http://www.bingo-neutrino.eu

BINGO:

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

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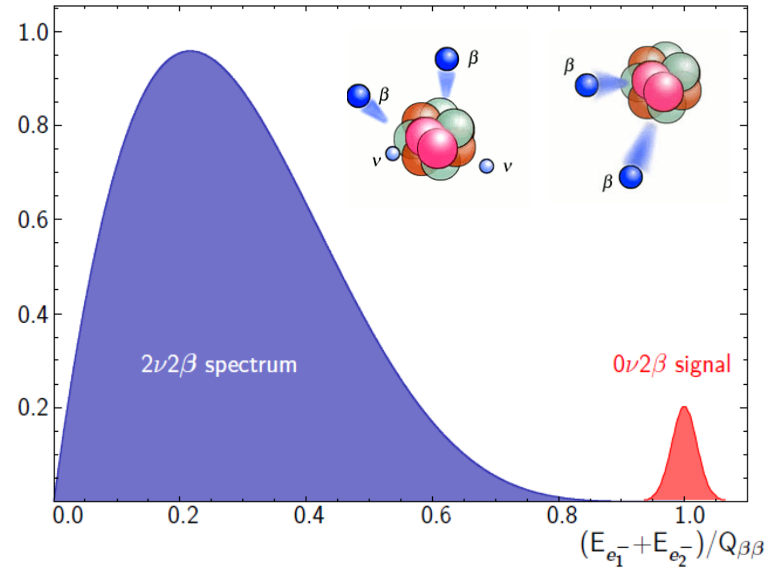
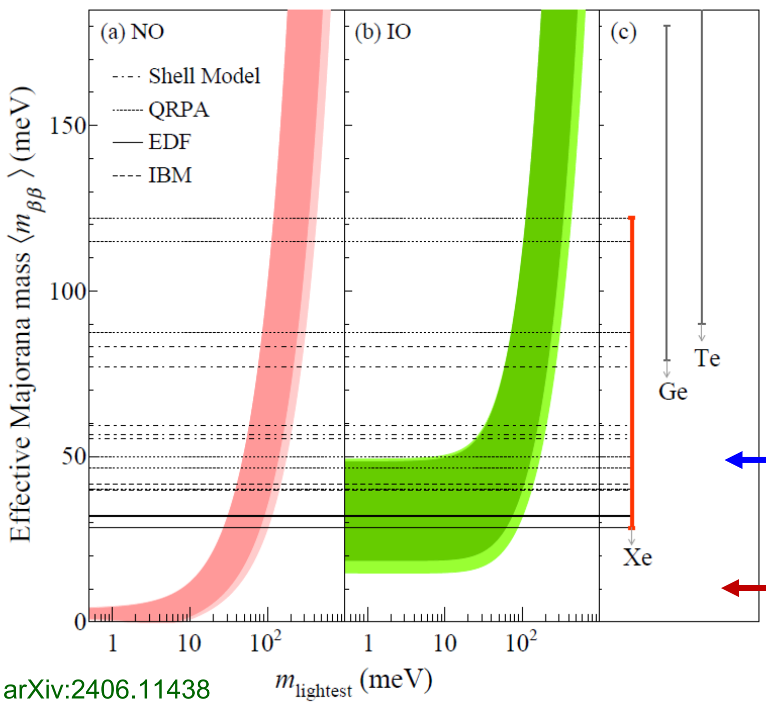
on behalf of the BINGO Collaboration

04/10/2024

Neutrinoless double-beta decay

- **Energetically possible as "ordinary" 2ν2β**
  - no 0ν2β signal is observed (most stringent limits lim$T_{1/2}$ ~ 10^{24}–10^{26} yr)
  - 2ν2β is detected for dozen nuclei (measured $T_{1/2}$ ~ 10^{18}–10^{24} yr)
- **Lepton Number Violating process (Δ*L* = 2)**
  - physics beyond the Standard Model (mechanism(s) of the 0ν2β process)
  - clue for the matter-antimatter asymmetry
- **Light Majorana neutrino exchange**
  - neutrino is equal to its antiparticle
  - scale of neutrino mass: $\left[T^{0\nu}_{1/2}\right]^{-1} \propto \langle m_{\beta\beta}\rangle^2$





