Cryogenic active shielding for 0νββ decay bolometric experiments

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P2IO BSM-ν   April 11, 2022

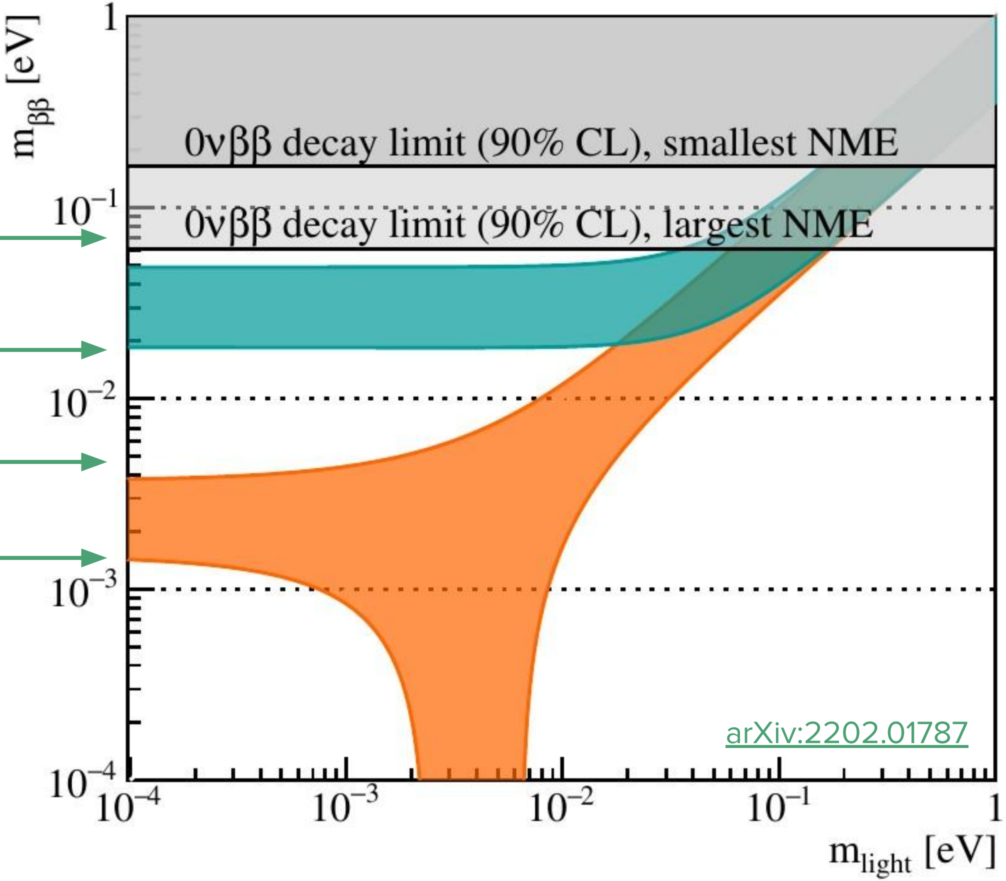
Planning 0νββ decay searches beyond the Inverted Ordering

Current exclusion limits (peer-reviewed only)

Next-generation experiments (CUPID, LEGEND-1000, nEXO)

