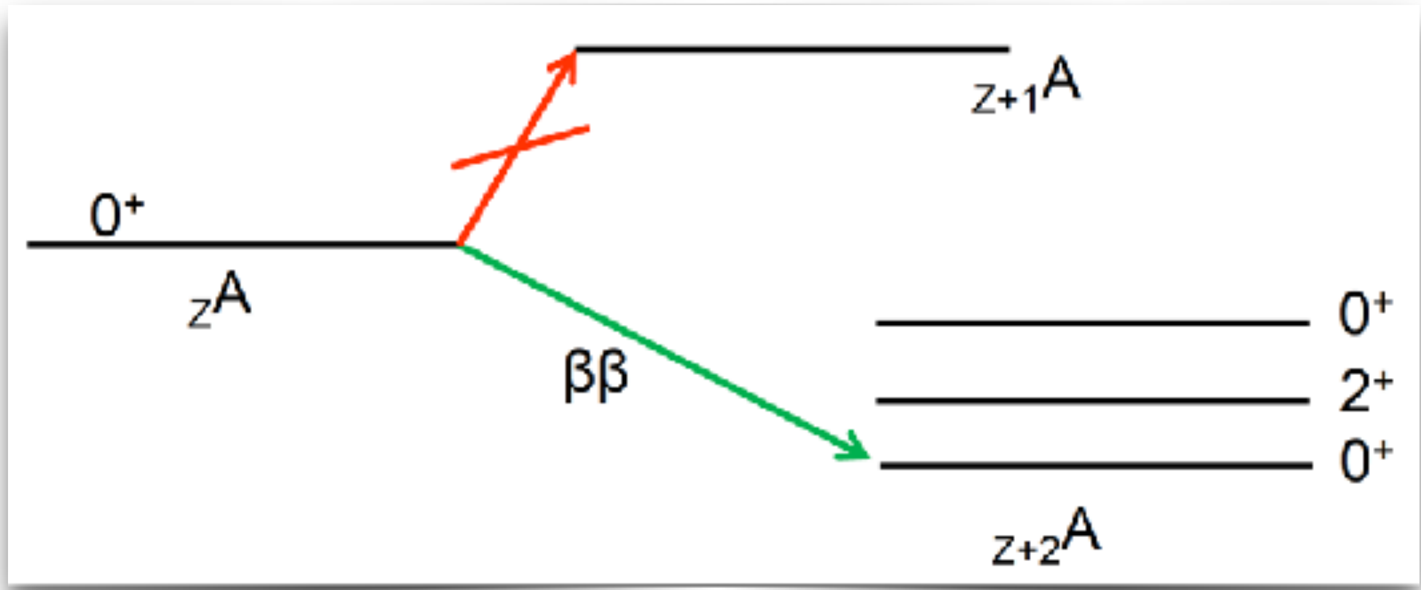
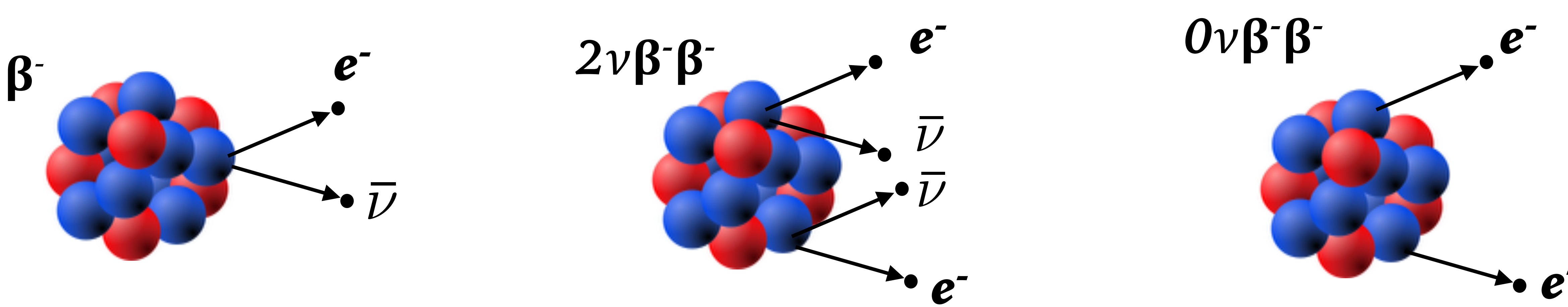
Status and perspectives of CUORE experiment at LNGS