arXiv:2406.11438

Bkg in ROI

To enter IO band

~ 10^{-3}-10^{-2} ckky

< 10^{-4} ckky

To explore IO & ~50% of NO

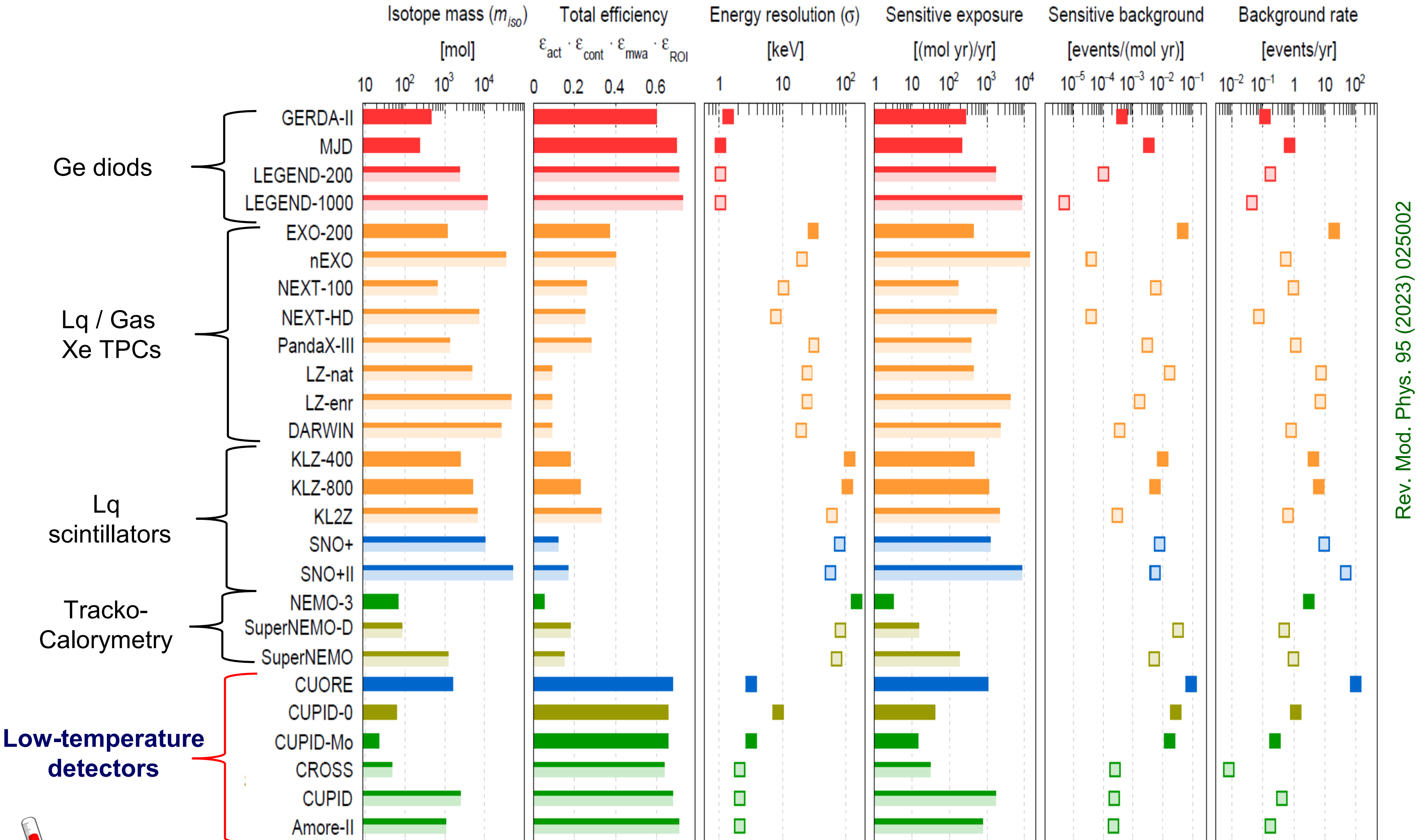
PRD 96 (2017) 053001

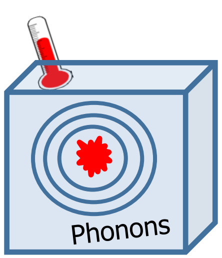
Sensitivity to 0ν2β

$$\lim T^{0\nu}_{1/2} \propto \begin{cases} \delta/W \cdot \varepsilon \cdot M \cdot t & \text{Zero background} \\ \delta/W \cdot \varepsilon \cdot \sqrt{\dfrac{M \cdot t}{B \cdot \Delta E}} & \text{Non-zero background} \end{cases}$$

- δ – isotopic abundance
- *W* – molecular weight
- ε – detection efficiency
- *M* – mass of a ββ source [kg]
- *t* – time of measurements [yr]
- Δ*E* – energy range of interest (ROI) [keV]
- *B* – background index in ROI [ckky]

Detectors for high-sensitivity 0ν2β searches

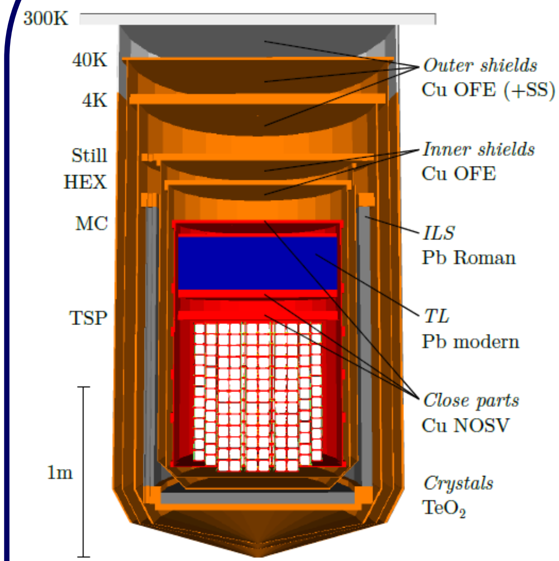


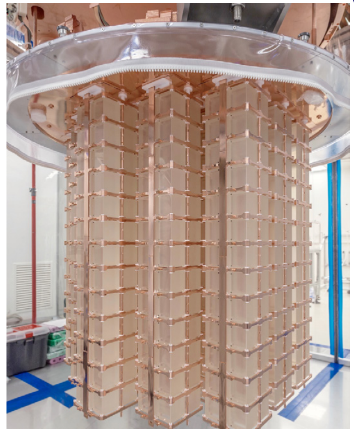


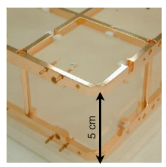
- Compatible with different ββ isotopes
- ββ source = detector (⇒ high efficiency)
- High energy resolution (‰ level at $Q_{\beta\beta}$)
- Good background control & understanding
- Scalability via arrays, long term duty cycle
- Multi-usage cryogenic apparatus

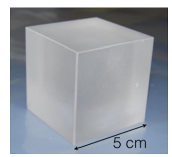
From CUORE to CUPID large-scale 0ν2β searches

CUORE: the largest bolometric 0ν2β search



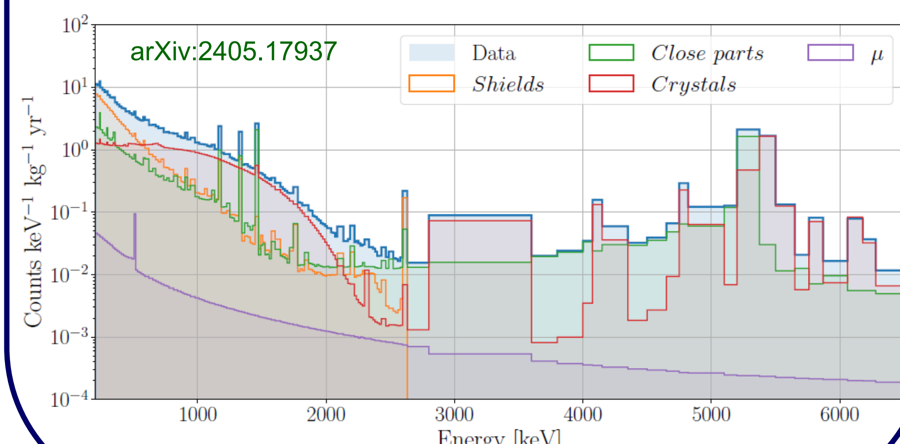






Prog. Part. Nucl. Phys.122 (2022) 103902

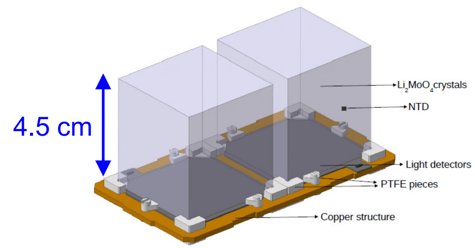
CUORE background & data-driven MC model

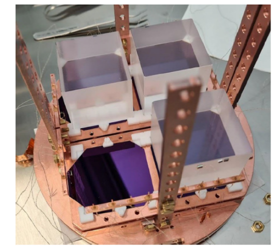


CUPID: CUORE Upgrade with Particle ID

arXiv:1907.09376

- ^{100}**Mo** instead of ^{130}Te ($Q_{\beta\beta}$ = 3034 keV vs. 2527 keV)
- **$Li_2{}^{100}MoO_4$** instead of TeO_2 (Scintillation vs. Cherenkov PID)
- **Light detectors** (for particle ID, 2ν2β pileup rejection)
- **CUORE infrastructure** (upgraded w/ μ-veto, PT, DAQ)