1-ton ^{100}Mo experiment with zero background

I should retire around this time

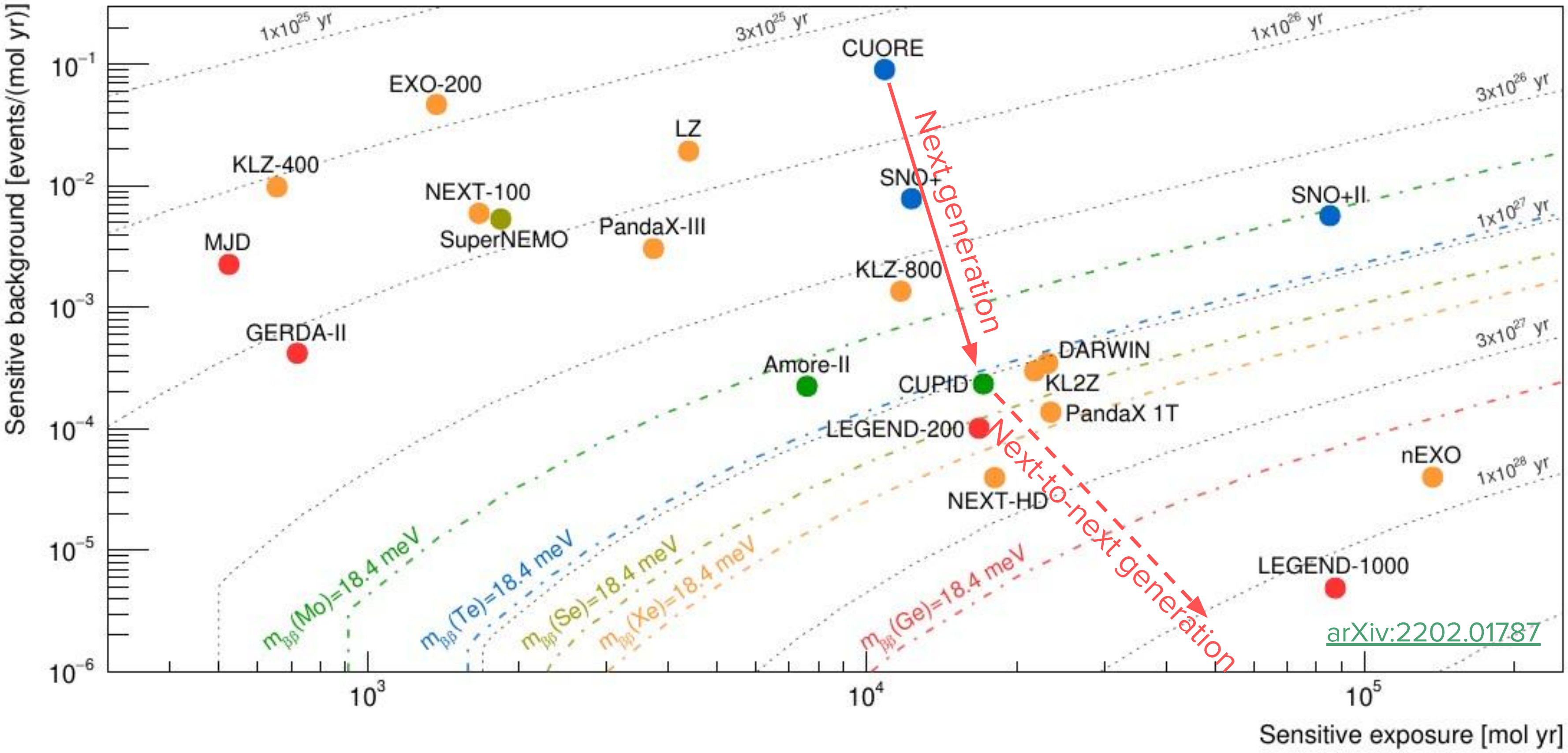


~2020

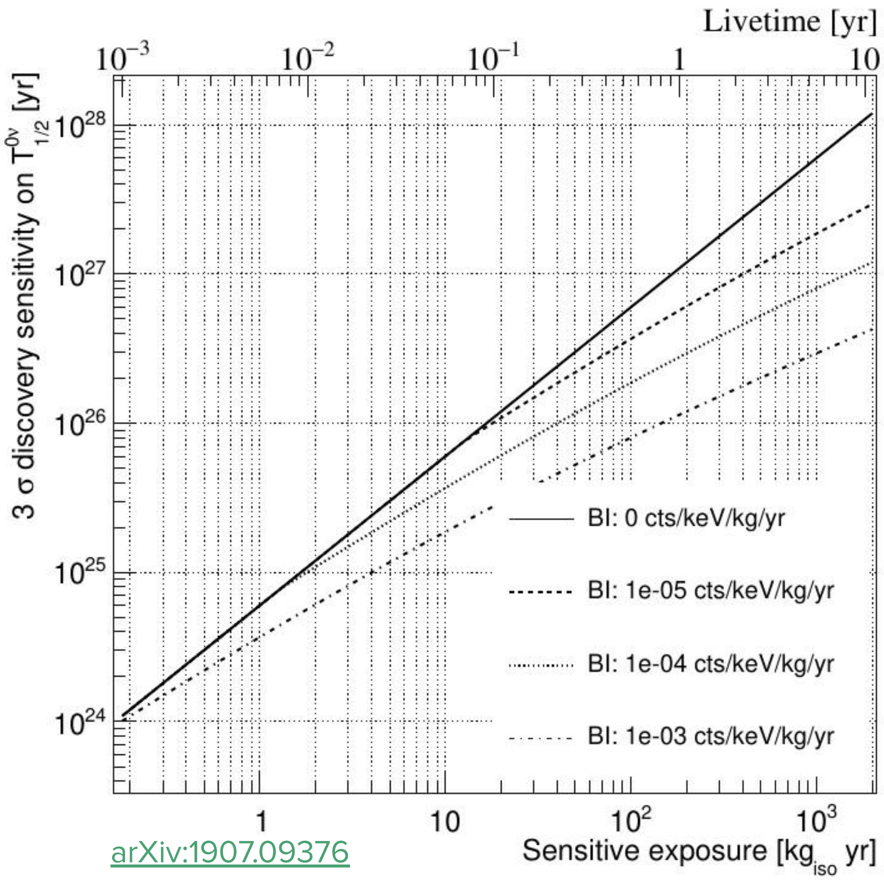
~2030?

~2040?

Planning 0νββ decay searches beyond the Inverted Ordering



What are the required isotope mass and background level?



