BINGO and TINY

towards next - next generation bolometric experiments for $0\nu\beta\beta$ decay searches

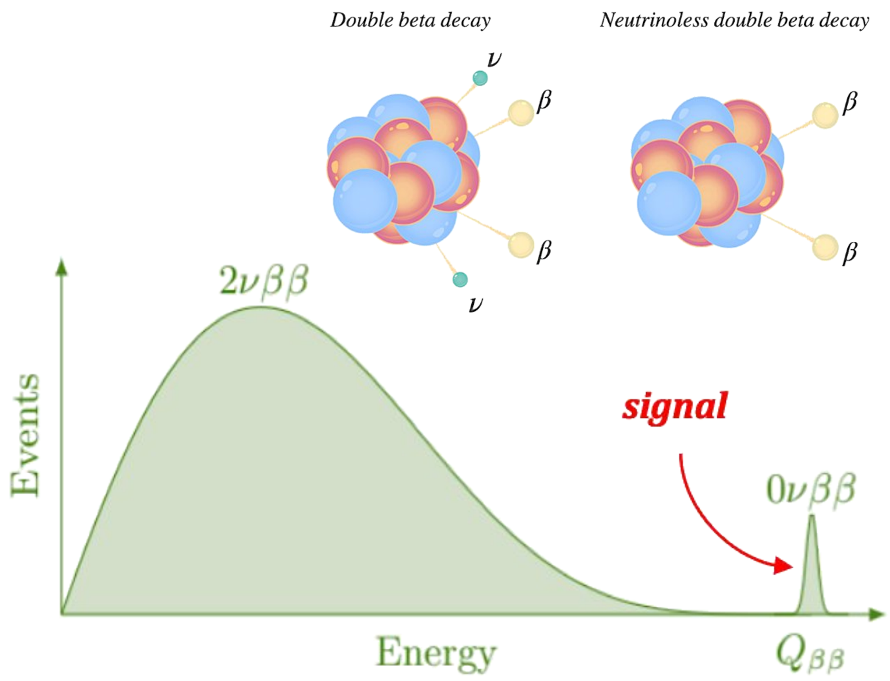
Assemblée Générale du GDR DI2I, 18/06/2026

Sara Vesce on behalf of the BINGO and the TINY collaborations

$0\nu\beta\beta$ decay

Experimental challenges:

- big mass
- low background at the ROI
- high resolution at the ROI



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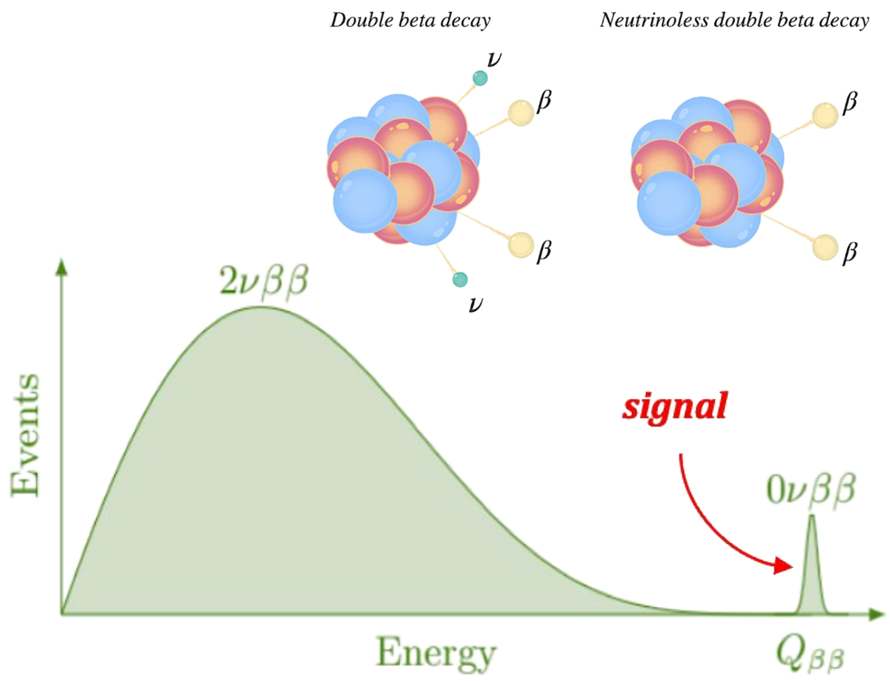

How to address these challenges?

$0\nu\beta\beta$ decay

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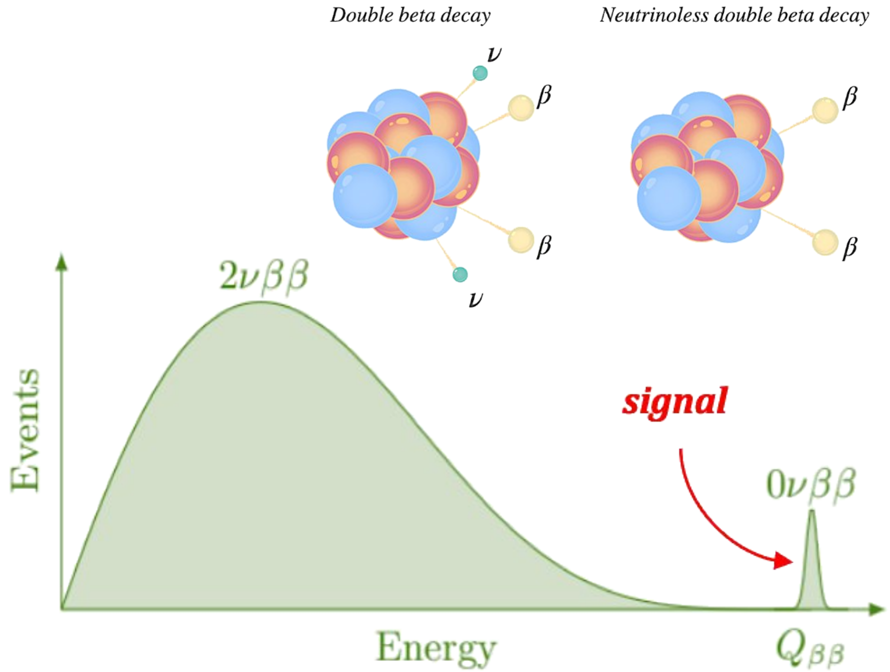
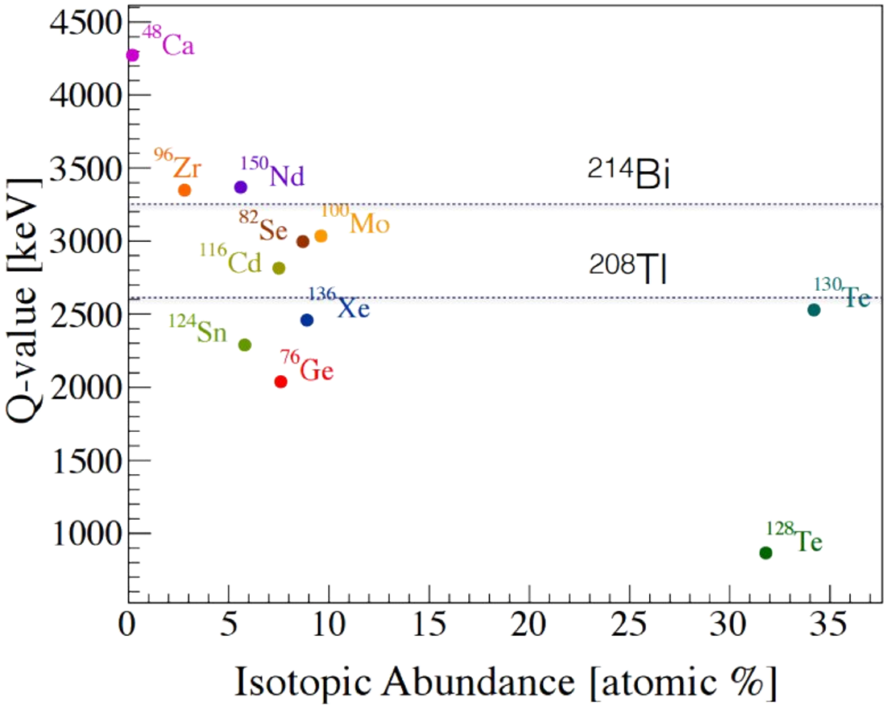


Isotope choice:

- high natural isotopic abundance (or possibility for enrichment)
- high $Q_{\beta\beta}$ value



$0\nu\beta\beta$ decay

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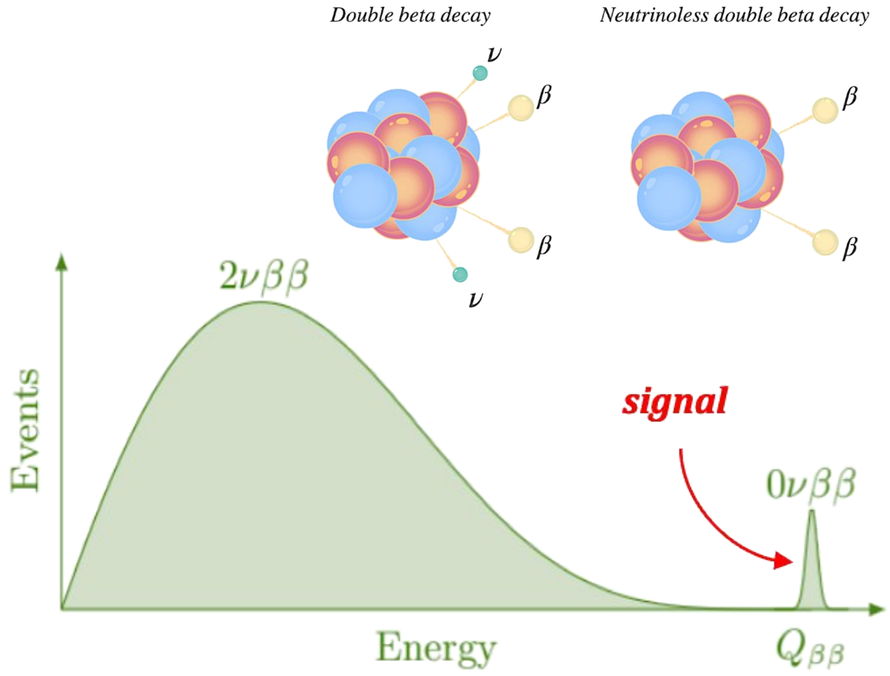
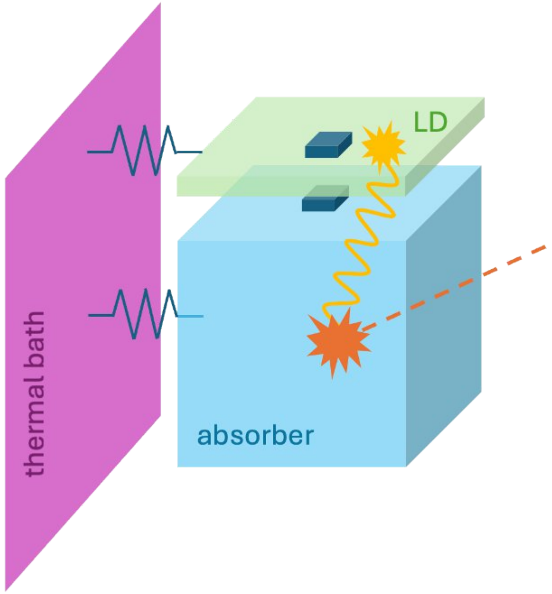
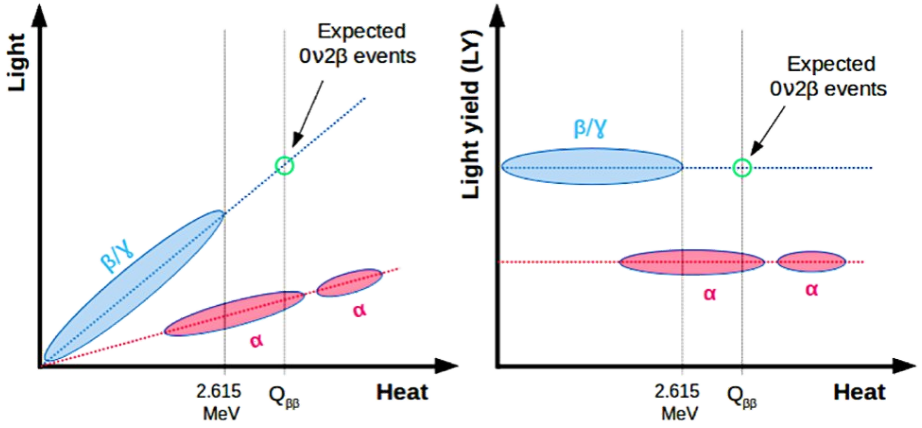