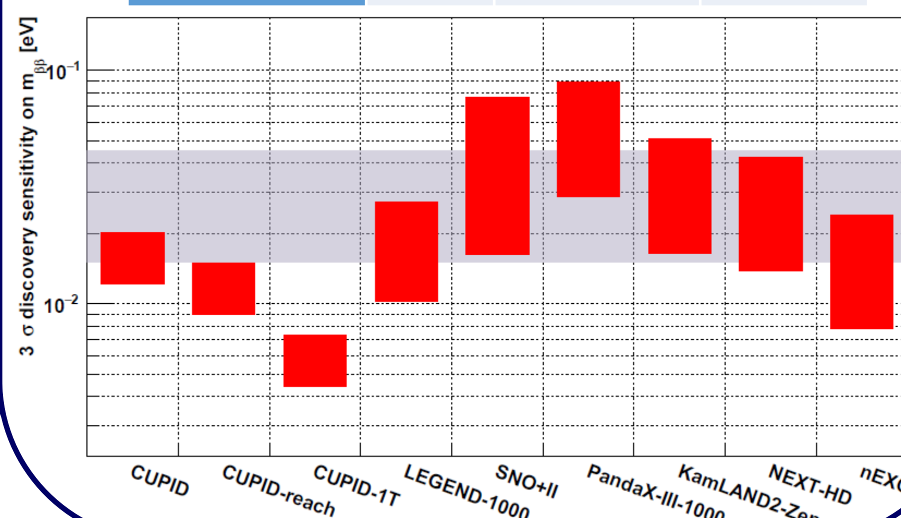




EPJC 82 (2022) 810

Experiment	CUPID	CUPID-reach	CUPID-1T
^{100}Mo (kg)	240	240	1000
Δ*E* FWHM (keV)	5	5	5
BI (ckky)	**10^{-4}**	**2×10^{-5}**	**5×10^{-6}**
$T_{1/2}$ (yr)	10^{27}	2×10^{27}	8×10^{27}

arXiv:1907.09376

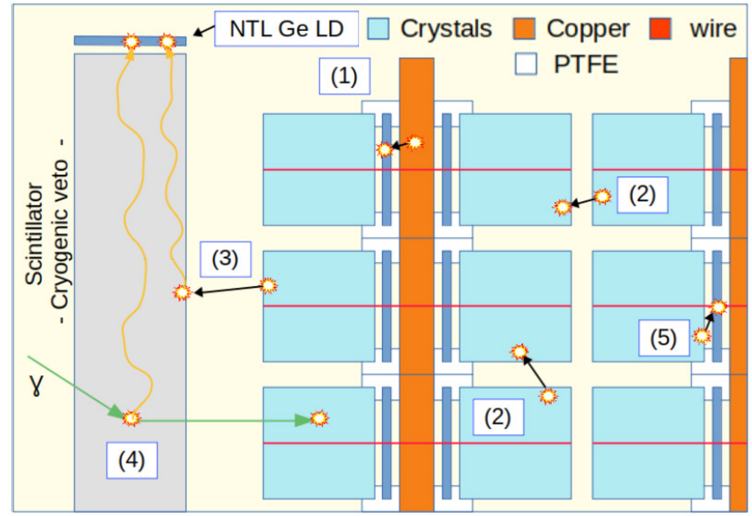


Bi-Isotope $0\nu2\beta$ Next Generation Observatory

BINGO erc

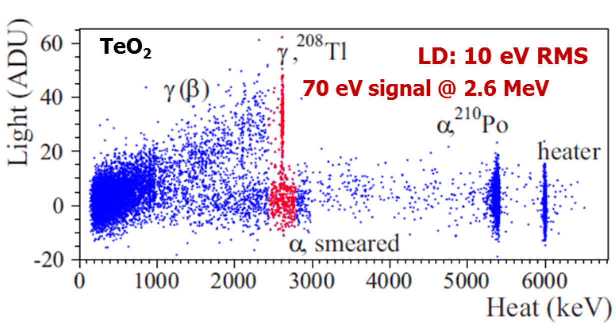
- **Bolometric search for $0\nu2\beta$ in ^{130}Te & ^{100}Mo**
  Promising $\beta\beta$ isotopes embedded in TeO_2 [CUORE] & Li_2MoO_4 [CUPID]
  Multi-isotope approach to probe $0\nu2\beta$ signal [EPJC 78 (2018) 272]
- **Innovative detector holder to reduce surface radioactivity**
  Strong reduction of α and β background from surfaces
- **Cryogenic veto based on a high density scintillator**
  Suppression of background from high energy γ's, in particular from ^{208}Tl decay, and tagging of multi-Compton events, using ZWO or BGO
- **High-performance bolometric photodetectors [NTL LDs]**
  To ensure α vs. $\gamma(\beta)$ discrimination (especially for TeO_2), to reject ^{100}Mo $2\nu2\beta$ pile-ups in LMO, & to readout the cryogenic veto

BINGO concept



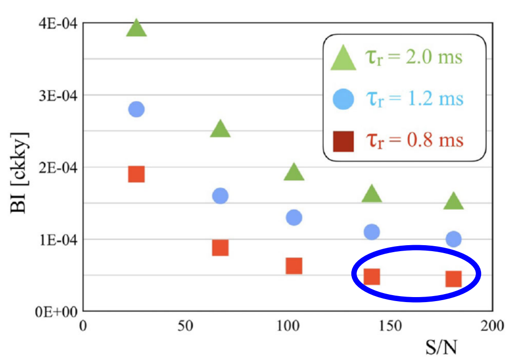
arXiv:2402.12262, accepted by NIMA

Cherenkov light based particle ID for TeO_2



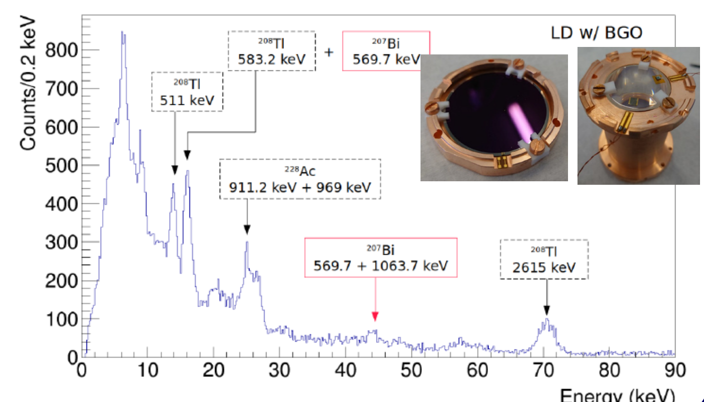
PRC 97 (2018) 032501

Rejection of $2\nu2\beta$ pile-ups w/ LD



EPJC 83 (2023) 373

BGO scintillation detected by cryogenic LD



arXiv:2204.14161

Mini-BINGO: demonstrator of BINGO innovations

Mini-BINGO

- **Demonstrator will be hosted at LSM (France)**
  Former place of the EDELWEISS dark matter search experiment & a new dilution refrigerator are foreseen

- **Two 12-crystal towers (LMO & TeO_2) will be studied**
  LMOs were produced following a protocol developed for LUMINEU & CUPID-Mo 2β experiments [EPJC 80 (2020) 44]
  TeOs, used in Cuoricino 2β searches [Astropart. Phys. 34 (2011) 822], will be reused in BINGO