arXiv:1907.09376

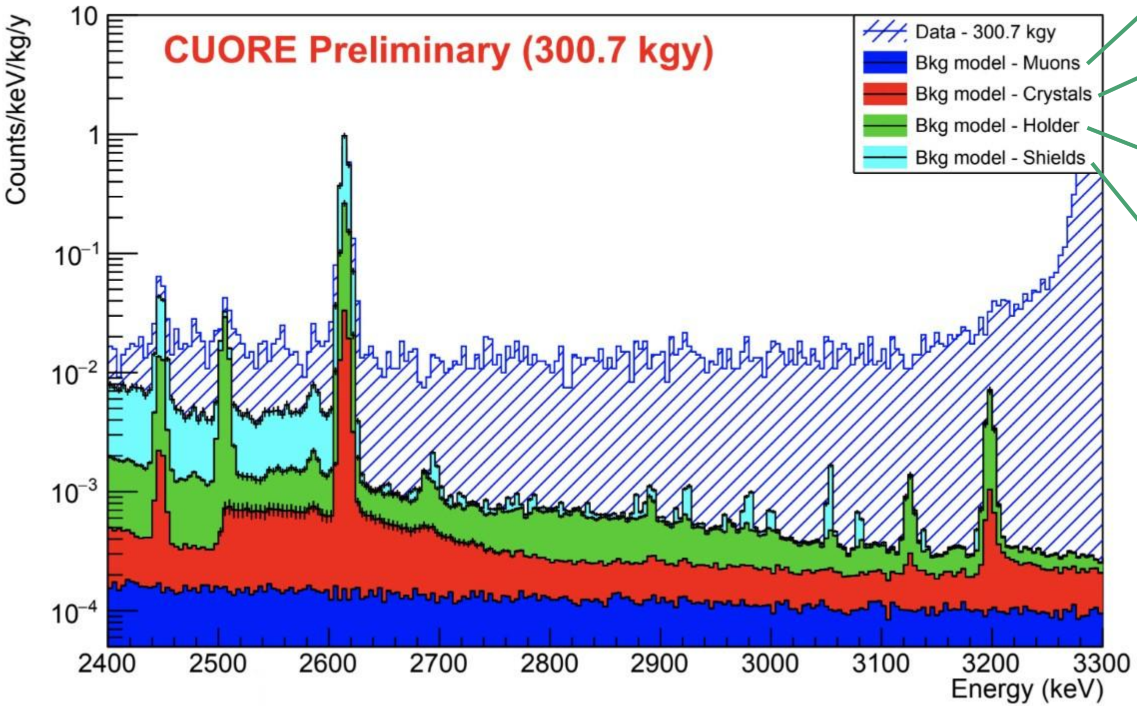
To get here we need:

- ≳1 ton of isotope
- BI ~10^{-6} cts/keV/kg/yr

Increasing the mass

- Purchase of raw element(s)
  → Easy for most element containing a 0νββ candidate isotope
- Isotopic enrichment
  → Large-scale production of “stable” isotopes only performed in Russia so far
  → Alternative productions in Europe or US are possible
  → Electricity drives the cost of centrifuge-based enrichment
  → The entire 0νββ community is facing this challenge together
- Crystal growth
  → Growth technique and capability heavily depends on crystal type
  → In general, multiple producers available in different countries

Reducing the background

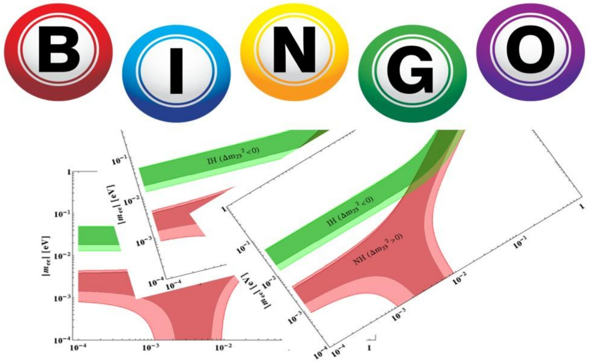


Muon veto with 99% efficiency

Cleaner crystals + less passive material

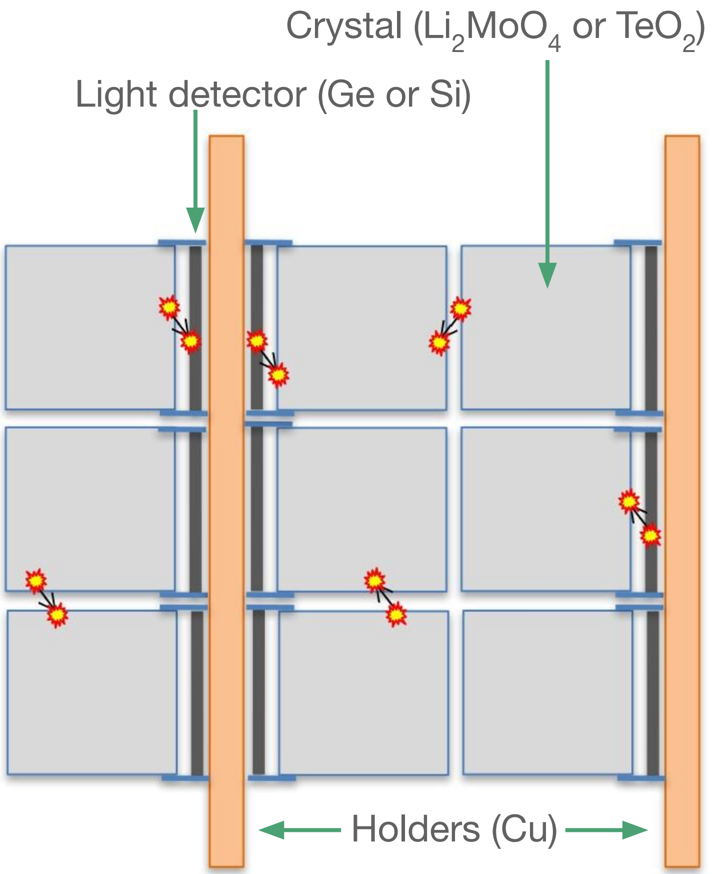
Crystal holders with less mass and surface