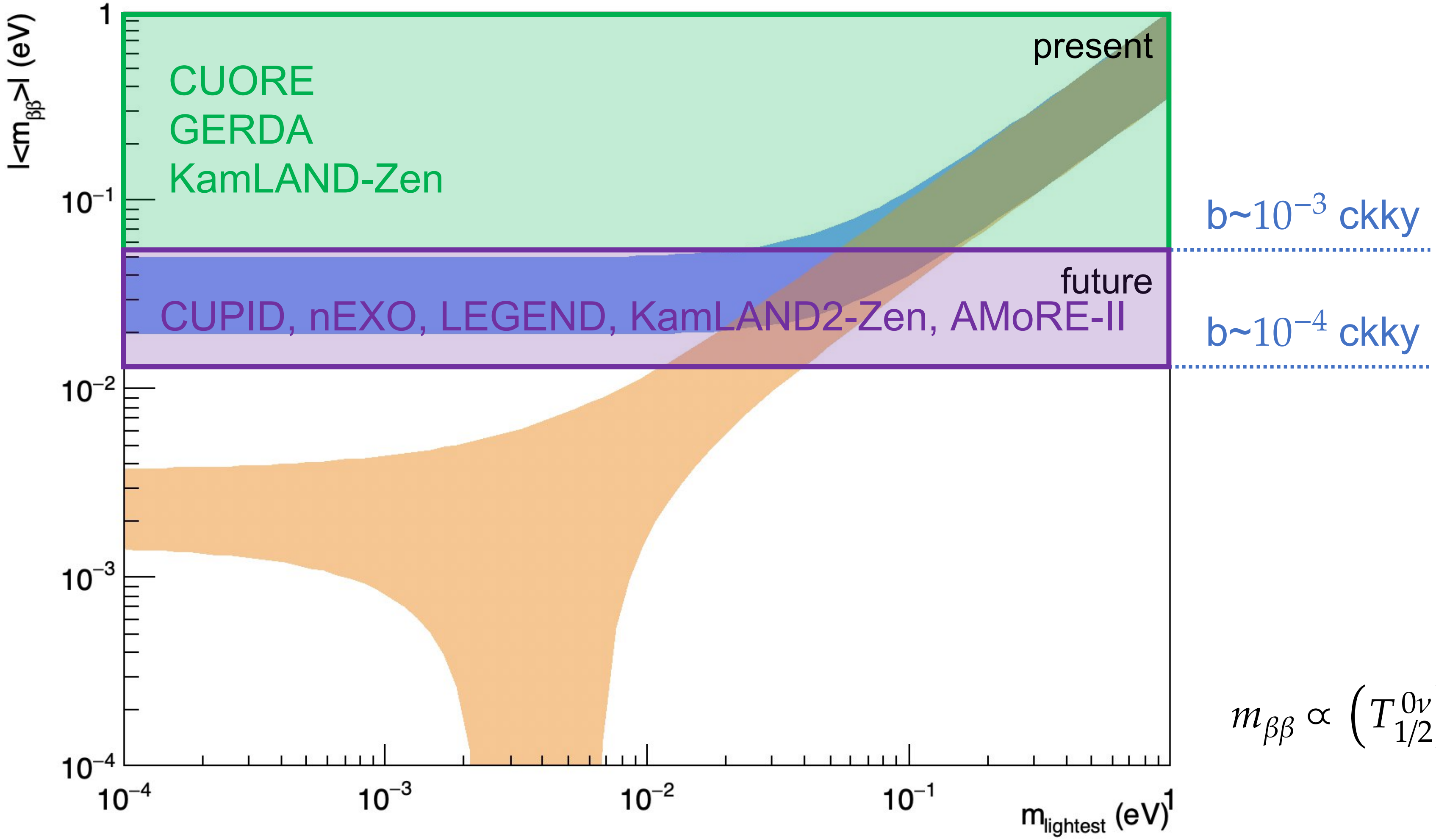
Detection technique:

- scintillating bolometers - dual readout



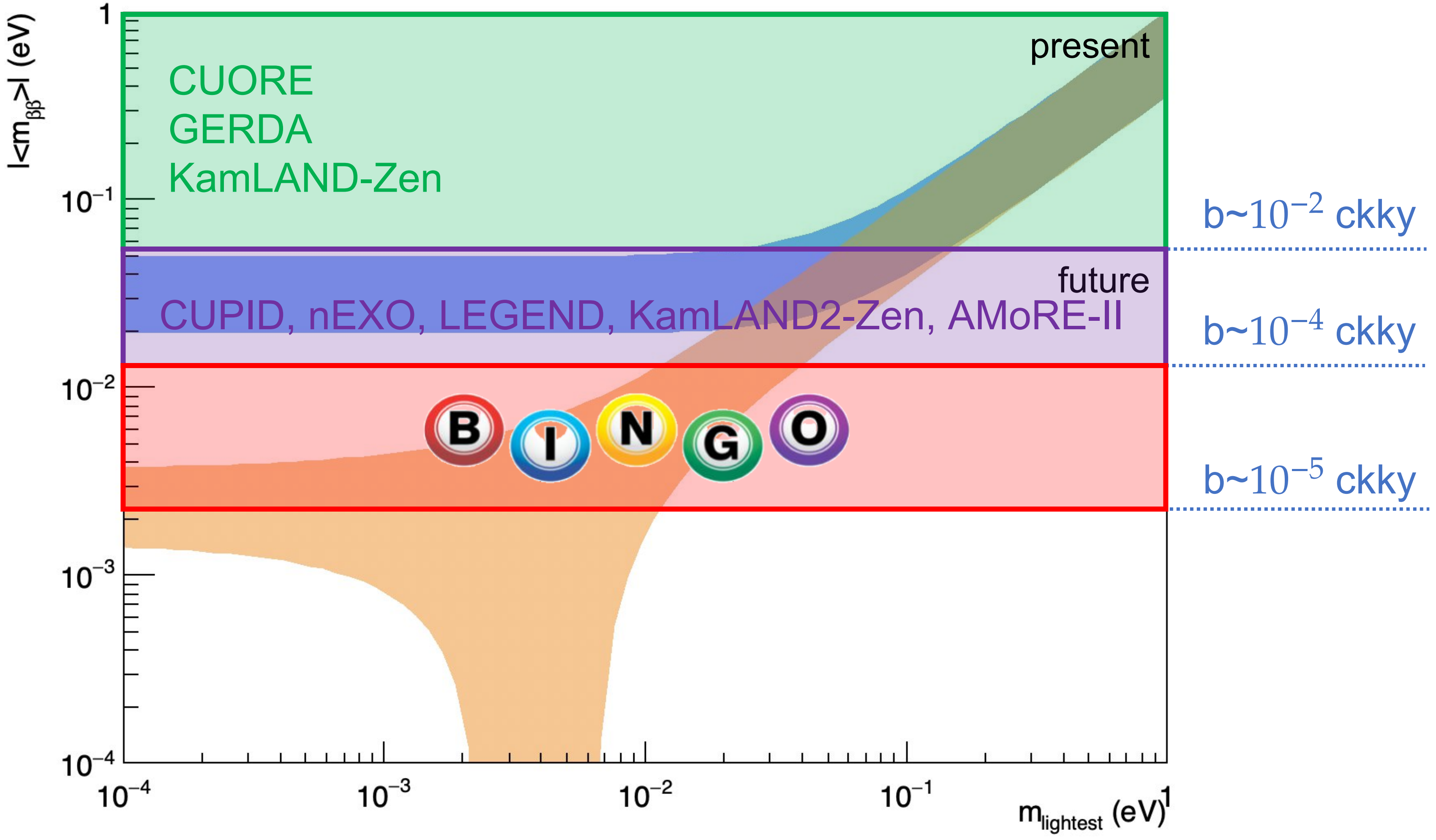


Where are we?



$$m_{\beta\beta} \propto \left(T_{1/2}^{0\nu}\right)^{-1/2} \propto b^{1/4}$$

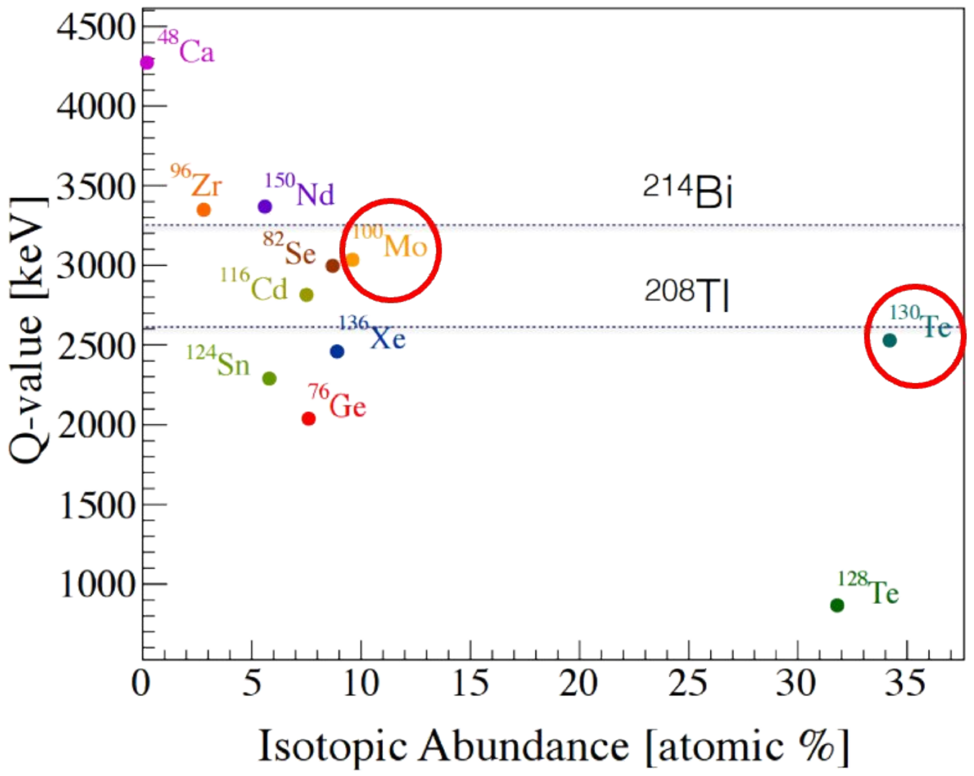
BINGO: Bi-Isotope 0νββ Next Generation Observatory

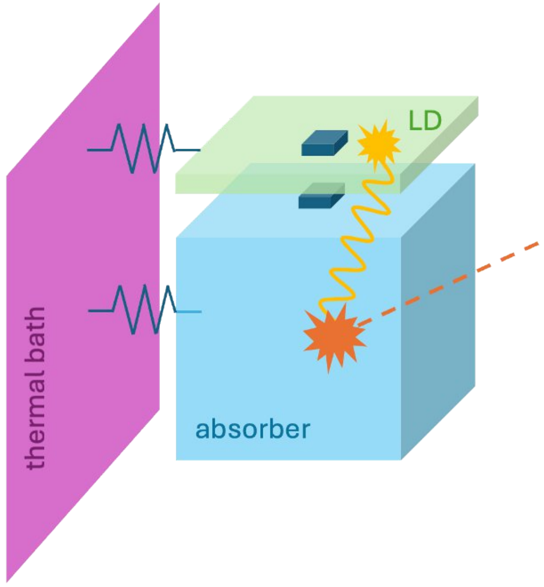


How?

Key features

- **scintillating bolometers (TeO_2 and Li_2MoO_4)**
- low radioactivity for all selected materials
- minimisation of passive materials
- BGO cryogenic veto
- Neganov-Trofimov-Luke enhanced light detectors





^{130}Te

- ✓ validated (CUORE)
- ✓ excellent energy resolution
- ✓ high internal radiopurity
- ✓ high natural abundance

- – $Q_{\beta\beta}$ below 2615 keV
- – very low light output

^{100}Mo

- ✓ validated (CUPID-Mo)
- ✓ excellent energy resolution
- ✓ high internal radiopurity
- ✓ $Q_{\beta\beta}$ above 2615 keV

- – $2\nu\beta\beta$ background in the ROI

How?

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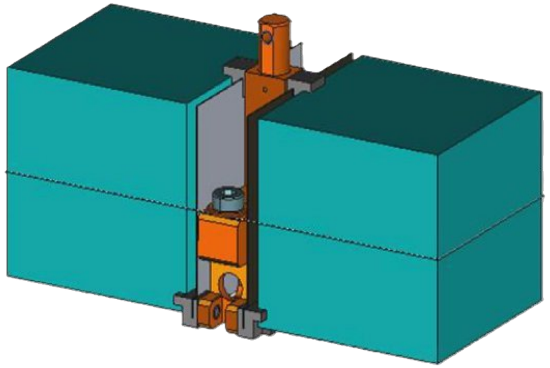
How to address the background?

How?

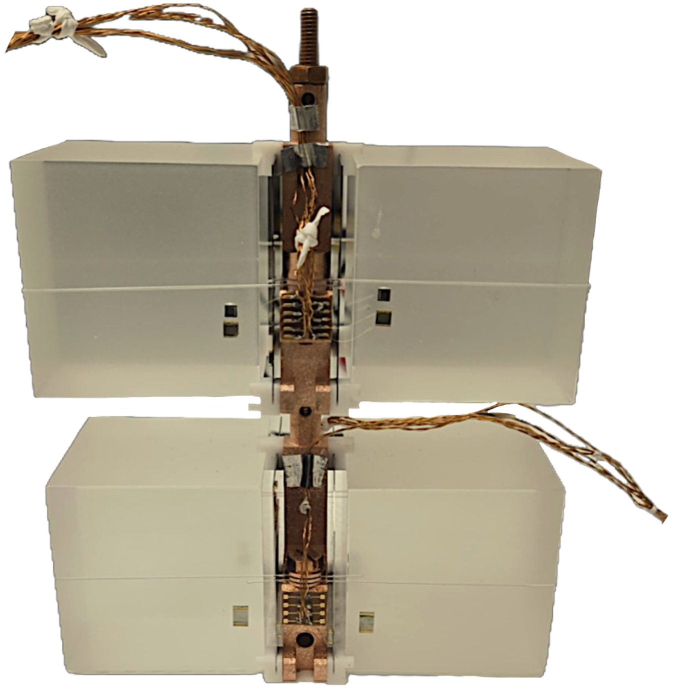


nylon-wire assembly

Key features

- scintillating bolometers (TeO_2 and Li_2MoO_4)
- **low radioactivity for all selected materials**
- **minimisation of passive materials**
- BGO cryogenic veto
- Neganov-Trofimov-Luke enhanced light detectors

✓ less passive materials
✓ crystal sees nothing except LD surface
✓ compact assembly
✓ no additional noise induced