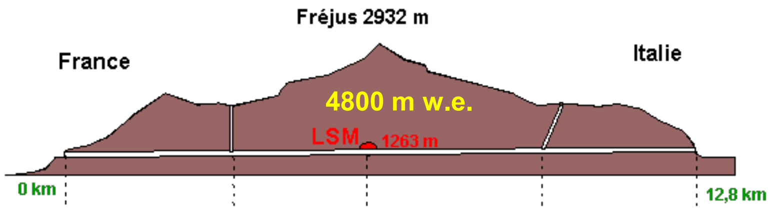
- **BGO-based cryogenic veto with a 4π coverage**
  BGO will be produced, R&D on radiopure BGO is in progress

Mini-BINGO	Crystals	Size (cm^3) [Shape]	Mass (kg)
LMO tower	12	4.5×4.5×4.5 [cubic]	3.4
TeO_2 tower	12	5.1×5.1×5.1 [cubic]	9.5
Veto lateral	32	20×23 [trapezoidal]	105
Veto top (Veto bottom)	8+1	18×5.0 [trapezoidal] 25×5.0 [octagonal]	6.0

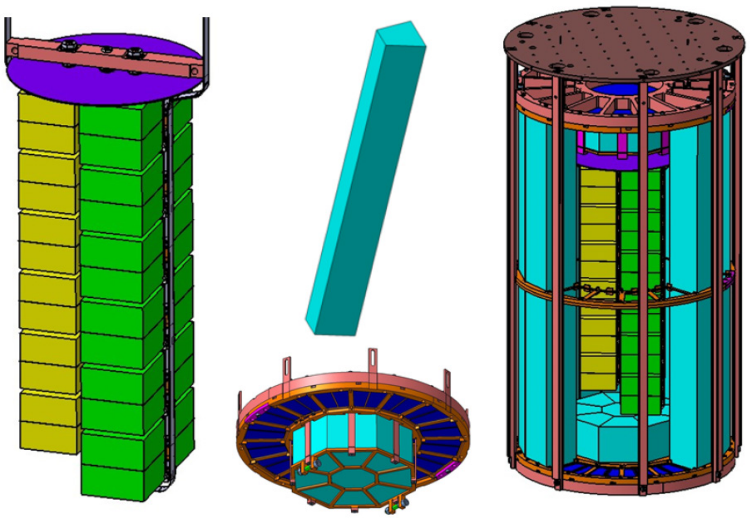
- **Start of Mini-BINGO operation in 2025**
  1 yr data taking is foreseen

arXiv:2402.12262

Laboratoire Souterrain de Modane



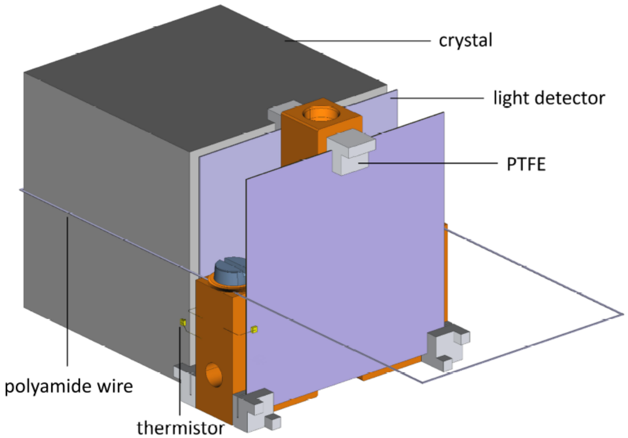
Mini-BINGO components

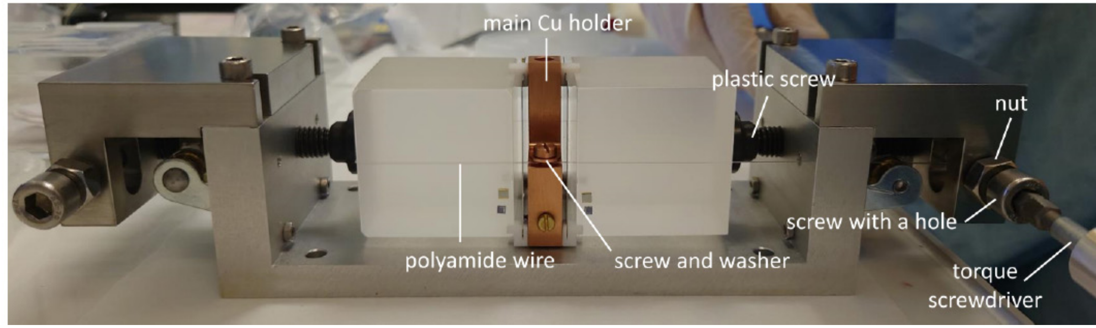


BINGO: innovative detector assembly

BINGO detector structure design & assembly tool

arXiv:2402.12262



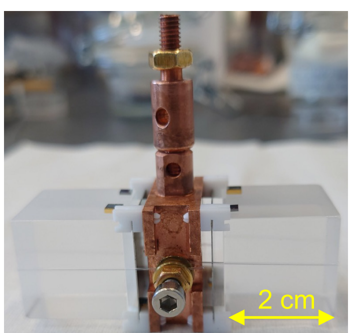


Polyamide wire (now / future):
- **Commercial fishing line** (Th / U ~ 30 / 20 ppt, K ~ 50 ppb)
- **Pure Nylon**