Cleaner cryostat + active shields



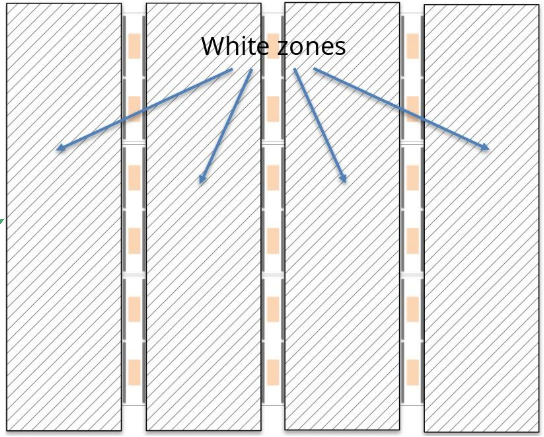
BINGO: Bi-Isotope 0νββ Next Generation Observatory

Main idea: the crystals should be surrounded only by active elements
→ Actively veto surface α and β radioactivity of crystal holders
→ Actively veto γ's from cryostat

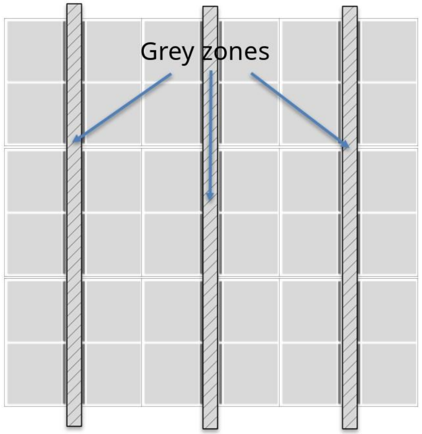


BINGO: Bi-Isotope 0νββ Next Generation Observatory

Top view:



Only crystals



Crystal holders, wiring, …

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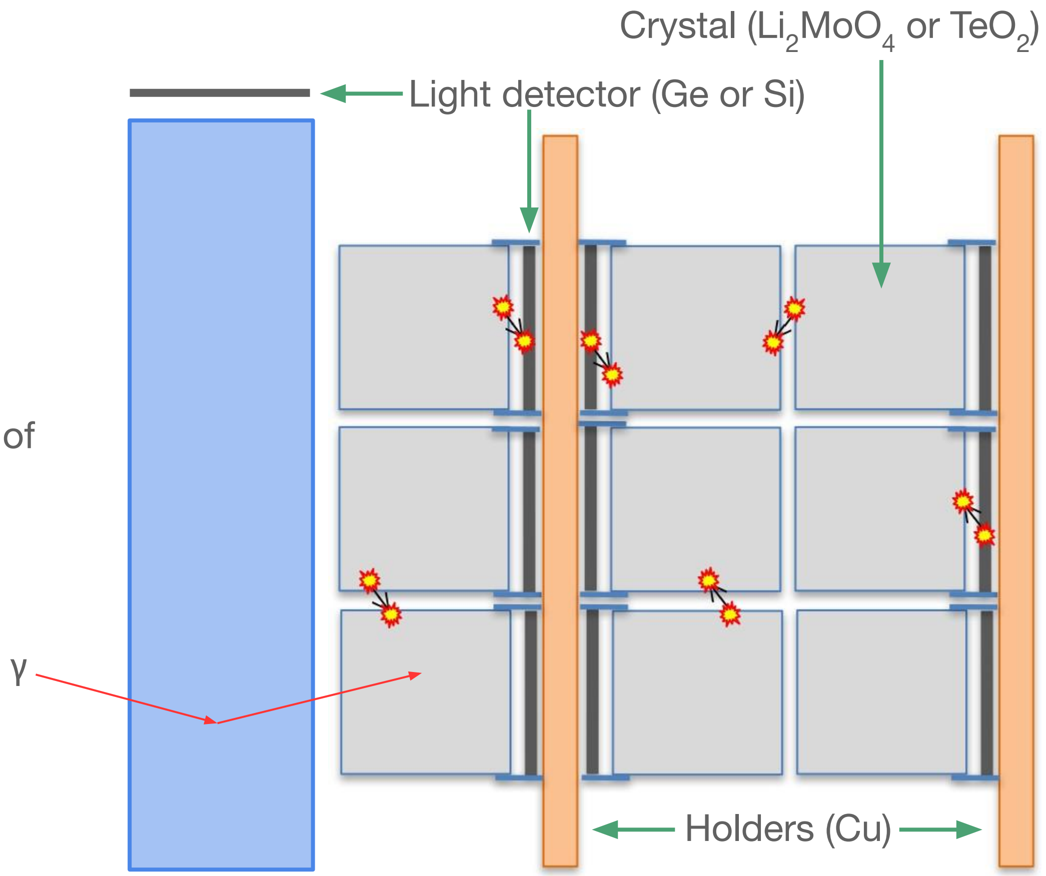
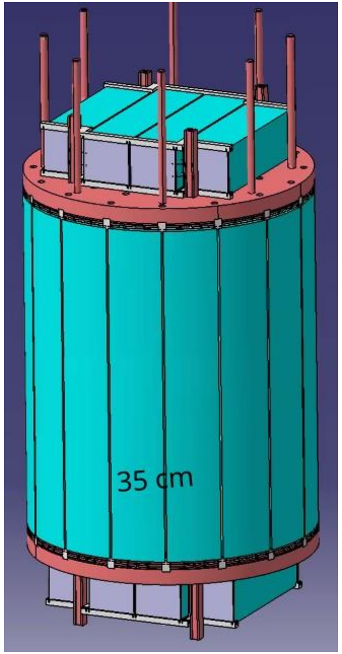
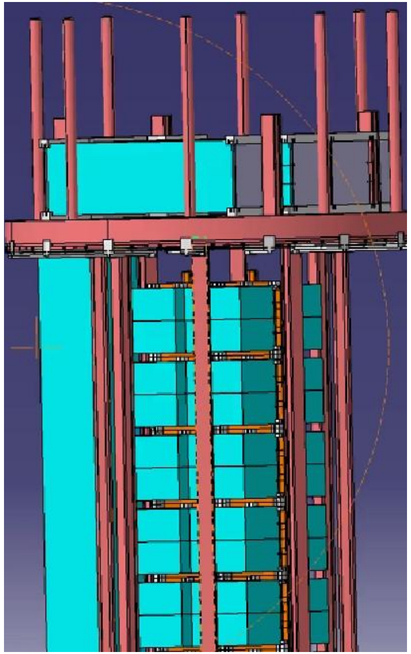
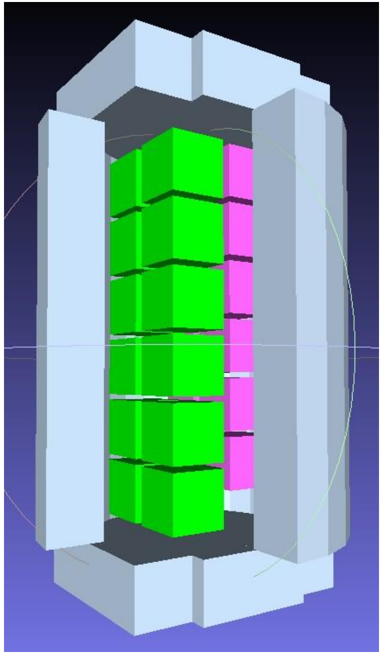