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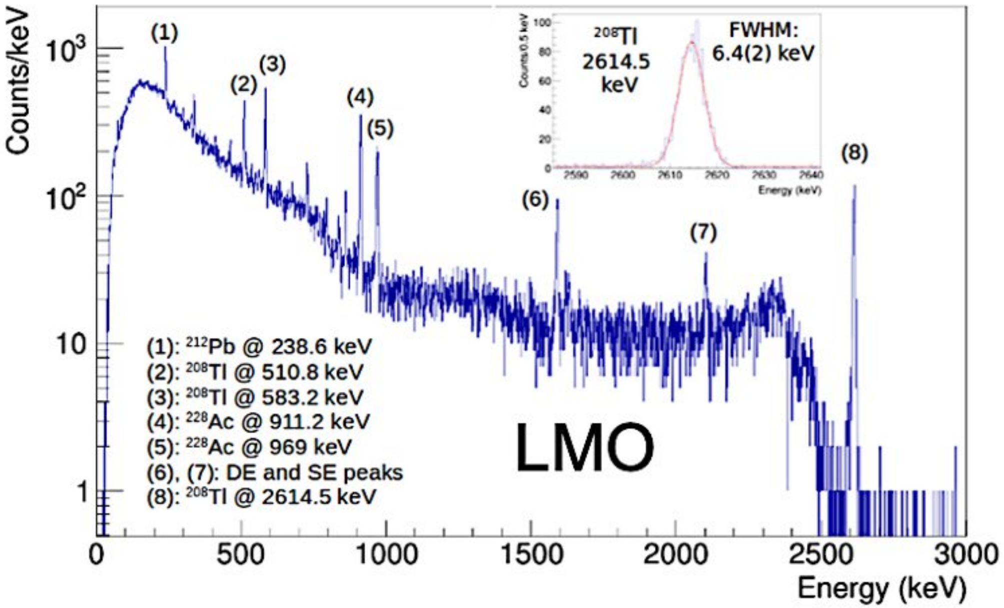
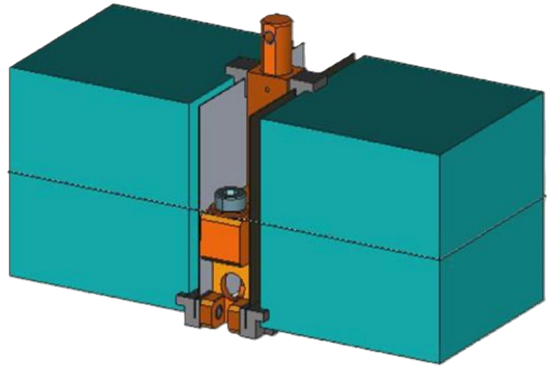


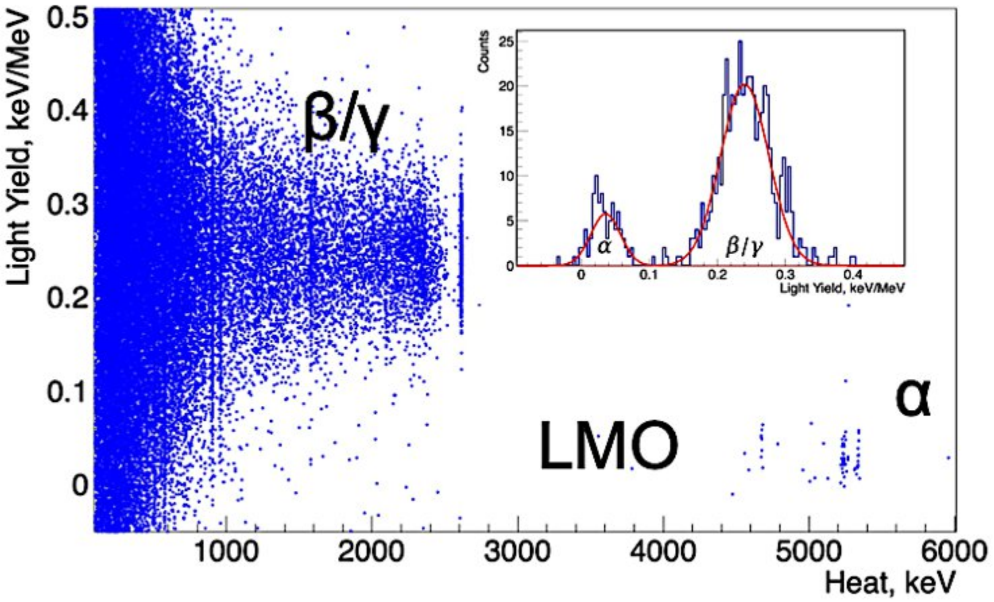


nylon-wire assembly

Two modules of Li_2MoO_4 tested and validated at LSC

- ~6keV FWHM at 2.6 MeV
- good discrimination between α and β/γ

no NTL enhanced results



status:
tested and validated

How?

Key features

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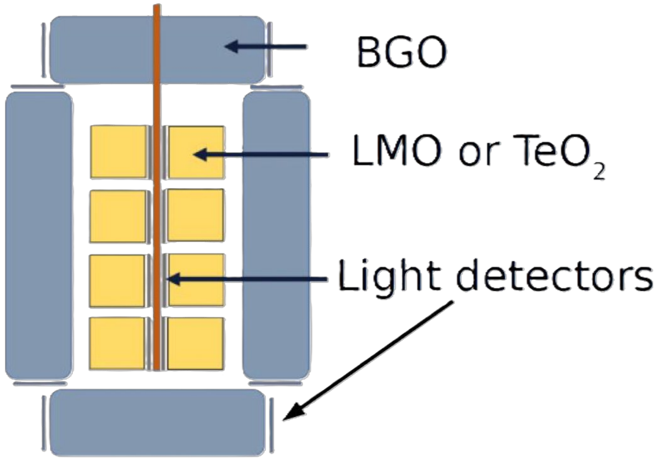
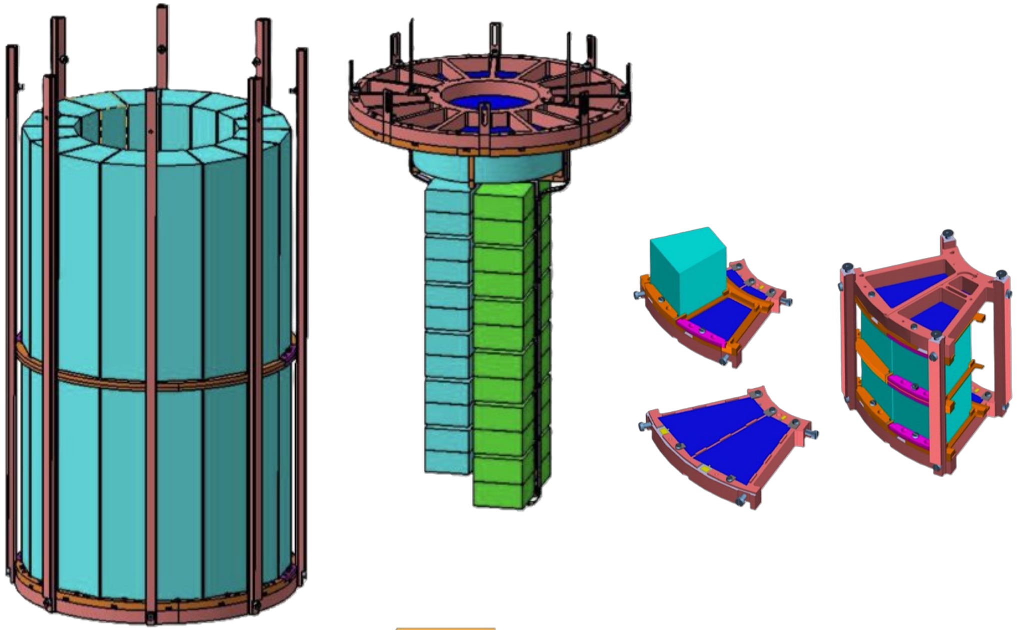
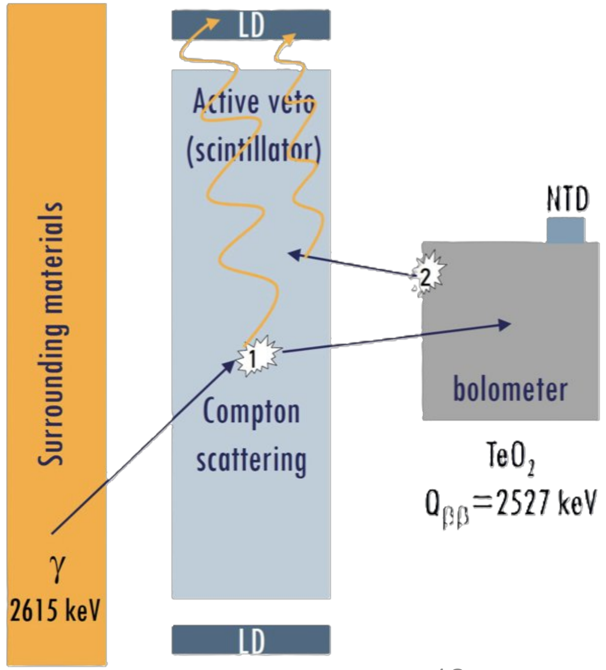
- **BGO cryogenic veto**
- Neganov-Trofimov-Luke enhanced light detectors

- scintillators (BGO) with 4π coverage





- ✓ suppression of external γ background
- ✓ rejection of surface contamination events



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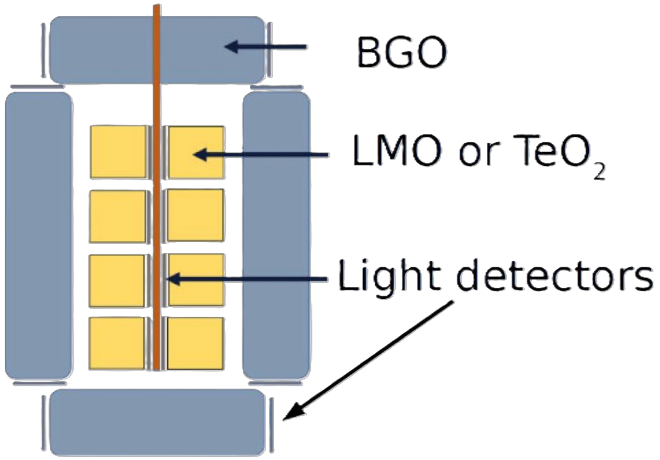
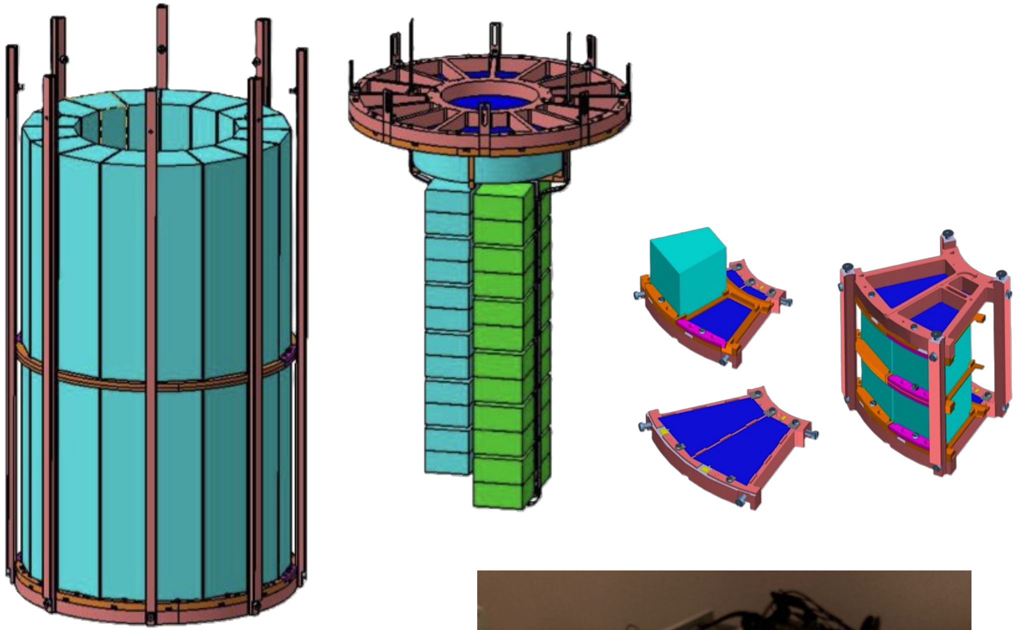
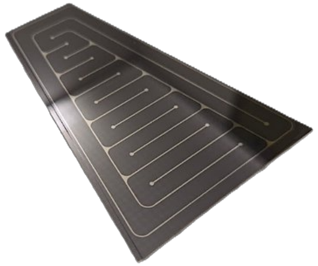


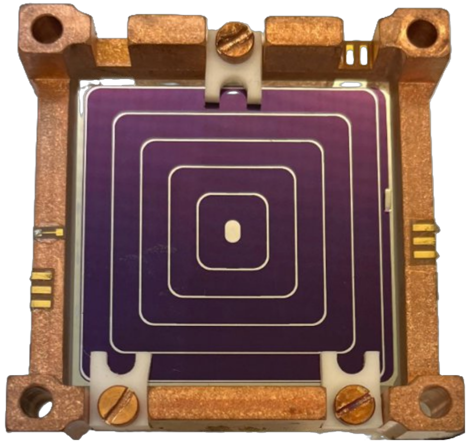


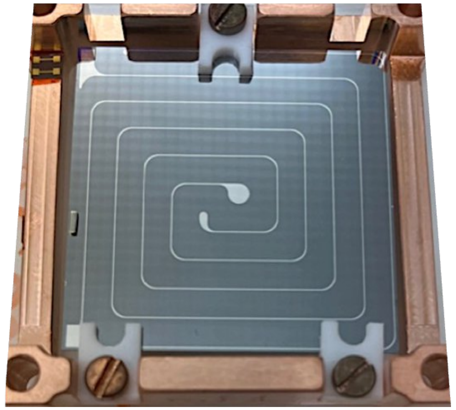
status:
trapezoidal LDs: tested and validated

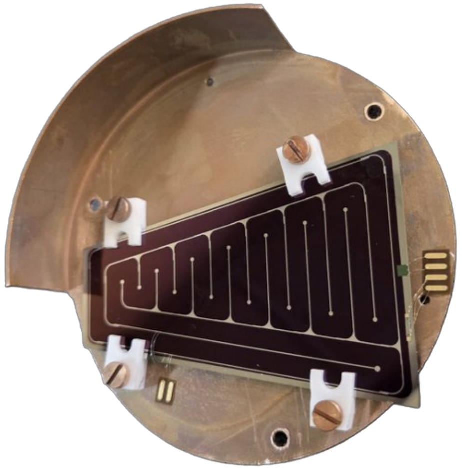
crystals: ready for integration pending crystal availability



How?