BINGO prototypes tested at low temperature

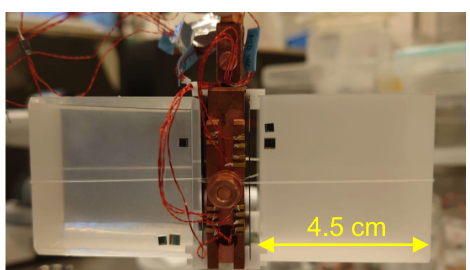
Small LMOs @IJCLab

arXiv:2204.14161



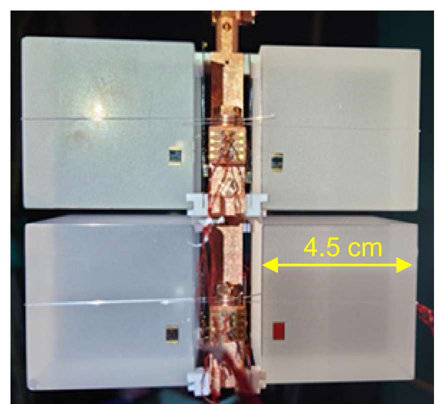
Large LMOs @IJCLab

arXiv:2301.06946



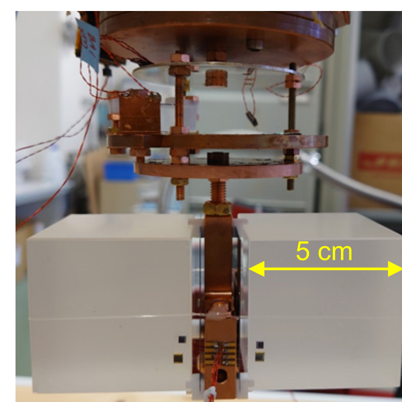
Large LMOs @LSC

arXiv:2402.12262



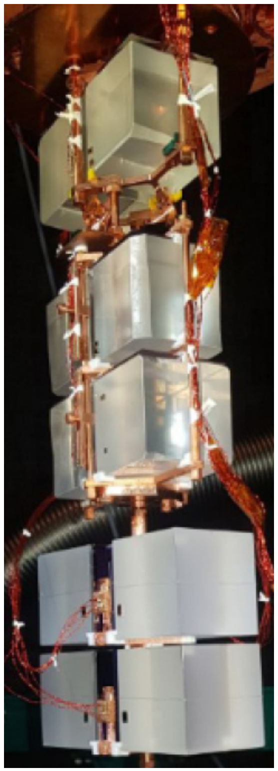
Large TeO_2 @IJCLab

Paper is in preparation



BINGO: 4-LMO-module @ CROSS set-up

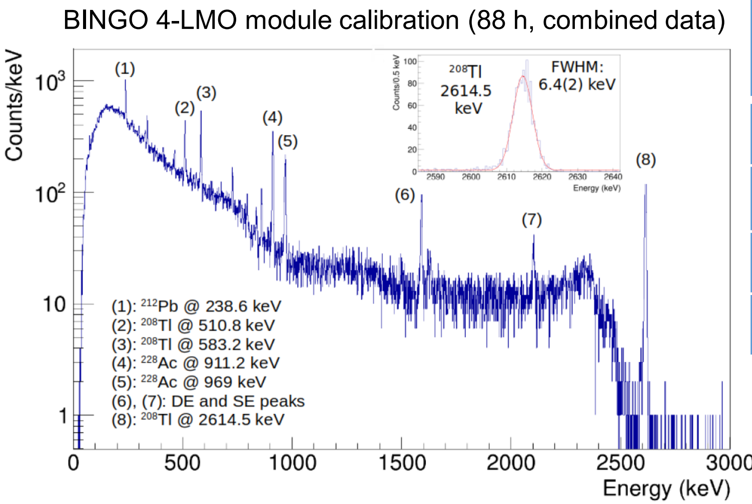
Laboratorio Subterráneo de Canfranc



JINST 19 (2024) P09014

arXiv:2402.12262

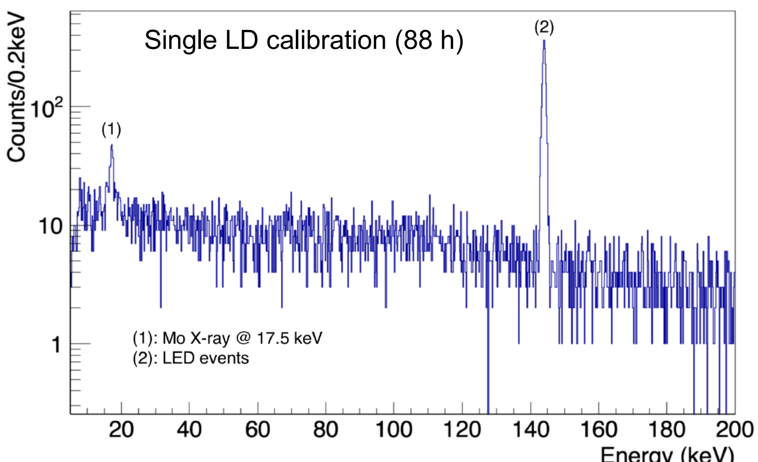
High-performance of BINGO LMOs in a BINGO-like pulse-tube cryostat



	Signal (nV/keV)	FWHM (keV) @ noise	FWHM (keV) @ 2615
LMO-1	31	2.5	**7.1(4)**
LMO-2	85	1.5	**5.6(2)**
LMO-3	57	4.6	**6.0(4)**
LMO-4	44	2.6	**6.6(4)**

- Good energy resolution close to ROI: around 6 keV FWHM at 2615 keV
- Performance of BINGO modules is similar to results of CROSS LMOs

Good performance of BINGO LDs [w/o NTL amplification test]

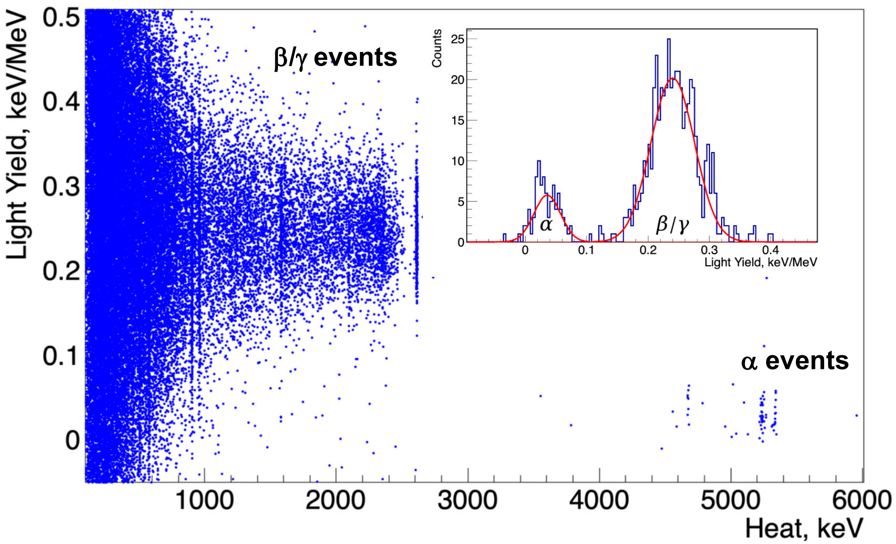


	Signal (μV/keV)	FWHM (keV) @ noise
LD-1	1.0	**0.24**
LD-2	1.7	**0.16**
LD-3	1.8	**0.21**
LD-4	1.3	**0.26**

- Around 0.2 keV FWHM noise
- Noise power spectra are similar to reference LDs of CROSS