Mini-BINGO

- Demonstrator of BINGO technology to be operated at Modane Underground Lab (LSM)
- Two towers of 12 crystals
  → Li_2MoO_4
  → TeO_2
- Innovative light detectors with Neganov-Luke amplification
- Cryogenic active shield



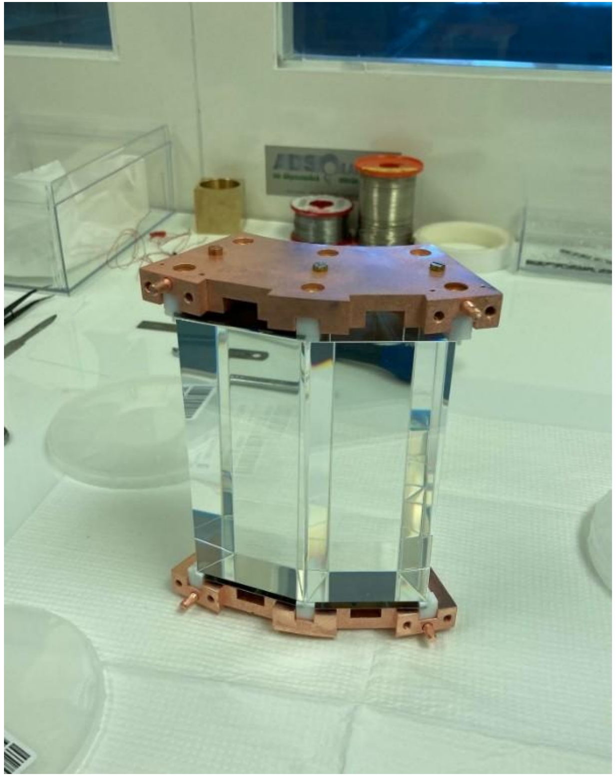




Planning the internal veto

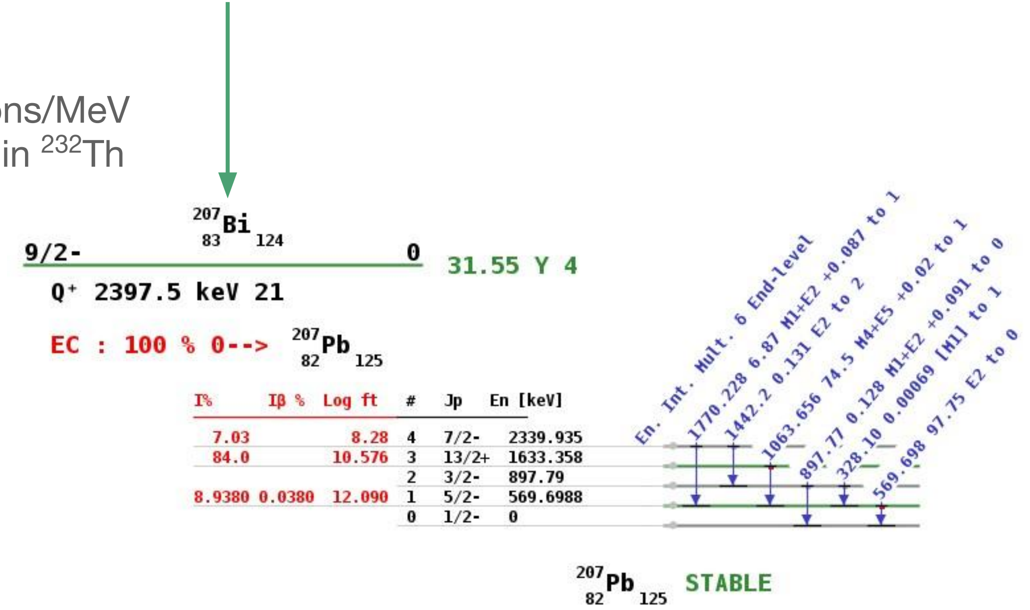
Requirements for the ideal internal veto:

- Absorb as many external γ's as possible
  → High density, large thickness
  → 4π coverage
- Do not induce any background or dead time
  → High radio-purity
- Flag as many events as possible, especially mildly Compton-scattered γ's
  → Low threshold of ~50 keV
  → High light yield and light collection efficiency

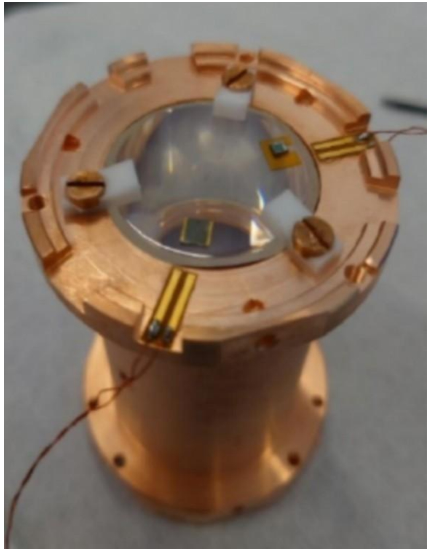


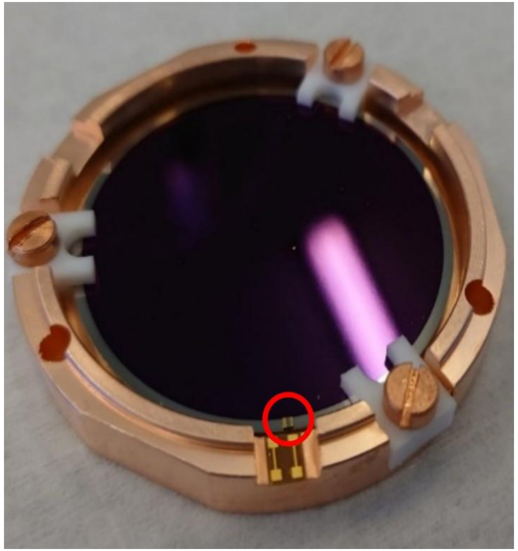
Which material for the veto?

- Bismuth Germanate: $Bi_4Ge_3O_{12}$
  → Density ~7.13 g/cm^3
  → Excellent light yield of 8-10·10^3 photons/MeV (nominal, at room temperature)
  → Available in large sizes
  → Several producers
  → Radiopurity to be verified, especially regarding ^{207}Bi
- Zinc Tungstate: $ZnWO_4$
  → Density ~7.62 g/cm^3
  → Excellent light yield of 9.5·10^3 photons/MeV
  → Excellent radiopurity: <0.17 μBq/kg in ^{232}Th
  → α contamination to be measured
  → Large sizes to be demonstrated
  → Only Russian producers



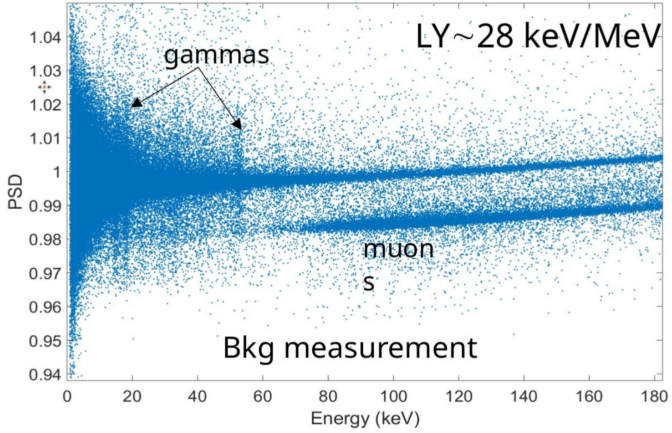
BGO characterization

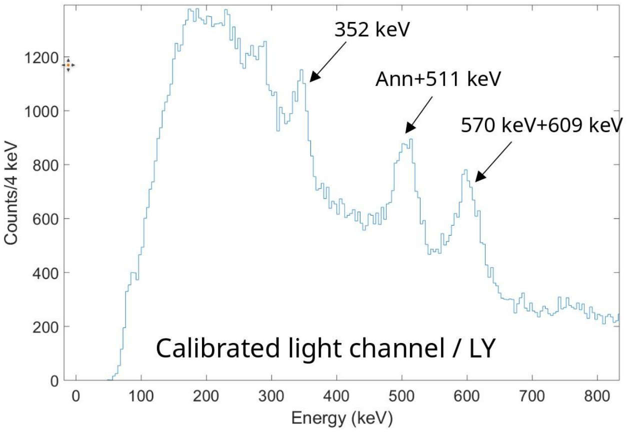


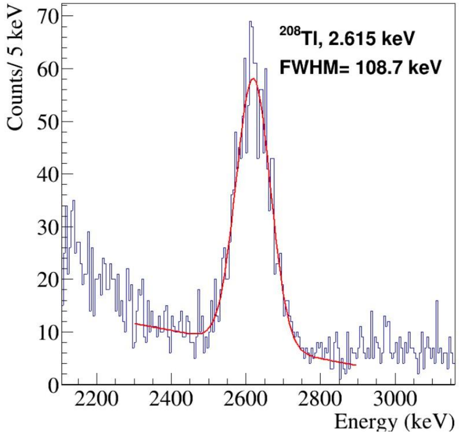


- ∅ 30 mm, h 60 mm
- Reflecting foil around the crystal
- Fixed with Teflon holder on copper frame
- Light detector: SiO-coated Ge wafer instrumented as bolometer
- Light detector readout with Neutron-Transmutation-Doped Ge thermistor