Key features

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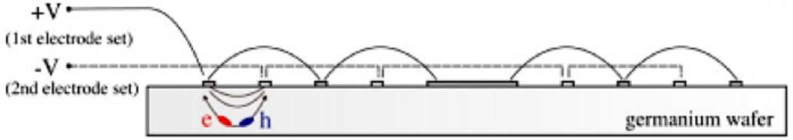
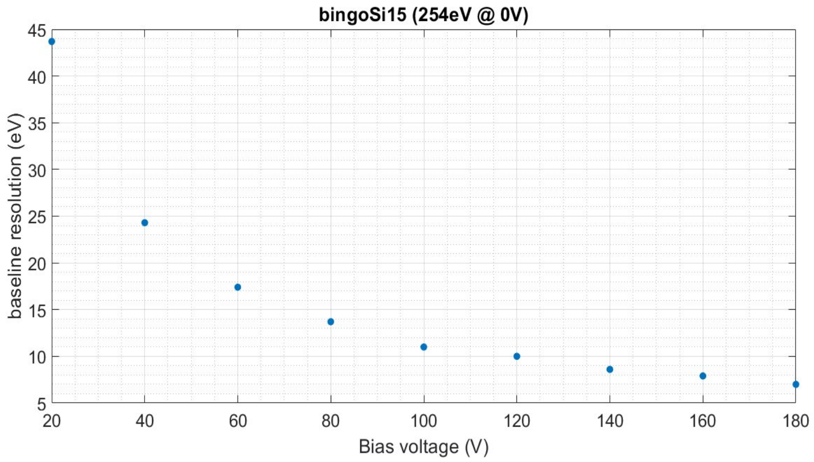
- low radioactivity for all selected materials
- minimisation of passive materials
- BGO cryogenic veto
- **Neganov-Trofimov-Luke enhanced light detectors**

- different electrodes geometry tested to increase the surface coverage
- at 0V: <100 eV RMS bsl resolution
- at 50-150V NTL bias: 12 eV RMS bsl resolution

- cryogenic validation of trapezoidal LDs for the veto
- at 140V NTL bias: effective gain of 15



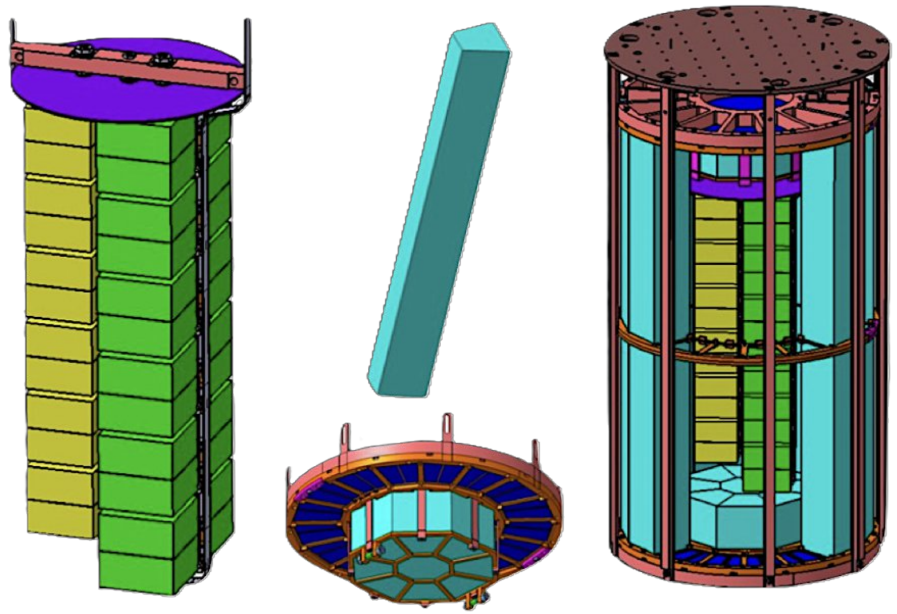


status: validated

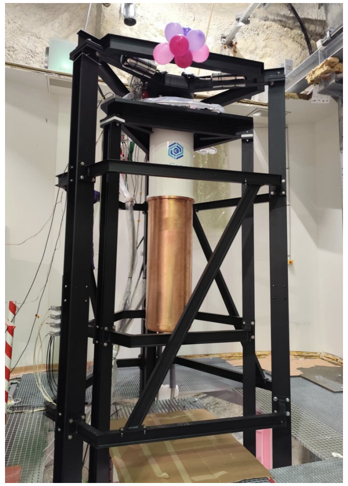
MINI - BINGO demonstrator at LSM

towers
12 LMO (45x45x45 mm)
12 NTL square LD (45x45 mm)
12 TeO_2 (50x50x50 mm)
12 NTL square LD (50x50 mm)

cryogenic veto
32 long trapezoidal BGO (23 cm)
32 NTL trapezoidal LD
16 short trapezoidal BGO (5 cm)
2 octagonal BGO

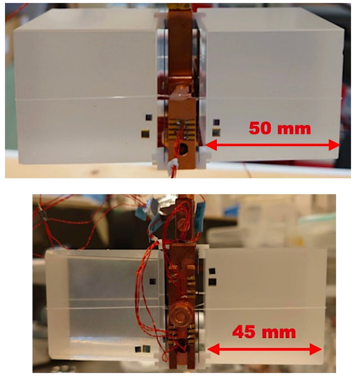


total demonstrator mass: 170 kg



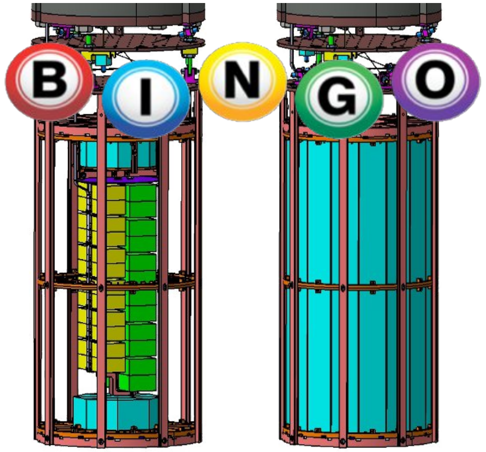
cryostat fully commissioned

temporary Pb shield installed



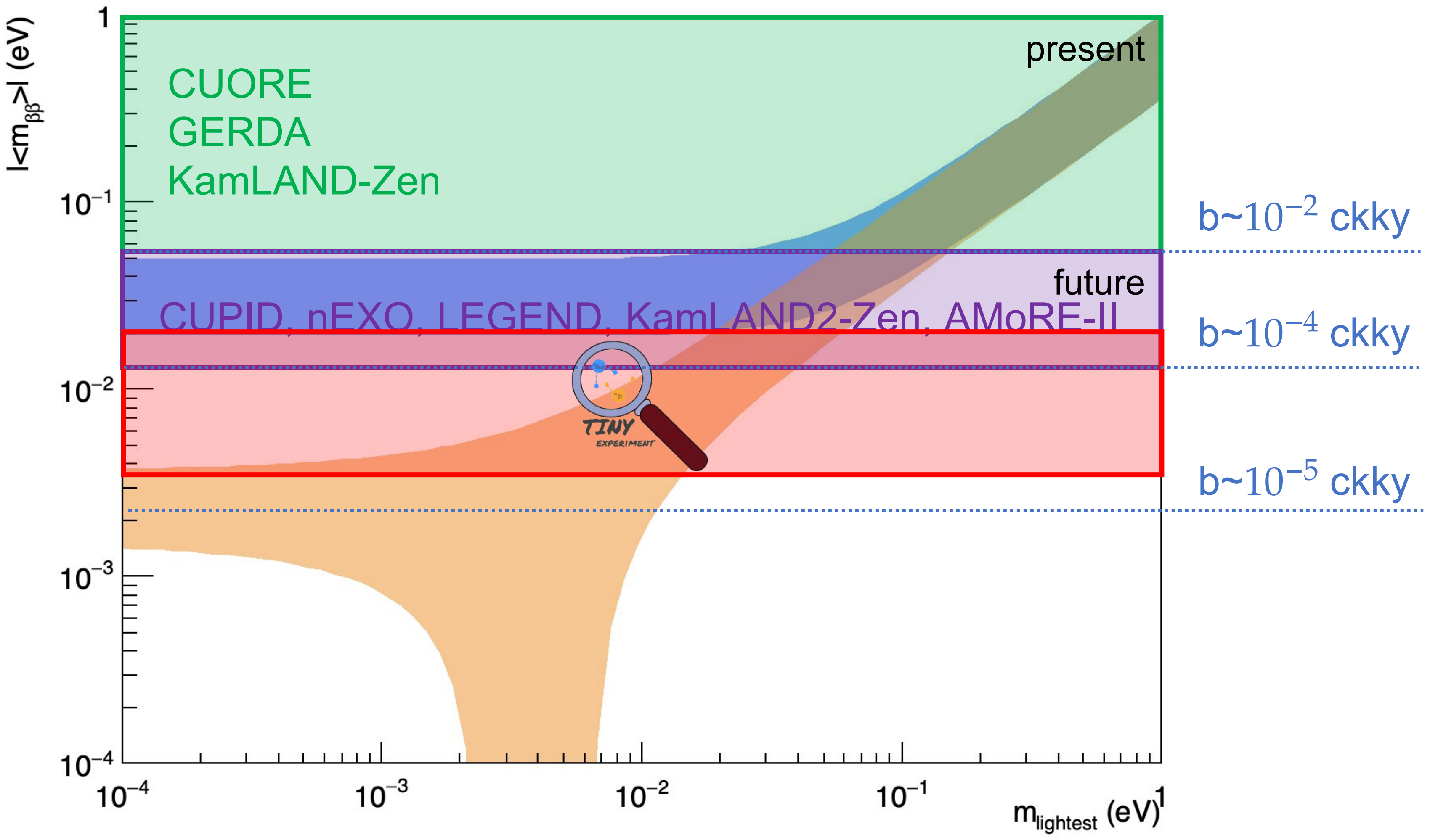
LMO/TeO modules validated

Spring 2026: lifting system, full Pb shield and clean room installed



Autumn 2026: commissioning of the demonstrator & physics run

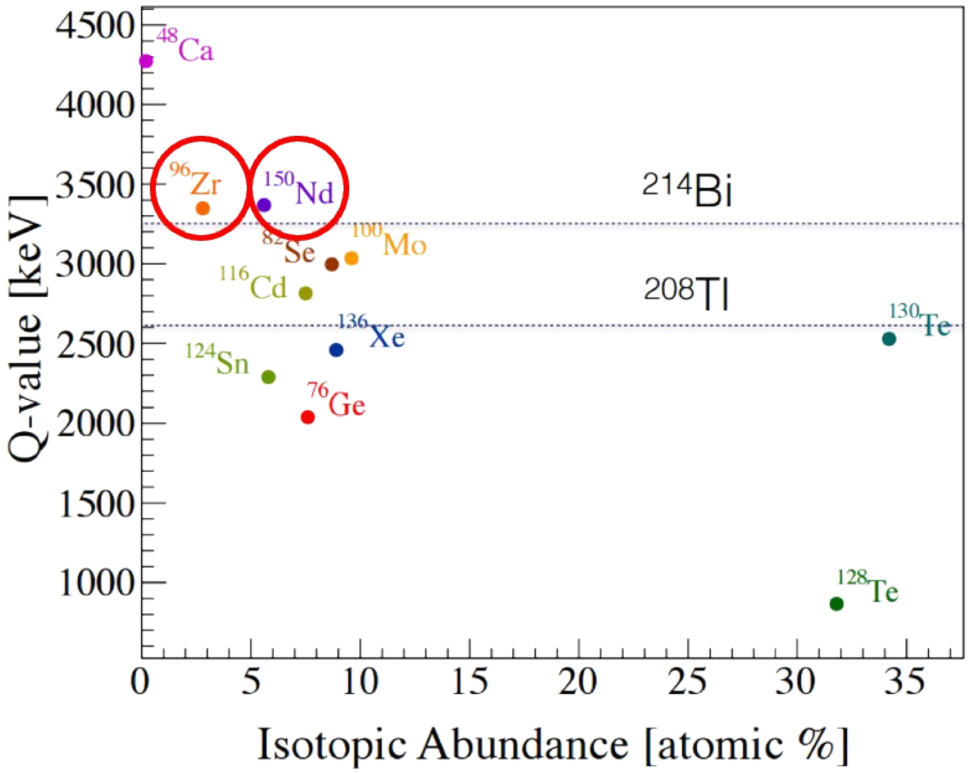
TINY: Two Isotopes for Neutrinoless double beta decaY search

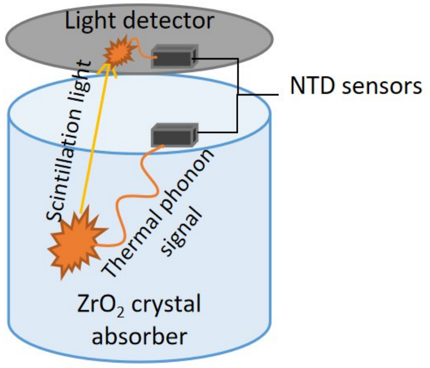


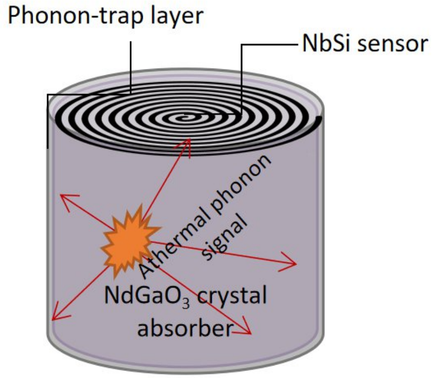
How?

Main focus

- **Zr and Nd isotopes**
  - Nd crystals and NbSi sensors
  - scintillating bolometers based on Zr







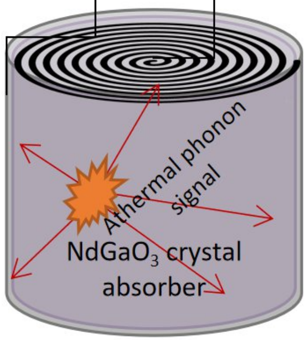
^{96}Zr

- ✓ $Q_{\beta\beta}$ above 3270 keV
- ✓ PID through scintillation
- – enrichment not commercially available on a large scale
- – R&D ongoing for validation

^{150}Nd

- ✓ $Q_{\beta\beta}$ above 3270 keV
- ✓ PID through PSD
- – magnetic material
- – R&D ongoing for validation

How?