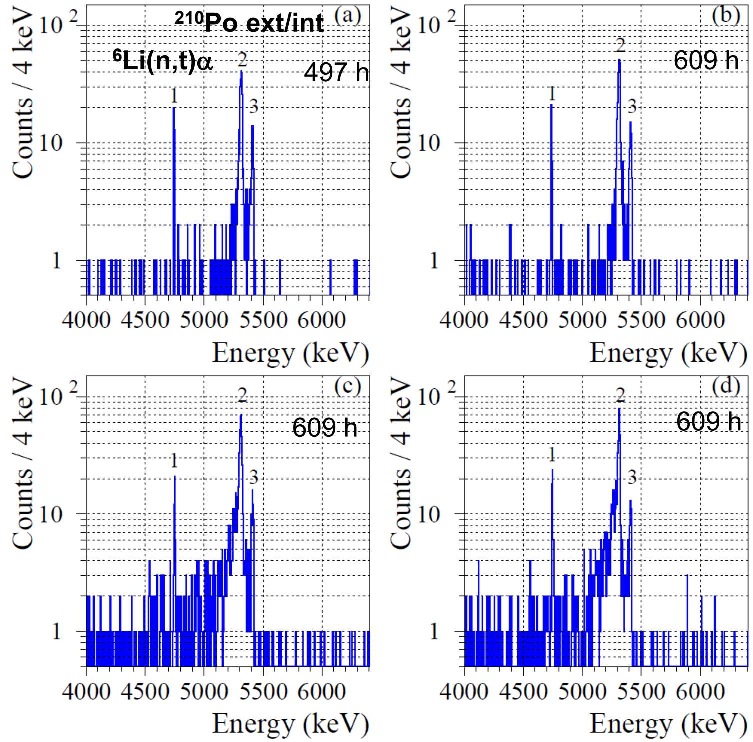
BINGO: 4-LMO-crystal array test

Efficient particle identification in the BINGO open structure & w/o NTL-LDs



	Light Yield for γ/β (keV / MeV)	Quenching Factor for α (%)
LMO-1	**0.22(3)**	15(3)
LMO-2	**0.25(3)**	12(2)
LMO-3	**0.24(4)**	17(1)
LMO-4	**0.22(4)**	17(2)

High radiopurity of BINGO LMOs



	α+t (cnts/d)	^{210}Po (μBq/kg)	^{226}Ra (μBq/kg)	^{228}Th (μBq/kg)
LMO-1	2.5(4)	137(17)	≤ **5**	**≤ 9**
LMO-2	2.2(3)	129(15)	≤ **8**	**≤ 8**
LMO-3	2.1(3)	117(14)	**≤ 10**	**≤ 10**
LMO-4	2.4(3)	113(14)	**≤ 13**	**≤ 10**

BINGO: cryogenic veto

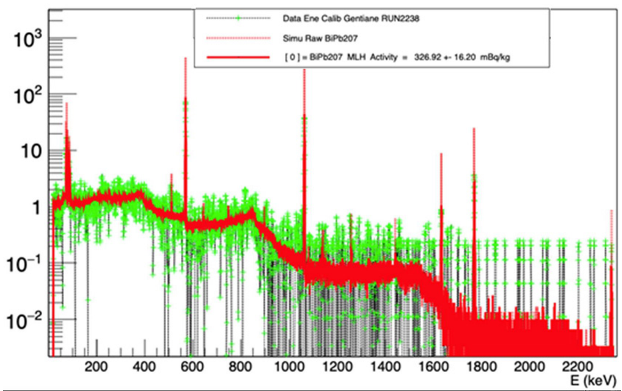
BINGO BGO-based veto development

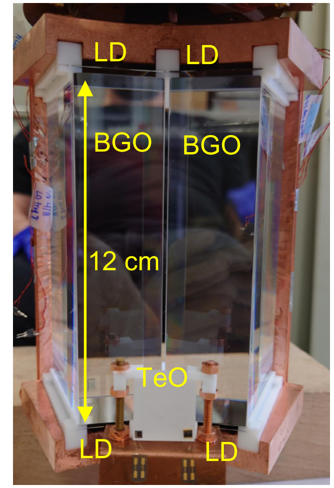
- Two prototypes made of large BGOs (w/ Ge LDs) facing TeO_2 / LMO bolometer (w/ U source on surface) were operated @IJCLab
- Ongoing optimization of light yield & structure
- Different BGOs were HPGe-screened @LSM & @CEA, a single bolometric module operated recently @LSC