BGO characterization: light yield

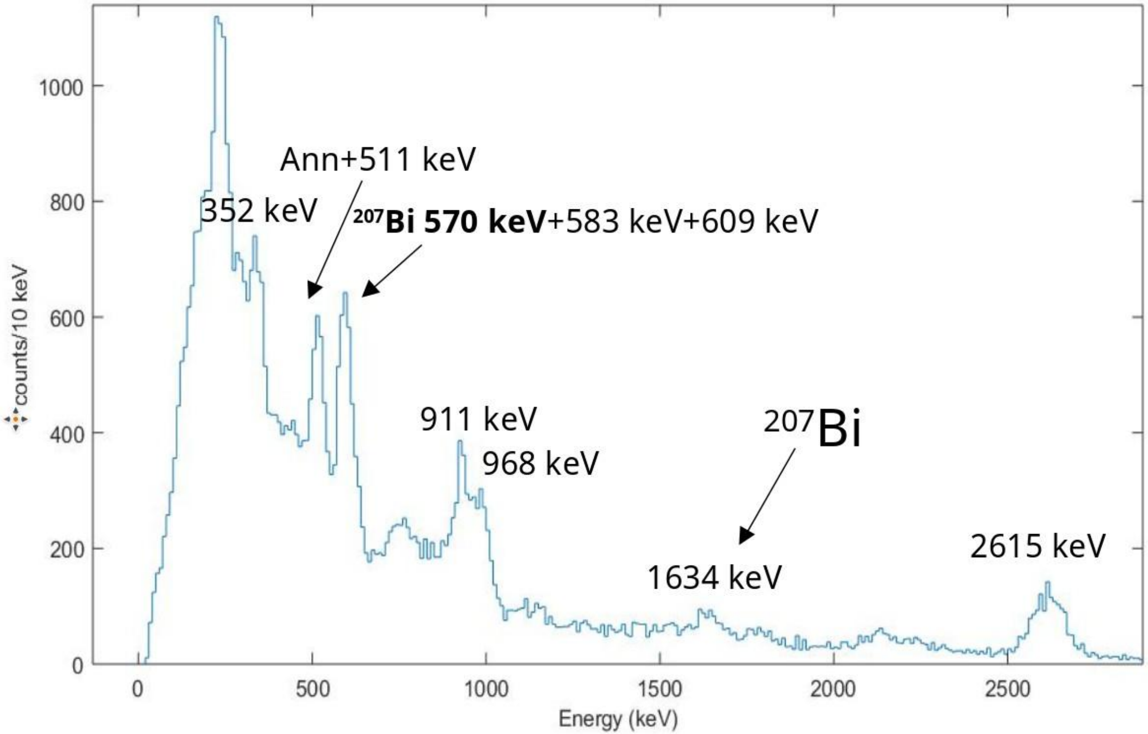






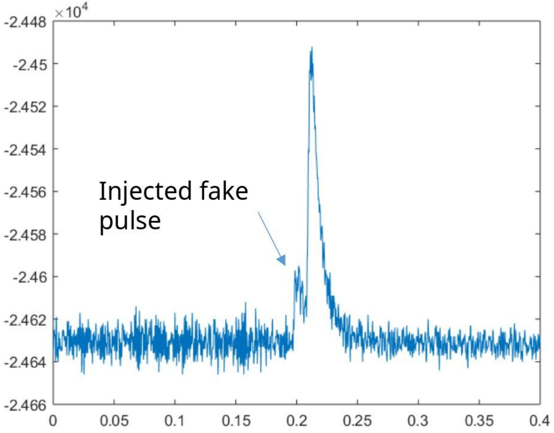
- Long cool-down time required
  → Not a show-stopper, as BGO is not directly operated as bolometer
- Light yield: 28 keV/MeV ~ $10.8 \cdot 10^3$ photons/MeV
- Rise time: 1.8 ms
- Decay time: 8.6 ms

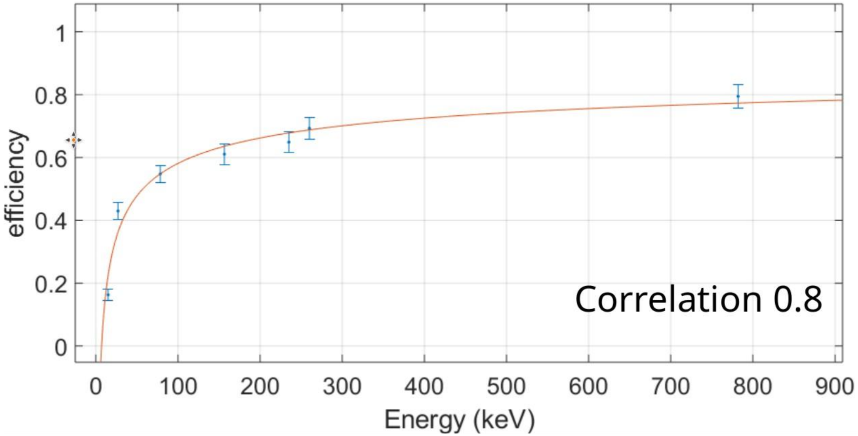
BGO characterization: radioactive contamination