Nd is **magnetic**

→ NTD sensors not viable

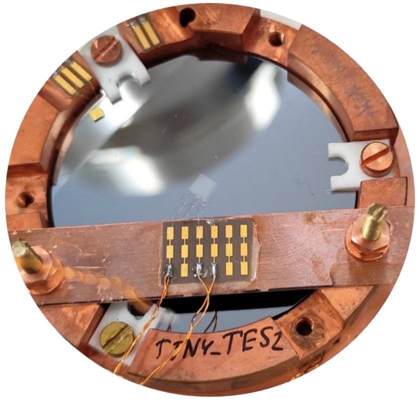
→ first step: production and validation of of **NbSi sensors** on Si wafers

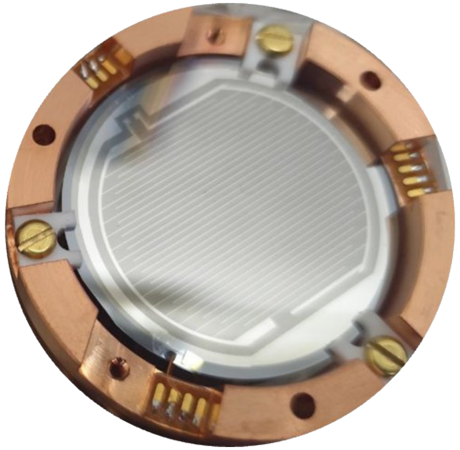
- successfully used in both TES and Anderson insulator regime in the past (https://doi.org/10.1007/s10909-022-02899-2, http://doi.org/10.1007/s10909-008-9764-z)

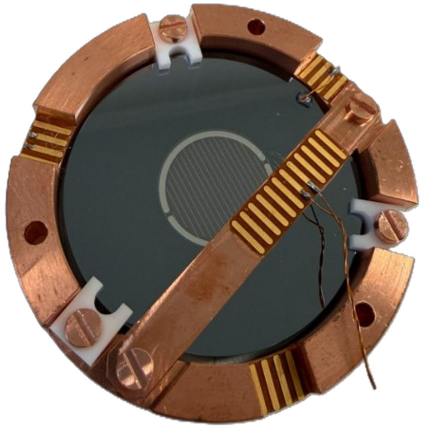
Main focus

- Zr and Nd isotopes
  - **Nd crystals and NbSi sensors**
  - scintillating bolometers based on Zr

- several tests performed with different geometries and production techniques
- technological problems in reproducing the previous evaporation conditions in terms of homogeneity







status: evaporator will undergo a major upgrade,
meanwhile production with a sputtering machine → will be tested soon

How?

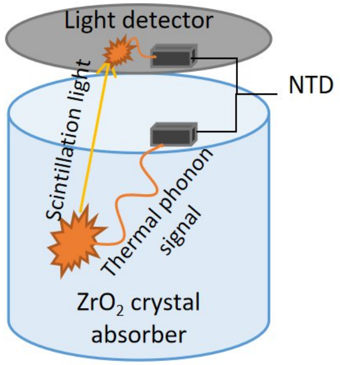
Main focus

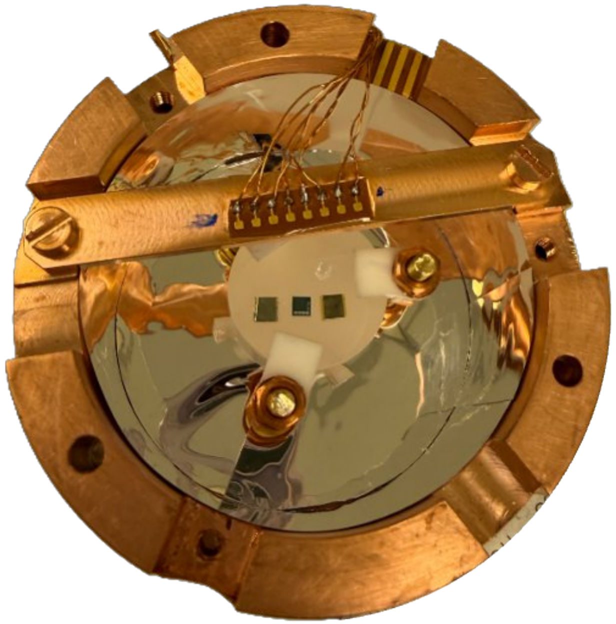
- Zr and Nd isotopes
  - Nd crystals and NbSi sensors
  - **scintillating bolometers based on Zr**

$\varnothing$20x20 mm, 20.4 g
highly hygroscopic

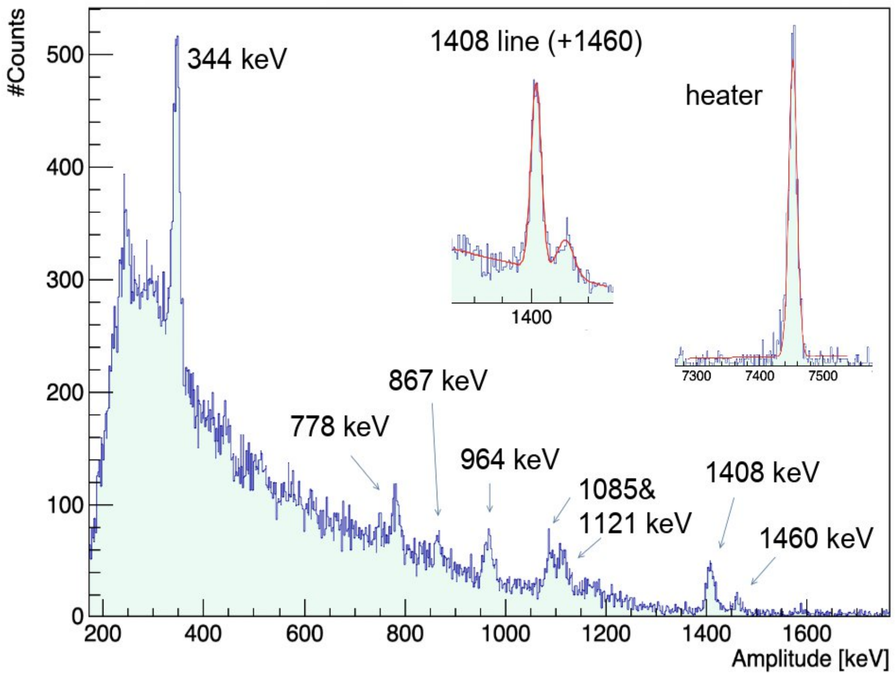
Cs_2ZrCl_6 (CZC): a promising candidate

- measured before as scintillator (https://iopscience.iop.org/article/10.1088/1748-0221/19/05/P05037/pdf)
- module tested and validated in CEA cryogenic facility as scintillating bolometer





sensitivity (90 nV/keV)
bsl resolution (6.2 keV sigma)



How?

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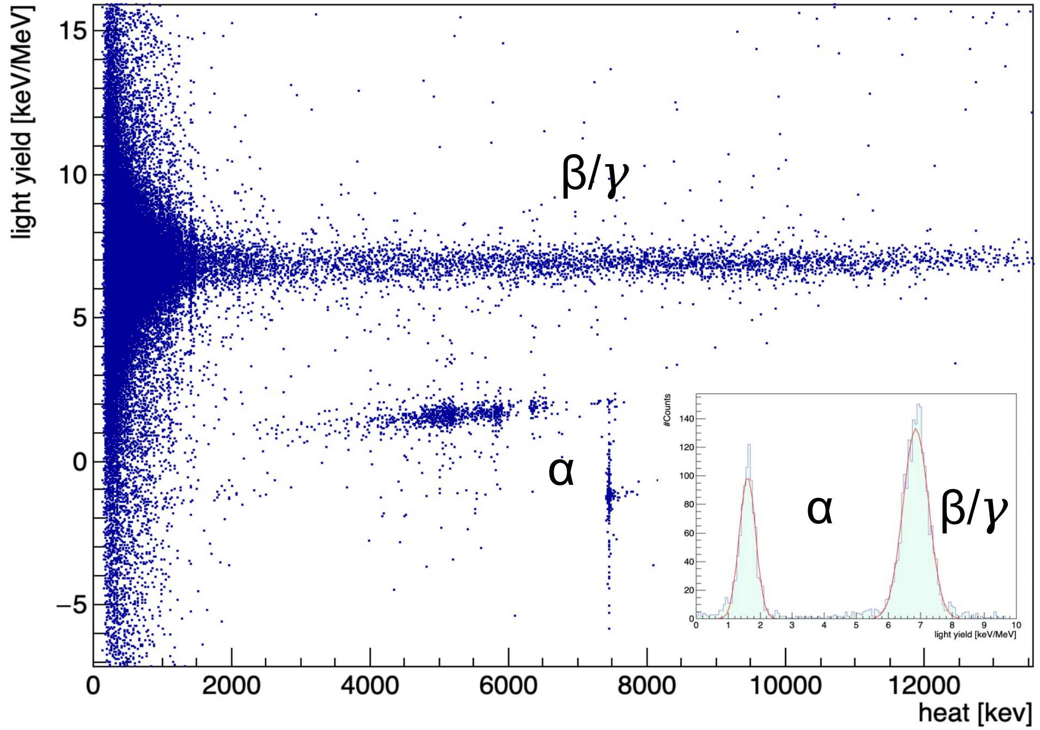


Main focus

- Zr and Nd isotopes
  - Nd crystals and NbSi sensors
  - **scintillating bolometers based on Zr**

- excellent scintillation (LY ~ 7 keV/MeV for β/γ, ~ 1.7 keV/MeV for α)
- excellent discrimination between α and β/γ (DP 13.4)

status:
larger and purer CZC under production;
underground measurement in LSM;

article in preparation

Conclusions

- The search for 0νββ decay is one of the most compelling and sensitive probes of neutrino physic
- Current and next generation experiments will reach sensitivities of O(10) meV to effective Majorana mass

- Both BINGO and TINY projects propose innovative methods to start the exploration of the normal hierarchy region towards higher sensitivities for next-next generation experiments

BINGO

DEMO
- MINI-BINGO demonstrator will be operative from autumn 2026
- background index achievable: b~10^{-4} ckky in 1 year of lifetime

R&D
- assembly, cryogenic veto and NTL enhancement validated
- simulations ongoing to evaluate the background achievable by a ton-scale experiment with this technology

TINY

DEMO
- background index achievable: b~10^{-3} ckky in 1 year of lifetime
- precision measurement of $2\nu\beta\beta$ spectra for both Zr and Nd

R&D
- viable option with Zr-based crystal assessed - bigger crystals for underground measurements
- work in progress to obtain a robust athermal phonon sensors technology
- Nd-based crystal viability to be confirmed

Thank you for your attention!

Backup slides

Simulations for BINGO

With a view to the mini-BINGO demonstrator, an intense background simulation work has started

Objectives:

- Calculate BI in the ROI considering known backgrounds
- Assess the experiment's sensitivity
- Reduce background by applying event selections across different detectors

Input of the simulation:

- Energy deposited in each detector within a time window
- Δt between energy deposits
- Multiplicity among detectors

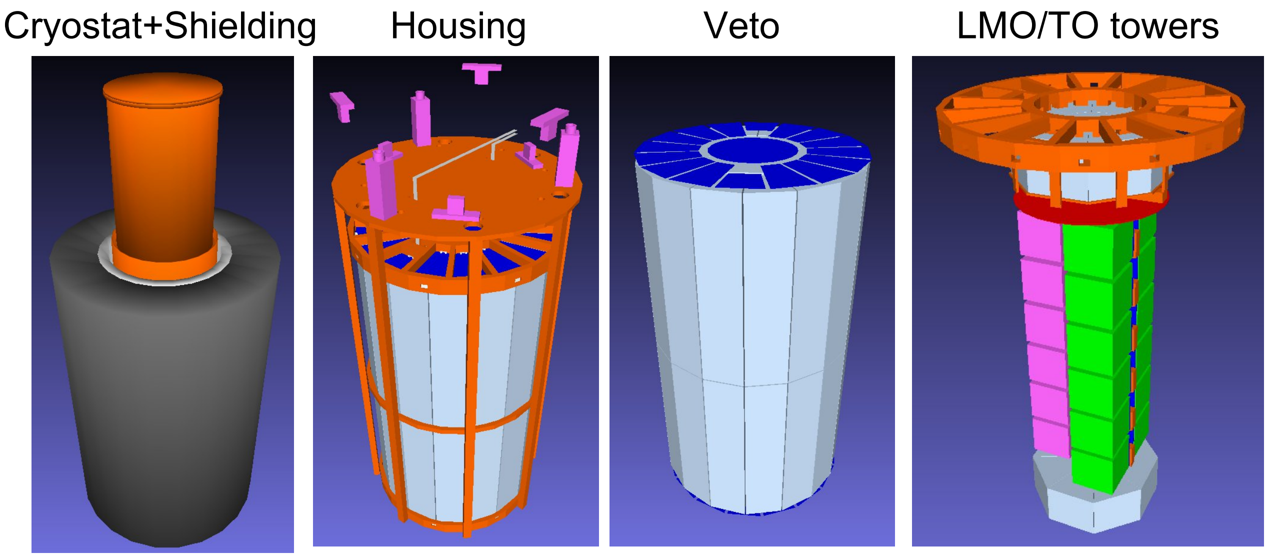
Example of simulation: 1e9 decays of K40 homogeneously distributed in BGOs

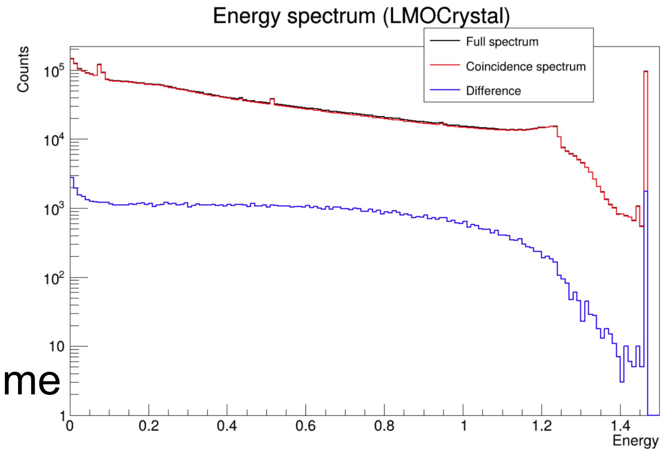
- Energy spectrum built for LMO and TeO2 crystals
- In coincidence and in anticoincidence with BGOs