⇒ BGOs with ^{207}Bi ~40 mBq/kg are produced by SICCAS

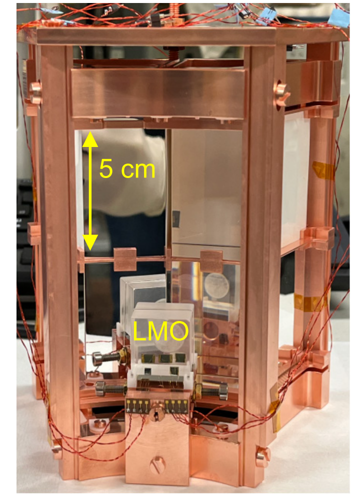
- Bi / BiO screening

⇒ BGOs with ^{207}Bi ~10 mBq/kg can be produced

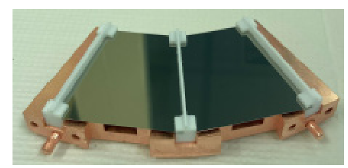


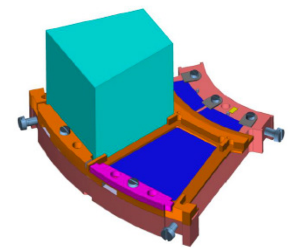


arXiv:2301.06946

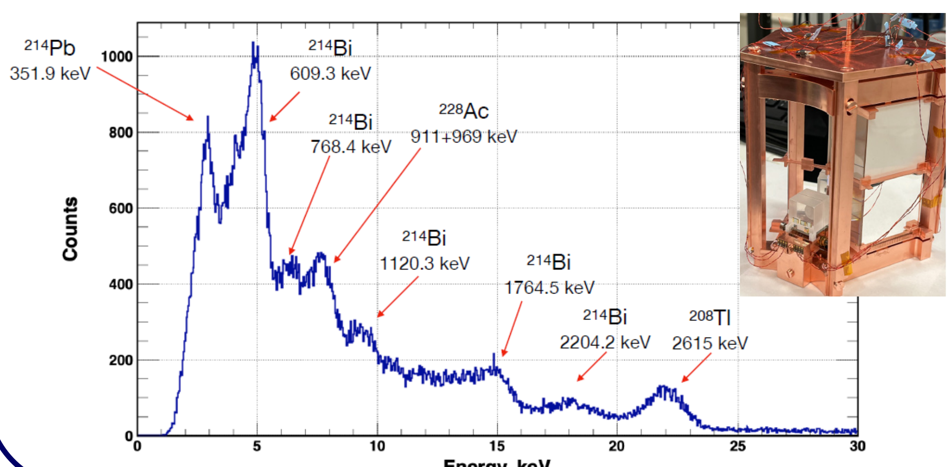


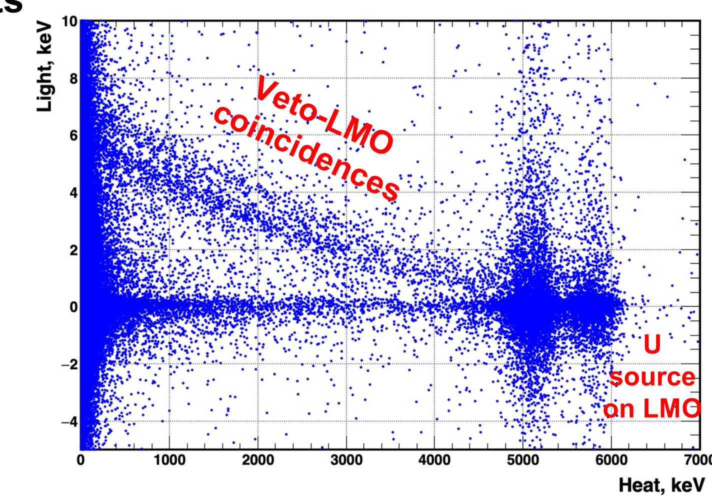
Paper in preparation





BINGO veto prototype results



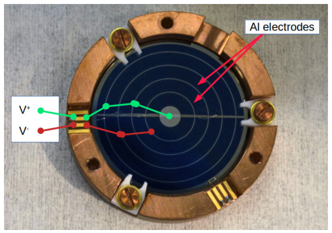


Paper in preparation

BINGO: light detectors with NTL effect

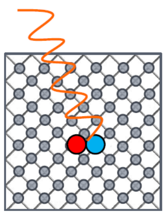
LDs assisted with Neganov-Trofimov-Luke

Circular electrode

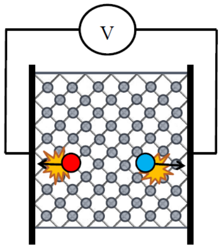


NIM A 940 (2019) 320

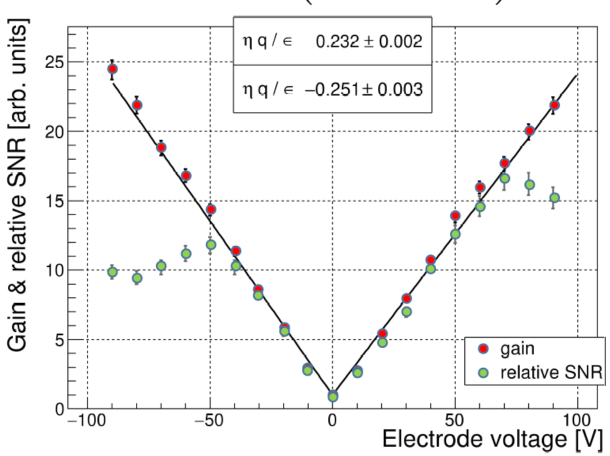
Ordinary LD



NTL LD

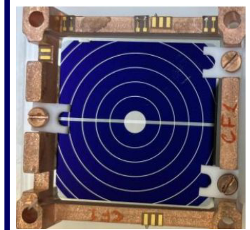


$$E_{tot} = E_0 \left(1 + \frac{q \cdot V_{el} \cdot \eta}{\epsilon}\right)$$

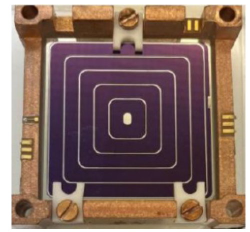


Several prototypes developed & tested @IJCLab (w/ CROSS)

Circular

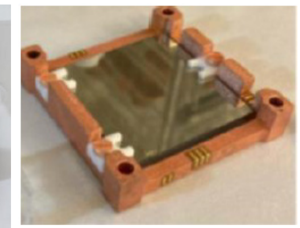


Square

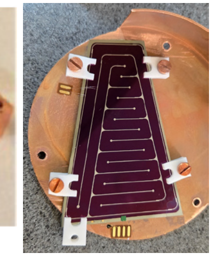


Spiral

Edge



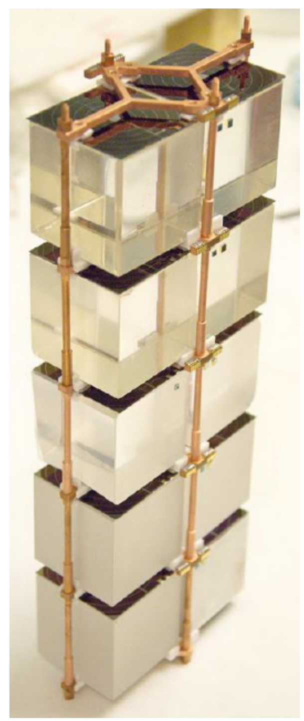
Zipper

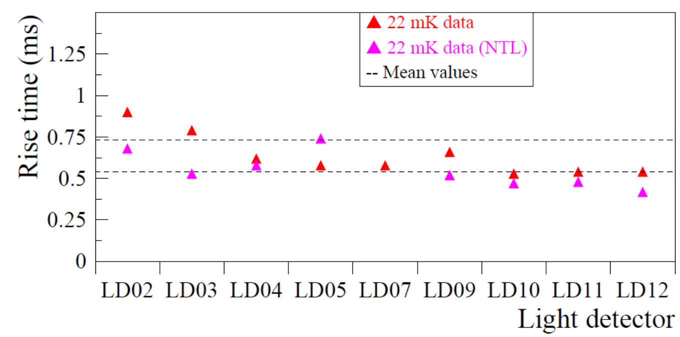


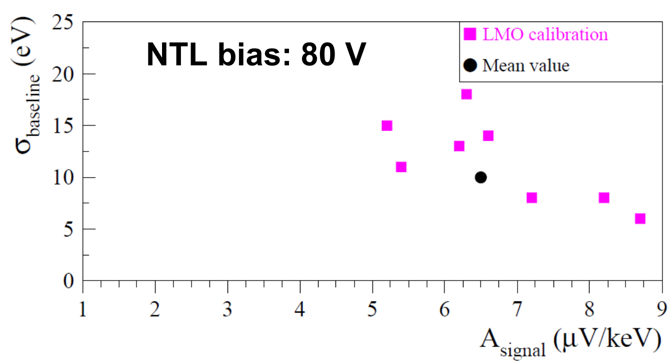
https://theses.fr/2023UPASP105

NEW

Demonstrator of 10x NTL-LD [Circular] @LSC





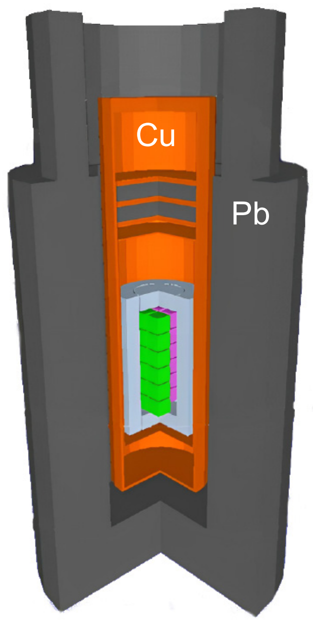


Paper in preparation

BINGO: Infrastructure @ LSM (France)

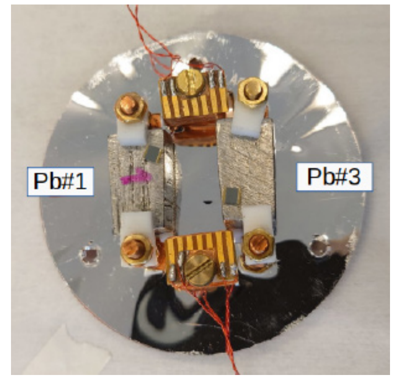
Pulse-tube cryostat installed at Modane underground laboratory