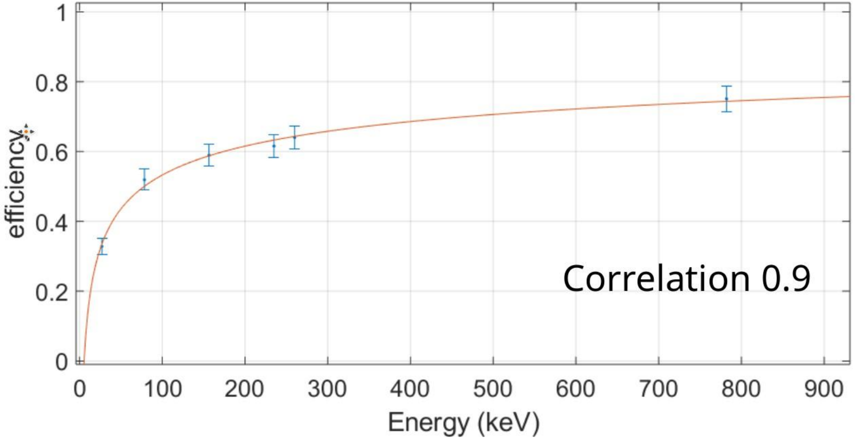


- ^{207}Bi visible with measurement on the surface
- Precise contamination measurement to be performed
- BGO radioactivity not itself a problem, but can bring to high dead-time

BGO characterization: trigger efficiency

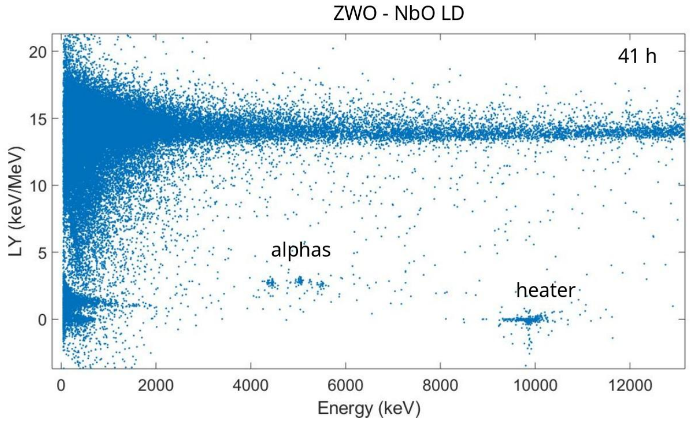


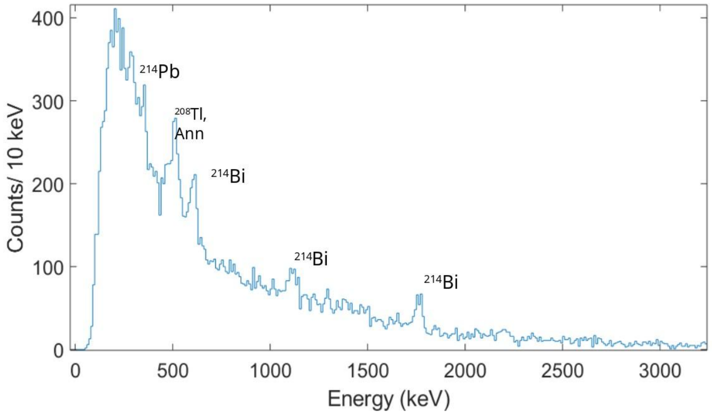




- Inject fake pulses with different amplitudes
- Trigger efficiency doesn't reach 100% due to pile-up
- More precise characterization to be performed underground

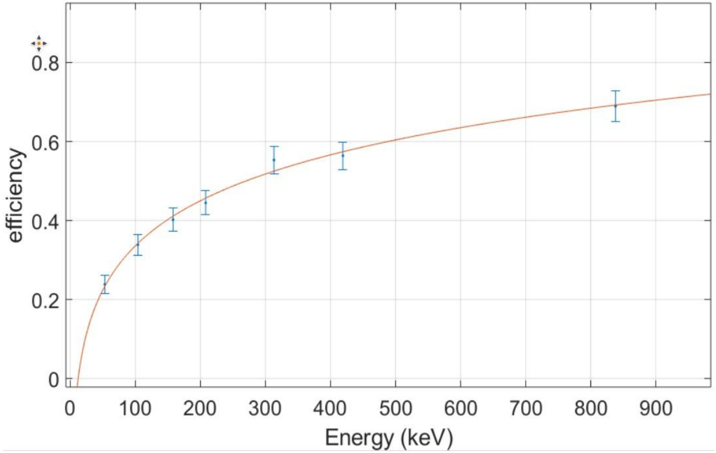
ZnWO characterization





- Tested with one LiO-coated and one NbO-coated light detectors
- ^{238}U contamination ~ 0.4 mBq/kg

Light detector	Rise time [ms]	Decay time [ms]	LY [keV/MeV]
SiO	1.3	5.3	13.6
NbO	2.1	9.6	14.2



Next steps for Mini-BINGO

- Optimization of cryogenic veto geometry via MC simulations
  → ongoing
- Evaluation of maximum tolerable ^{238}U, ^{232}Th and ^{207}Bi contamination
  → ongoing
- Optimization of light collection through simulation of optical photons
  → ongoing
- Finalization of passive external shielding design
  → ongoing
- Cryostat setup at LSM
  → expected to start in Winter 2022-2023