DOUBLE BETA DECAY



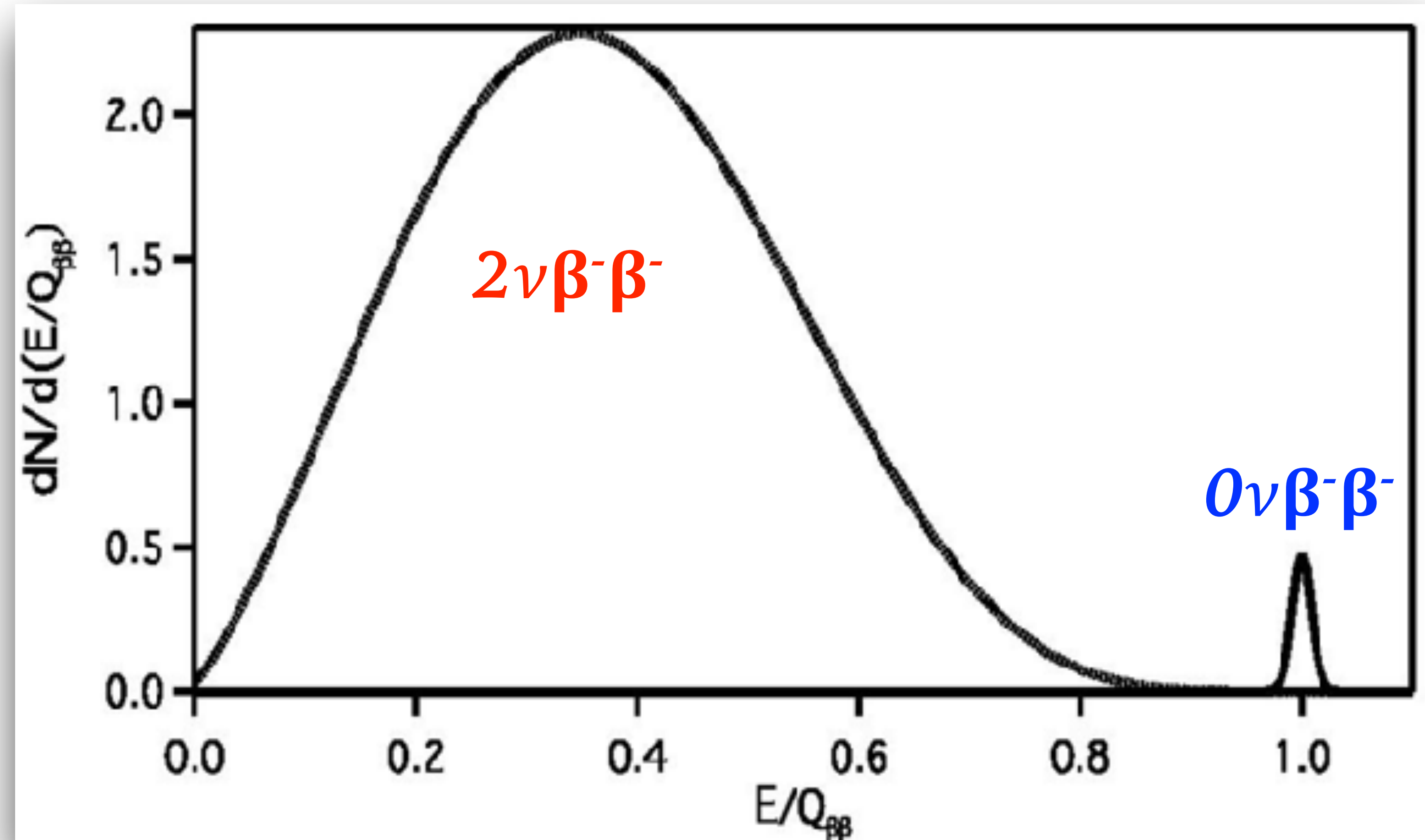
- 2nd order weak interaction
- Normal beta decay suppressed by Q value or J^{π}