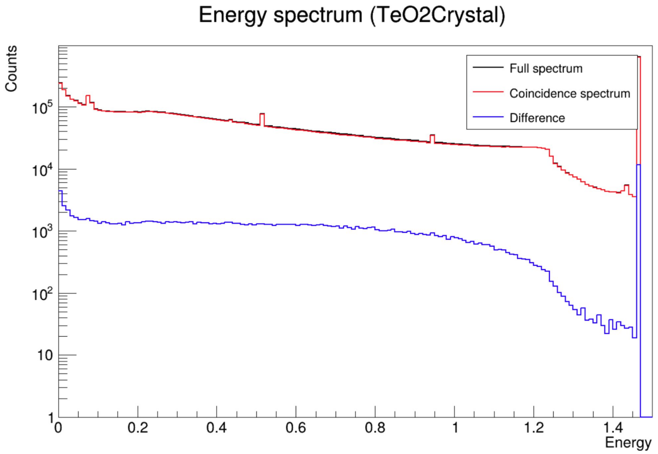
90 % of simulations already done

Next steps :

- Ragrupate bkg contributions originated in the same volume
- Build contribution spectra and assess BI



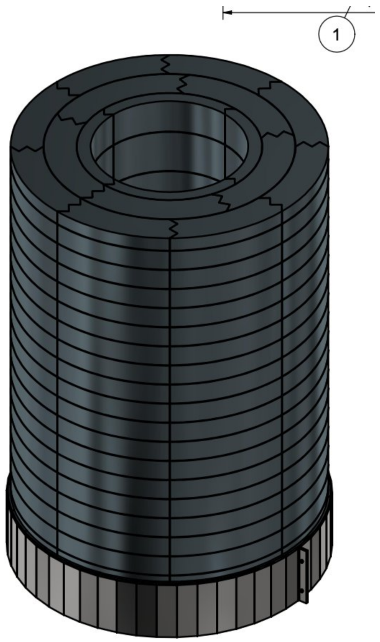


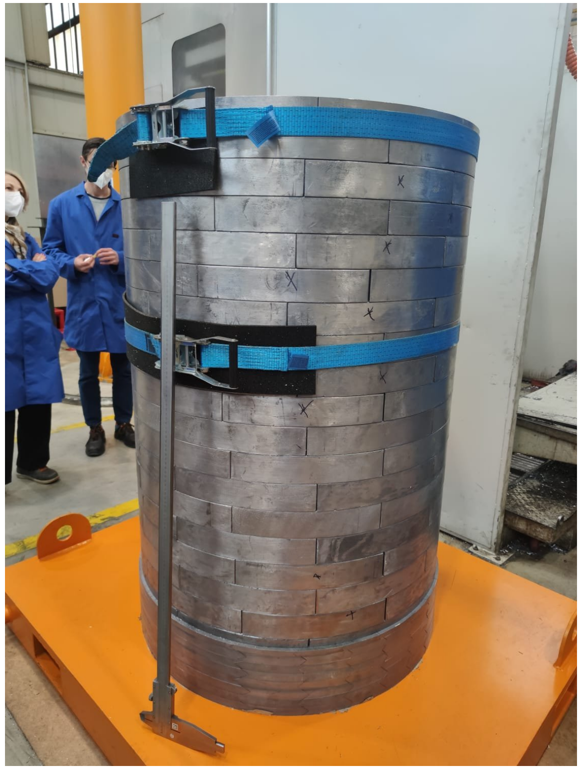


BINGO: Pb shielding

- The external lead shield consists of two separate
- cylinders with total thickness of 230mm + 5mm
- gap between two layers.

- 5 cm of Pb < 10 Bq/kg
- 15 < 50 Bq/kg





$0\nu\beta\beta$ decay rate

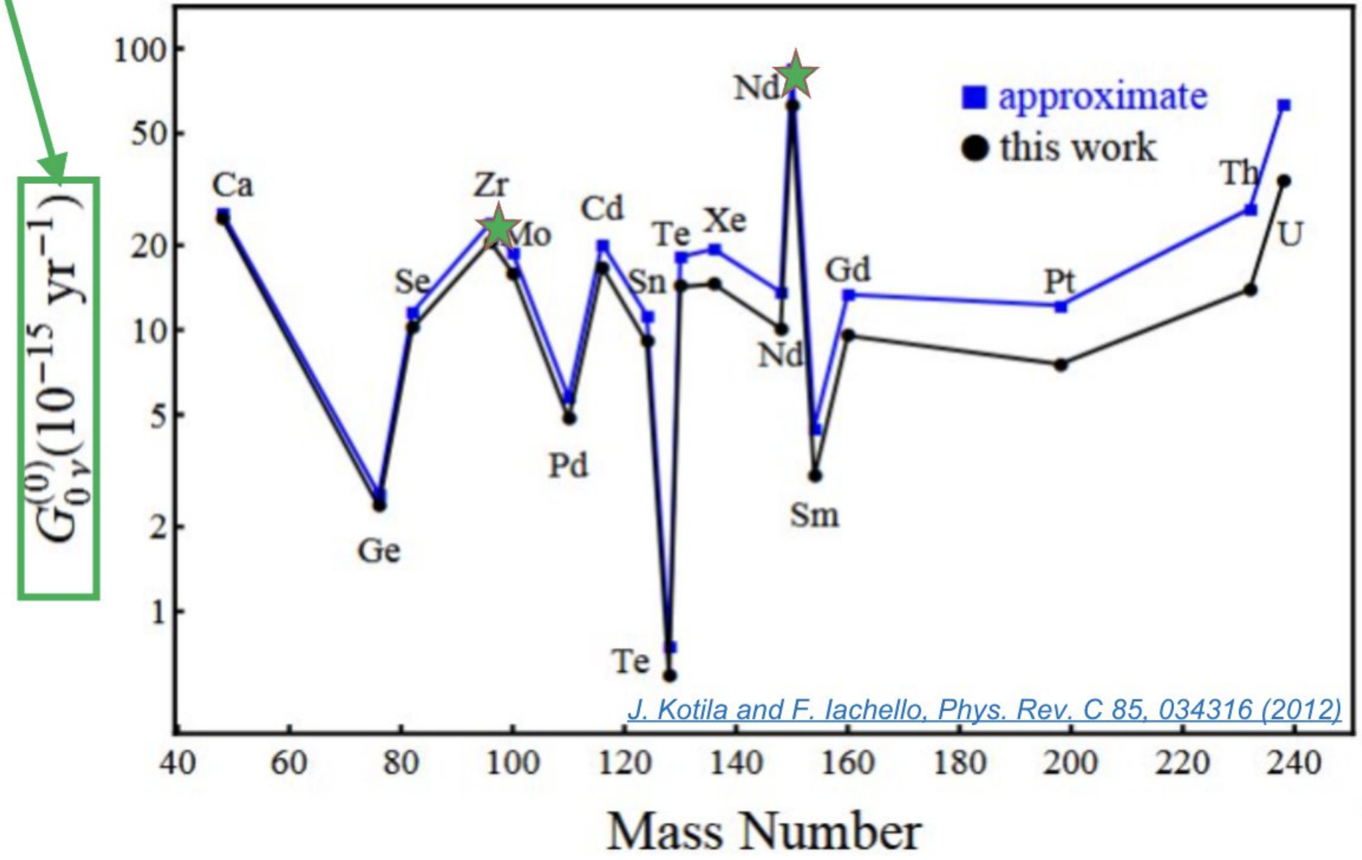
Effective Majorana mass - the unknown

$$(T_{1/2}^{0\nu 2\beta})^{-1} = G(Q,Z) g_A^4\, |NME|^2 \langle m_{\beta\beta} \rangle^2$$

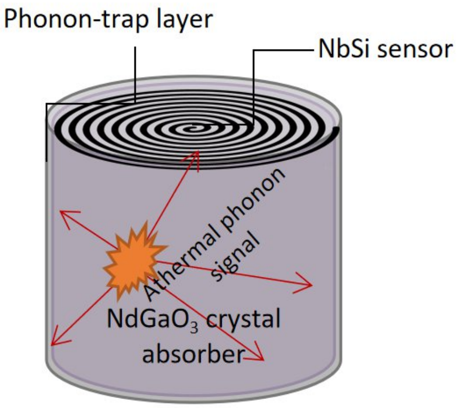
Phase space factor

Observable

Process is allowed in 35 nuclei → **only few are interesting** for experiments



Nd



Nd is **magnetic**

→ NTD sensors not viable:
tests performed on $\mathrm{NdGaO_3}$ crystals
very long cool-down, high heat capacity, low sensitivity

Main focus

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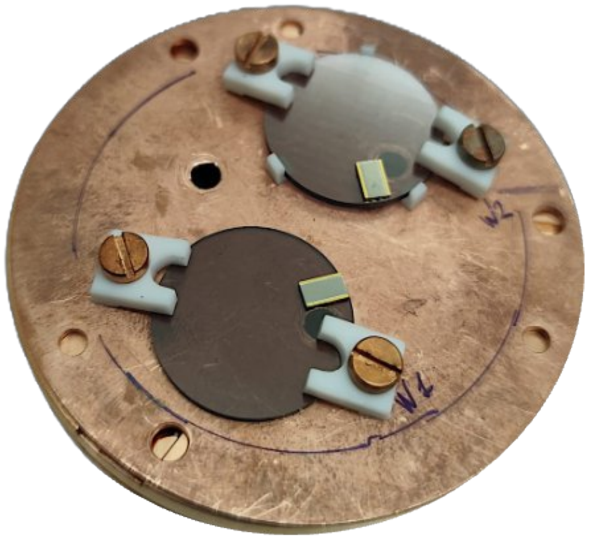
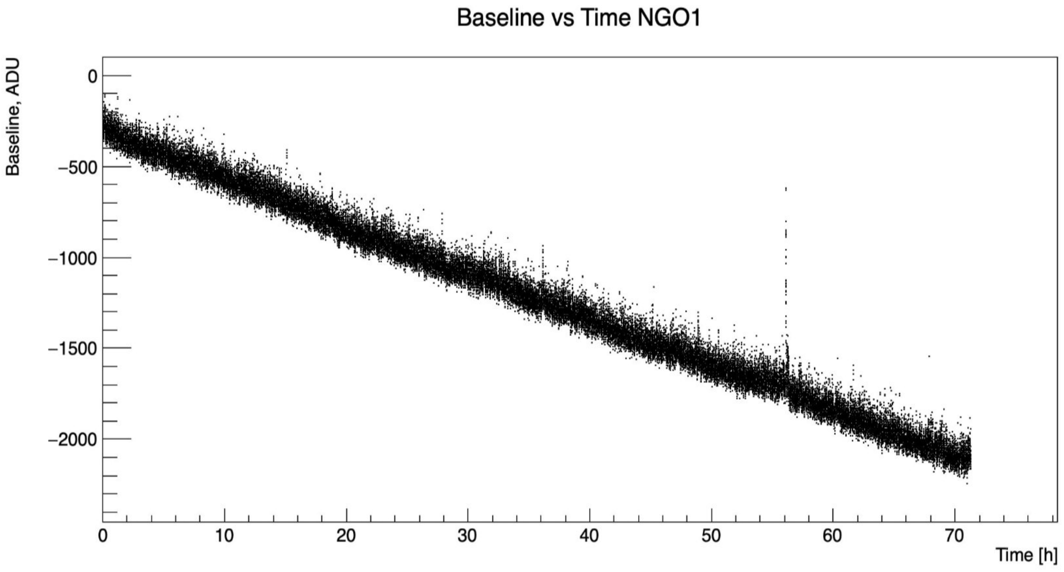
  - **Nd crystals and NbSi sensors**
  - scintillating bolometers based on Zr





→ move to athermal phonon sensors

Zr enrichment

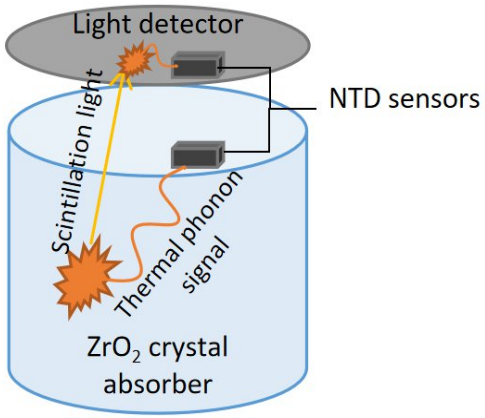
- Only russian company (ISOTOPE)so far provides the gas centrifugation enrichment: high yield, reasonable costs.

- Problematics: highly flammable gaz, high cost of R&D to set up the production.
  No other companies are interested in development of Zr enrichment without big investment and plans for large production so far.
- TINY demonstrator can confirm this need, in case of scaling of experiment to 100 kgs or more. But detector technology comes first in this case, to justify the investments.

