_2MoO_4 cubes / 50 mm side TeO_2 cubes
- 450 μm diameter Nylon wire
- 3x3 mm Teflon clamps
- 300 μm x 45 mm x 45 mm Ge LD
- Central copper support structure
- Preliminary CuPEN readout cable strips

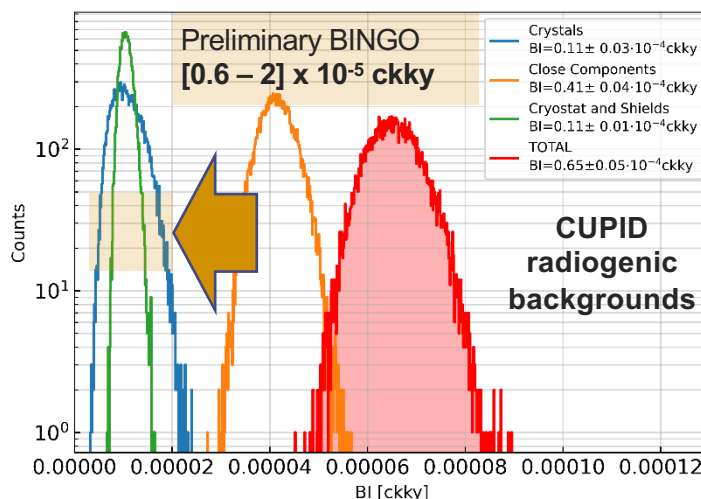


Simulation of a CUPID-like experiment with BINGO detector structure

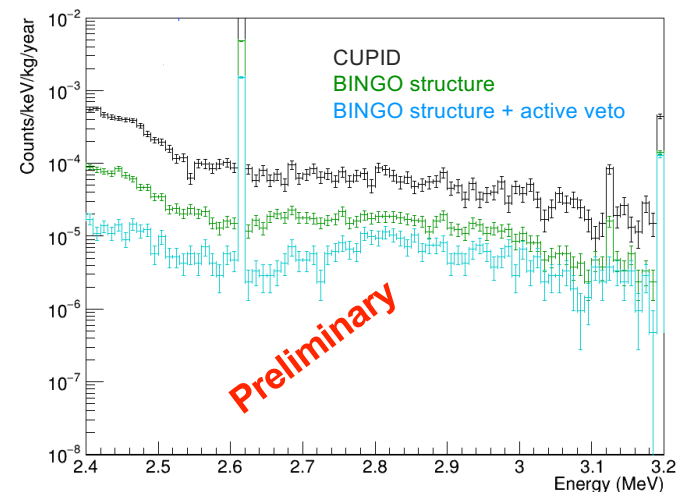
- Use CUORE/CUPID cryostat simulations
- Simplified/idealized active veto (5 cm thick BGO) or no veto at all
- Preliminary: substantial improvement on background from close surface contaminations in Li_2MoO_4

Large uncertainty due to ambiguity in CUORE background model (to be solved with a new screening campaign)

Promising for CUPID-1T



Example: Th-chain, copper surface contamination



Simulations on TeO_2 - ongoing



Conclusions

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

- Original combinations of methods to reach $b \sim 10^{-5}$
- **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

*Exciting physics adventures waiting
for MINI-BINGO and beyond !*