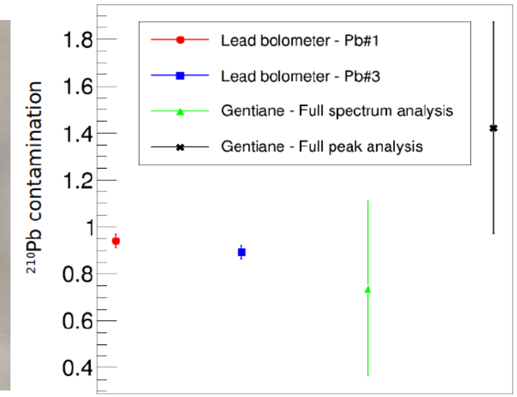
GEANT4 model of Mini-BINGO inside shields



Wiring, shielding and tests with BINGO modules will be realized in coming months

Screening of Pb (a stock @CEA) using **bolometric technique** (@IJCLab) & **HPGe** (@LSM)





https://theses.fr/2023UPASP105

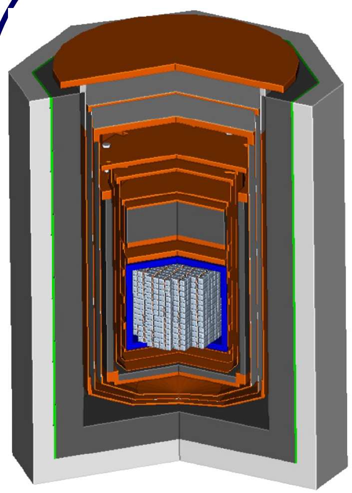
⇒ **Lead shield with low (~1 Bq/kg) ^{210}Pb activity** production is in progress

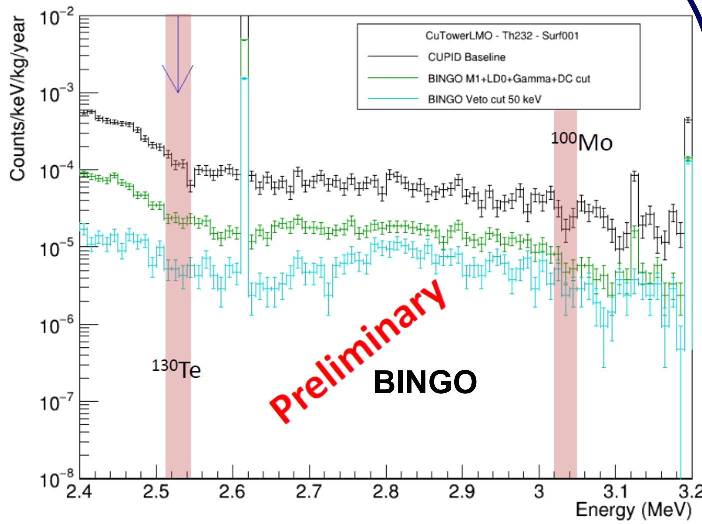
The cryostat commissioning @LSM (Sept. 2024)

9.5 mK achieved !

Prospects of BINGO for CUPID

BINGO GEANT4 MC in the CUORE shielding



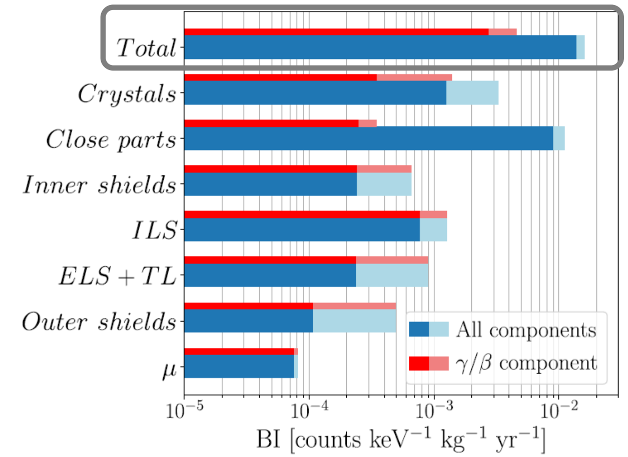


BINGO implemented in CUPID

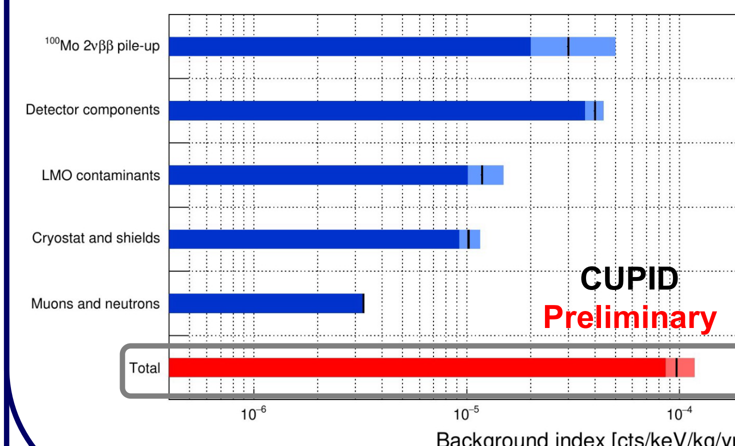
⇒ *O*(x10) reduction of surface induced background

Experiment in CUORE set-up	Main features	BI (ckky) in ROI
CUORE	CUORE structure, no PID, no muon/cryo veto	**~ 10^{-2}**
CUPID	CUPID structure, PID, muon veto	**~ 10^{-4}**
BINGO	BINGO structure, PID, muon & cryo veto	**< 10^{-5}**

CUORE & CUPID Bkg budget in ROI



arXiv:2405.17937



P. Loaiza @Neutrino-2024

Summary

- **BINGO proposes innovative methods to reach BI ~ 10^{-5} ckky in large-scale bolometric $0\nu2\beta$ searches** (like CUPID), to probe the effective Majorana neutrino mass at a few meV.
- **Innovative detector assembly** with a polyamide-wire support for large-volume cubic crystals (LMO & TeO_2) has been developed & tested in aboveground / underground pulse-tube cryostats, showing good performance.
- Proof-of-concept of a **cryogenic veto** has been demonstrated in abovergound measurements with large BGO crystals with a bolometric scintillation readout in anti-coincidences with a small LMO / TeO_2 bolometer.
- Several designs of **Neganov-Trofimov-Luke light detectors** (w/ different electrode coverage) have been developed & tested. A demonstration test of 10 NTL-LDs with circular electrodes was carried out @LSC. R&D on such devices is ongoing to optimize the NTL amplification.
- **MINI-BINGO demonstrator** with 12-crystal towers of LMO / TeO_2 scintillating bolometers is in preparation @LSM (France). A dedicated pulse-tube cryostat has been commissioned underground reaching ~10 mK. Stay tuned for more updates!

B I N G O

http://www.bingo-neutrino.eu