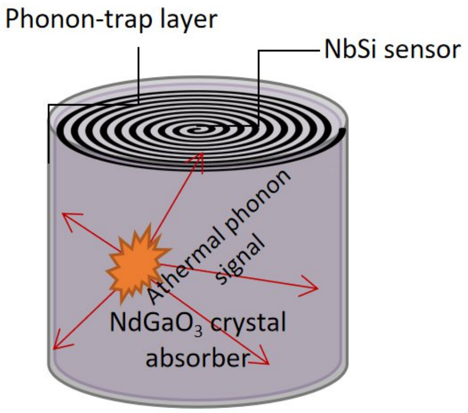
TINY underground demonstrator

in absence of enrichment

- New limits for both isotopes even without the enrichment
- Proof-of-concept with natural crystals
- The transition from natural to enriched crystals was previously done with other isotopes and experiments: clear path for future

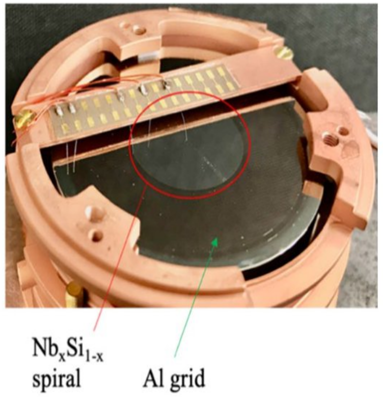


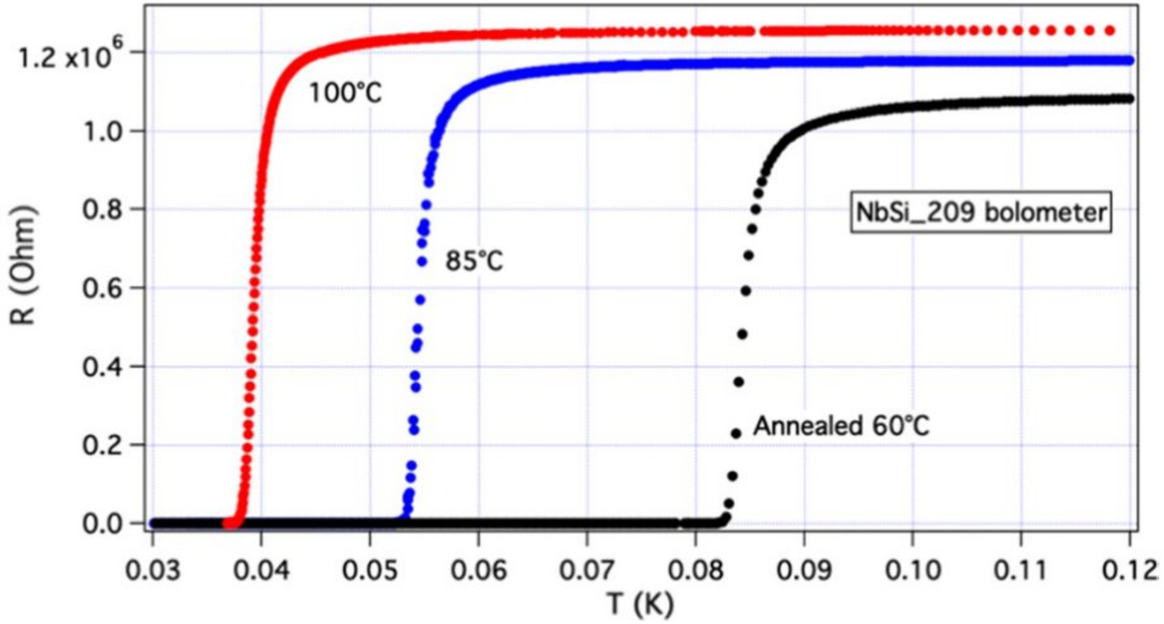
Isotope	Exposure NEMO-3, kg×yr	Present limits NEMO-3, yr	Exposure TINY, kg×yr	New limits TINY, yr	TINY sensitivity to m_{bb}, meV
^{96}Zr	0.031	9.2×10^{21}	0.042	**6×10^{22}**	1433-3401
^{150}Nd	0.191	2×10^{22}	0.062	**5.7×10^{22}**	1047-2501



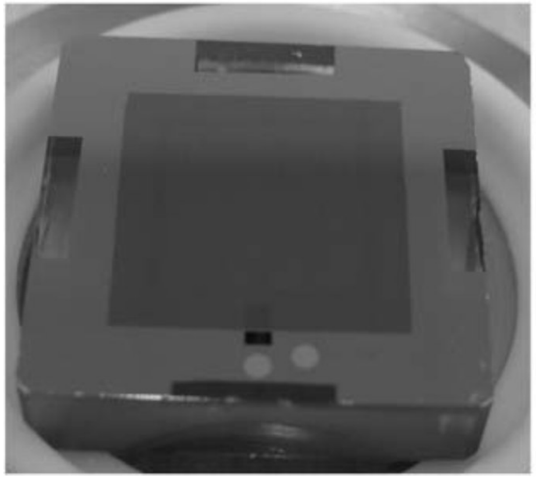
NbSi athermal phonon sensors – previous studies

- **NbSi as high impedance TES sensors (2022)**
  https://doi.org/10.1007/s10909-022-02899-2





- **NbSi as Anderson insulators (2008)**
  http://doi.org/10.1007/s10909-008-9764-z

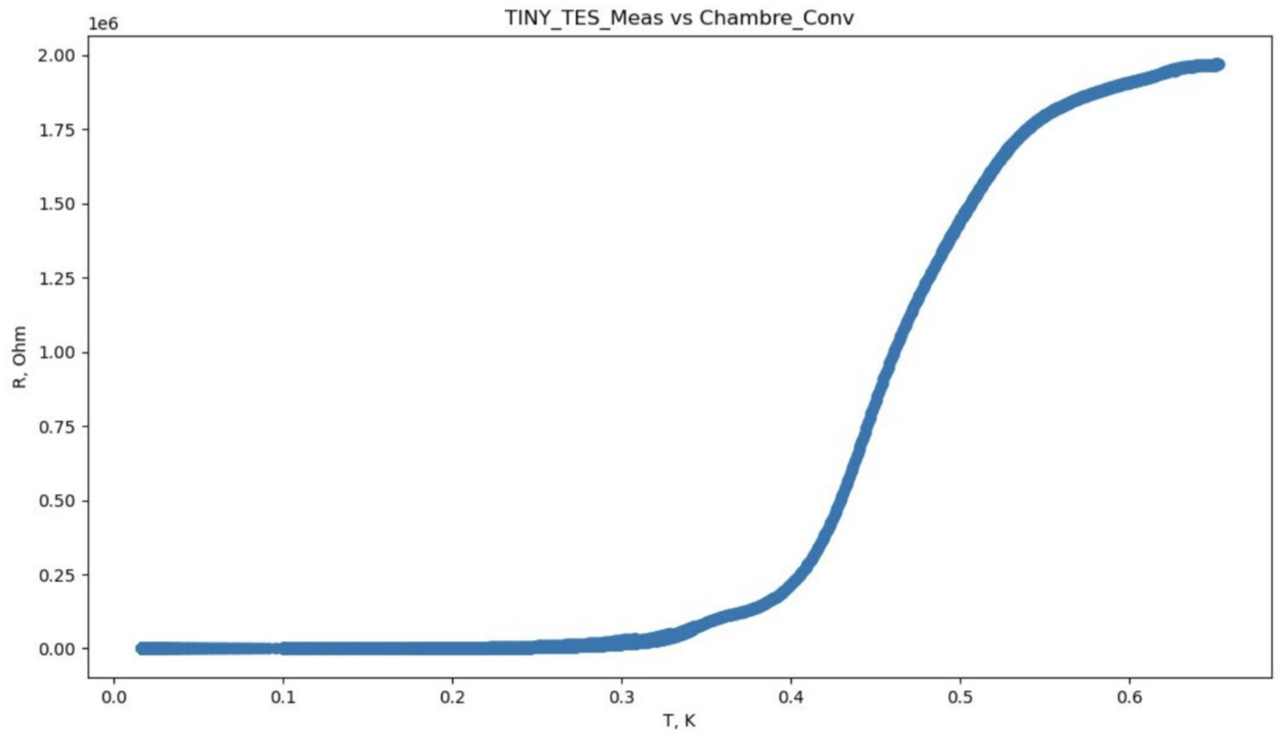


two NbSi films effectively used in insulating mode on a small TeO2 crystal to discriminate between surface and bulk events

→ try to reproduce

NbSi athermal phonon sensors as TES

- Attempts with large-surface TES sensors:
  transition too wide due to inhomogeneity of the evaporation
- very complicated to fix as it comes from geometrical factor during evaporation

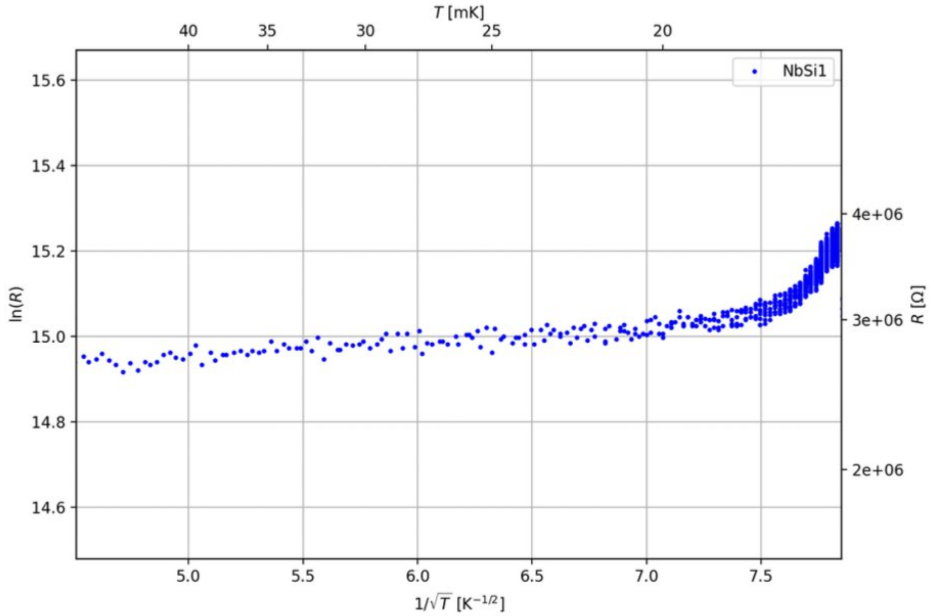


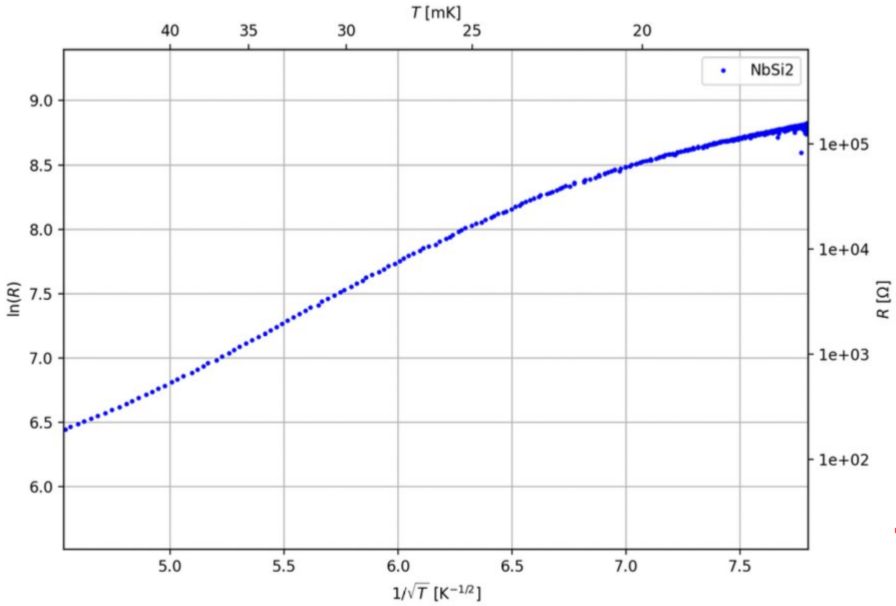
→ try insulation regime

NbSi athermal phonon sensors as Anderson insulators

- NbSi in the insulating mode should be less senisitive to inhomogeneity during evaporation
- Several tests done:

  Test #1: two sensors produced with **mechanical masks** (measured in Actuator @ IJCLab)

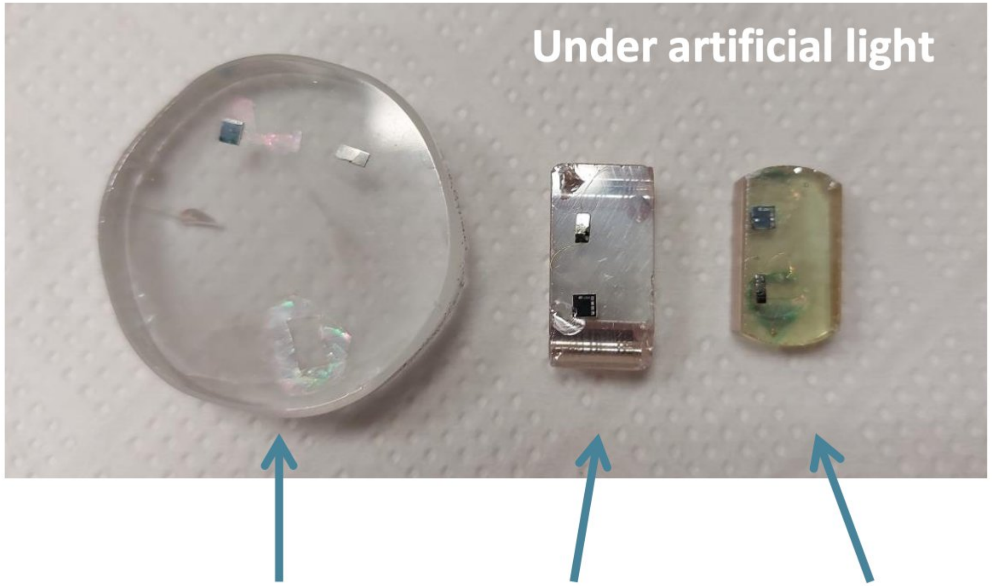




→ try to anneal

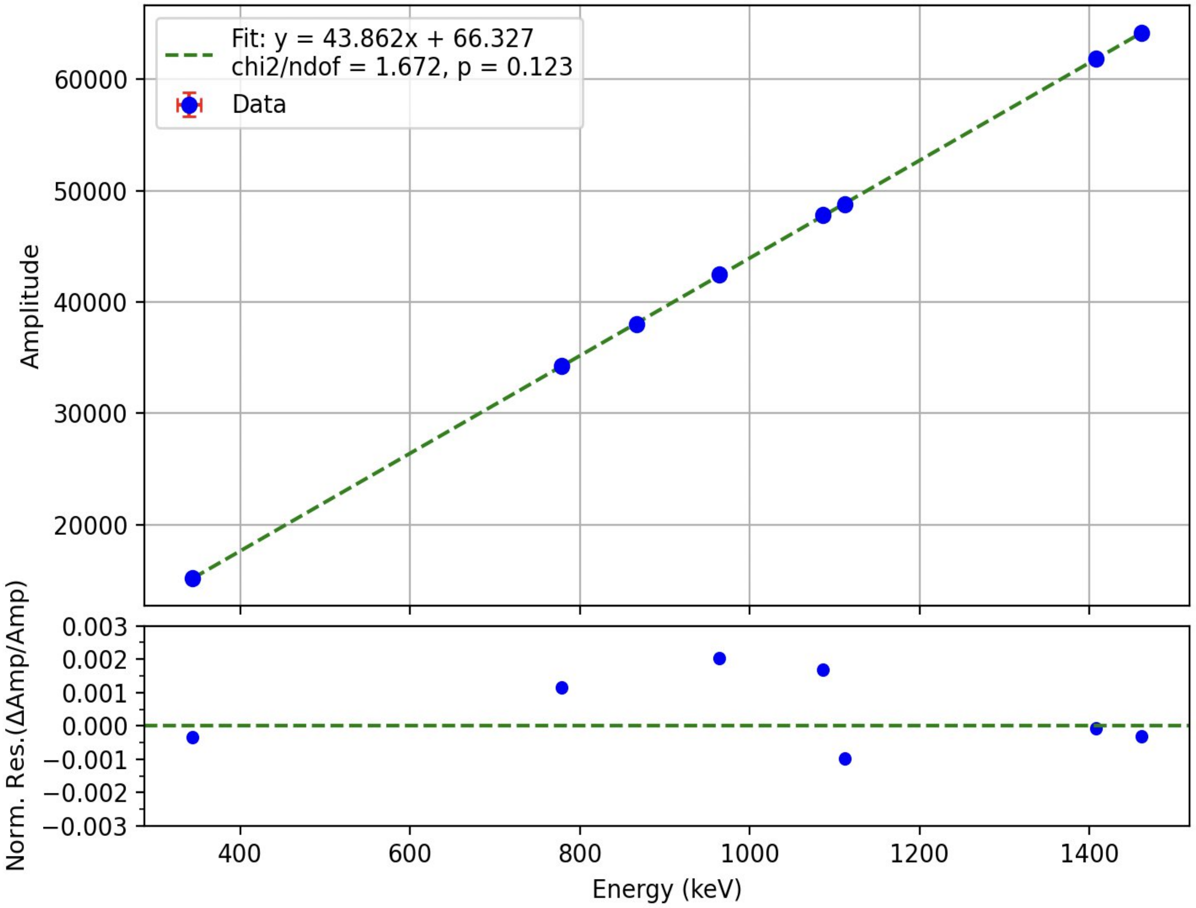
Nd-doped crystals

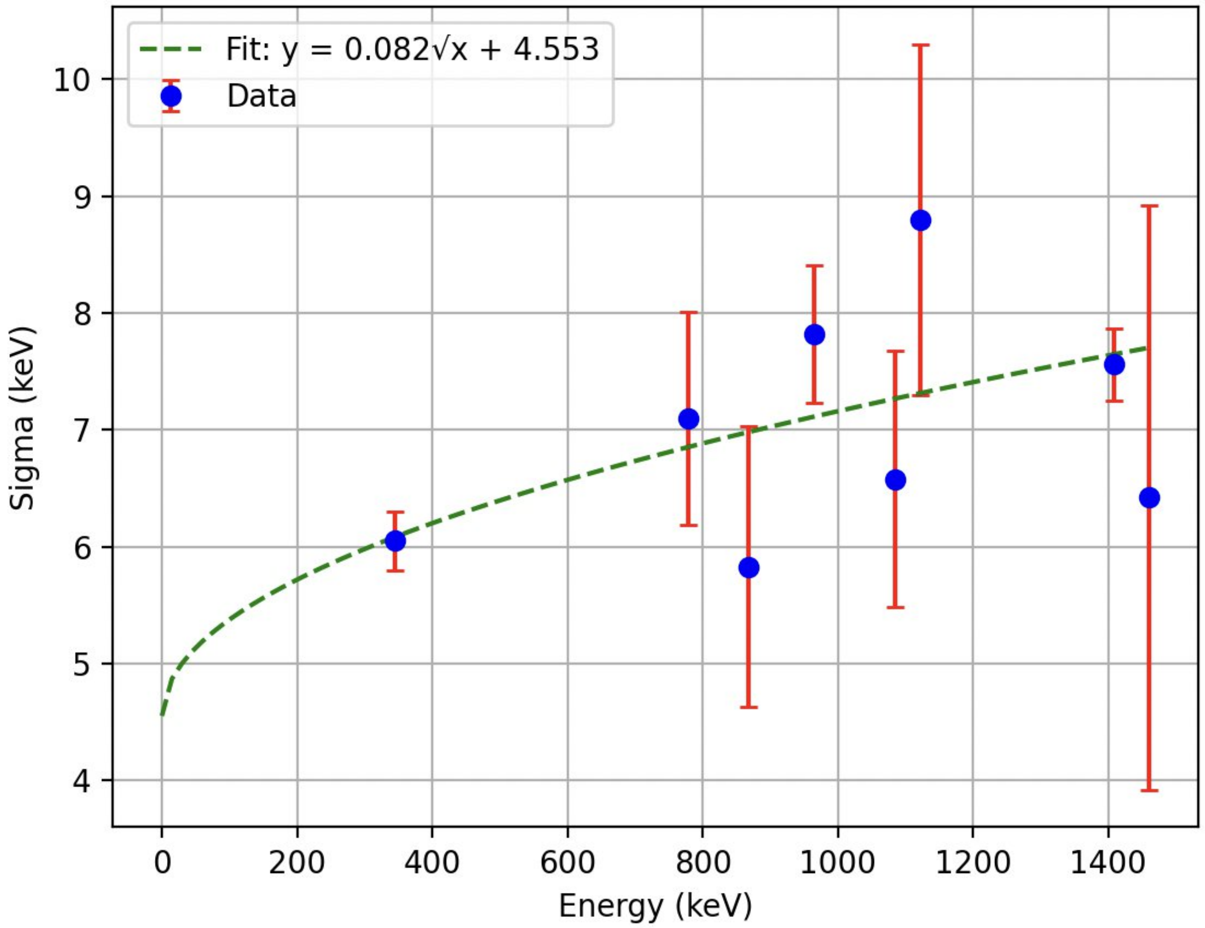
- Very near future: measure some Nd-doped crystals even if we know that doping is really small (few percent), not optimal for large experiment



YAG:Nd $PbWO_4$:Nd $PbMoO_4$:Nd

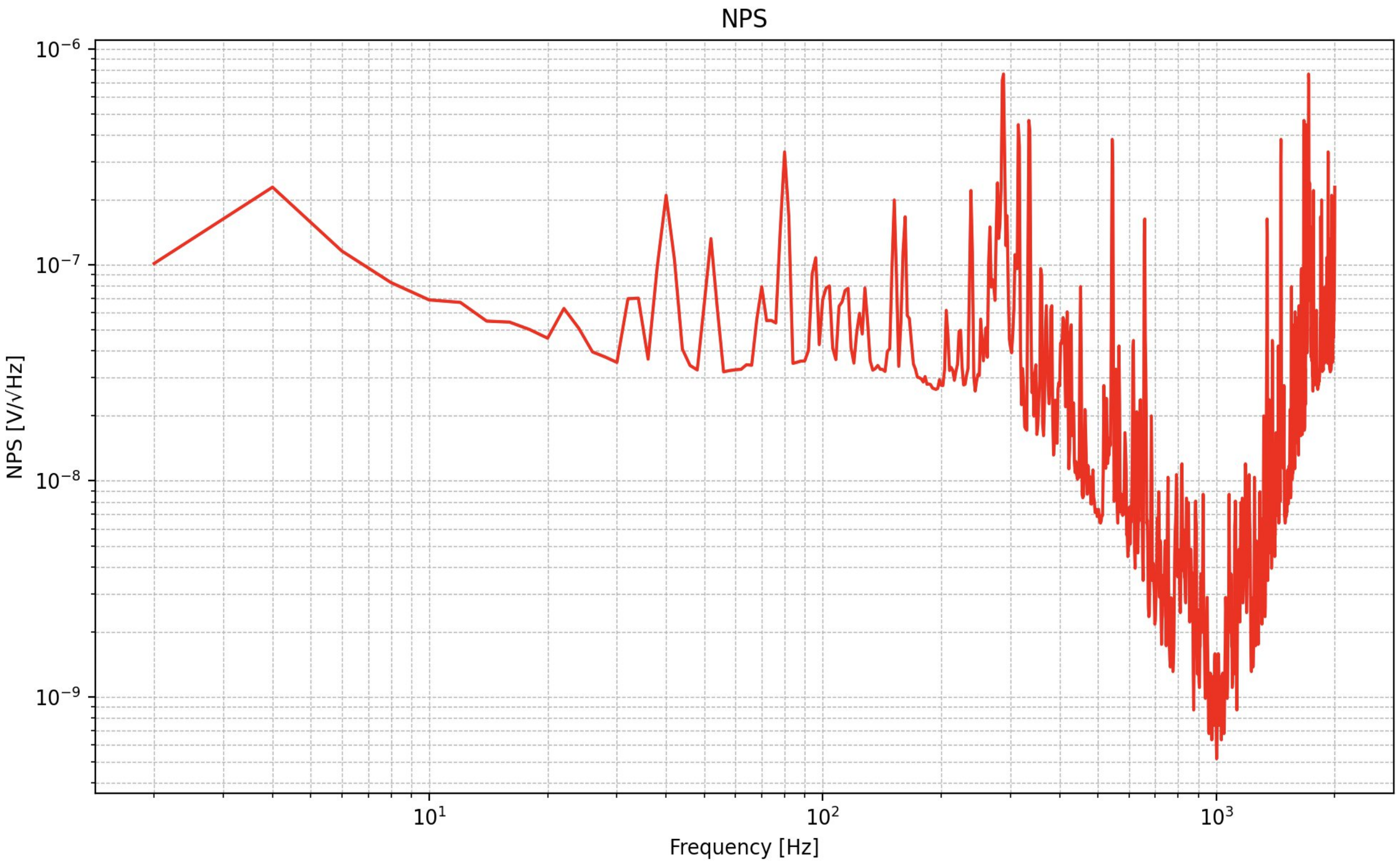
CZC linearity and resolution

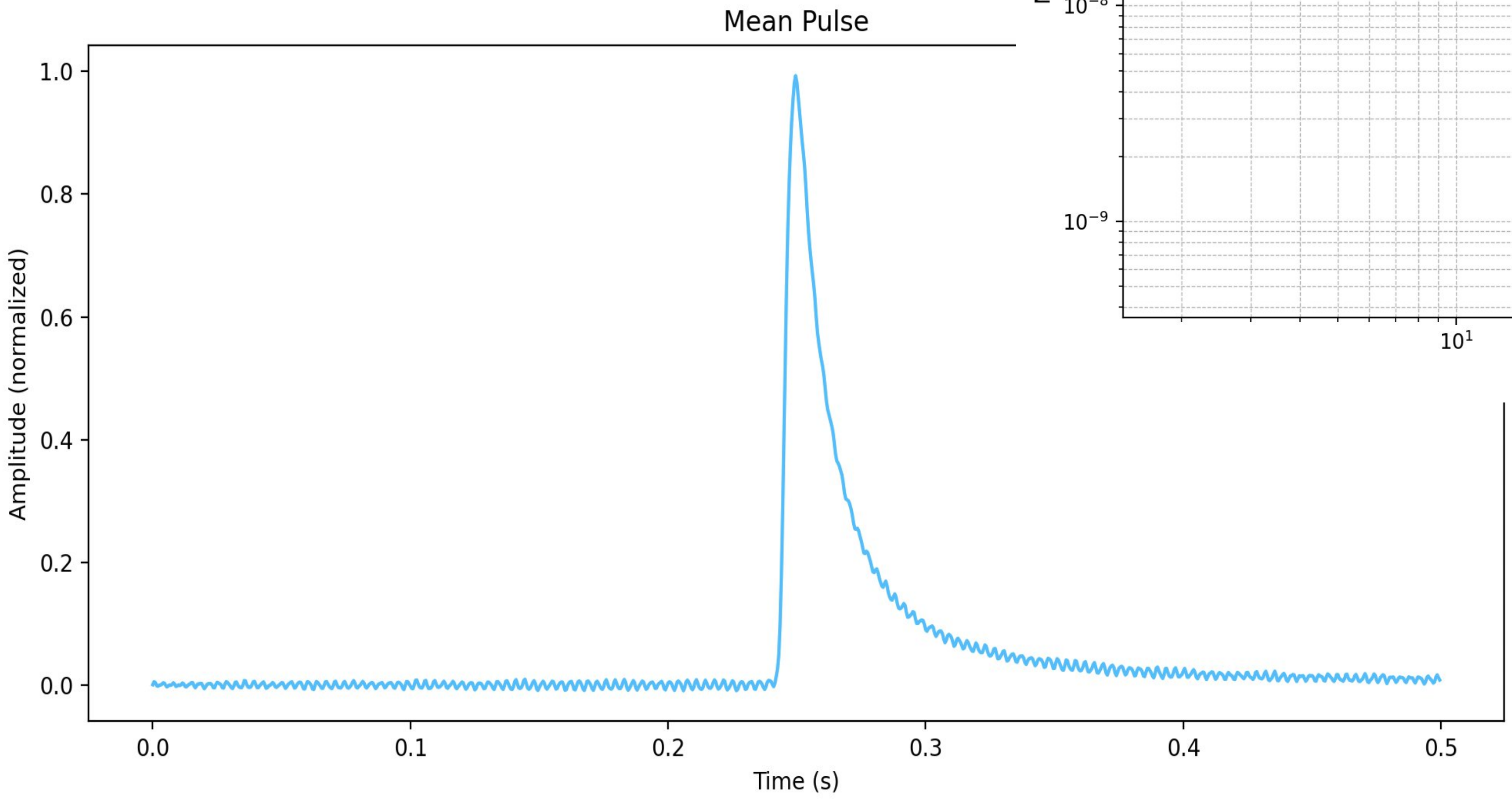




- M11 - peaks from 152Eu source
- errors from fit

CZC M14:
bkg run (114h)





Rbol = 6.22 Mohm
parallel Johnson noise = 6.42 e-9 V/√Hz

CZC-alphas

- external alpha source (238U/234U) inside the copper holder
- very near future: redo the measurements without the source to better assess the contamination