Processes explained by the Standard Model

- *Lepton number not conserved*
- *Occurs if neutrinos have mass and are their own antiparticle*

EXPERIMENTAL SIGNATURE

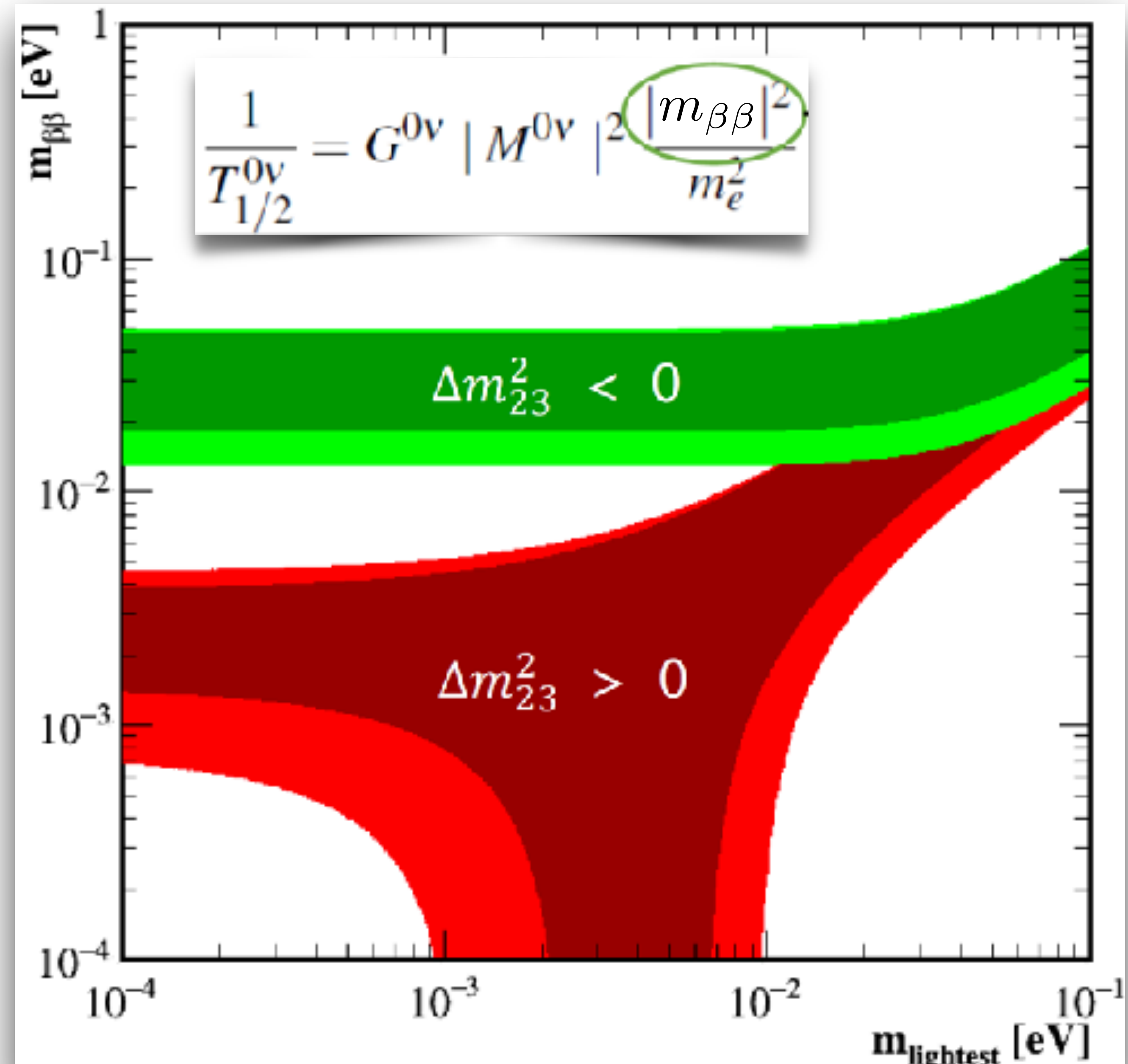


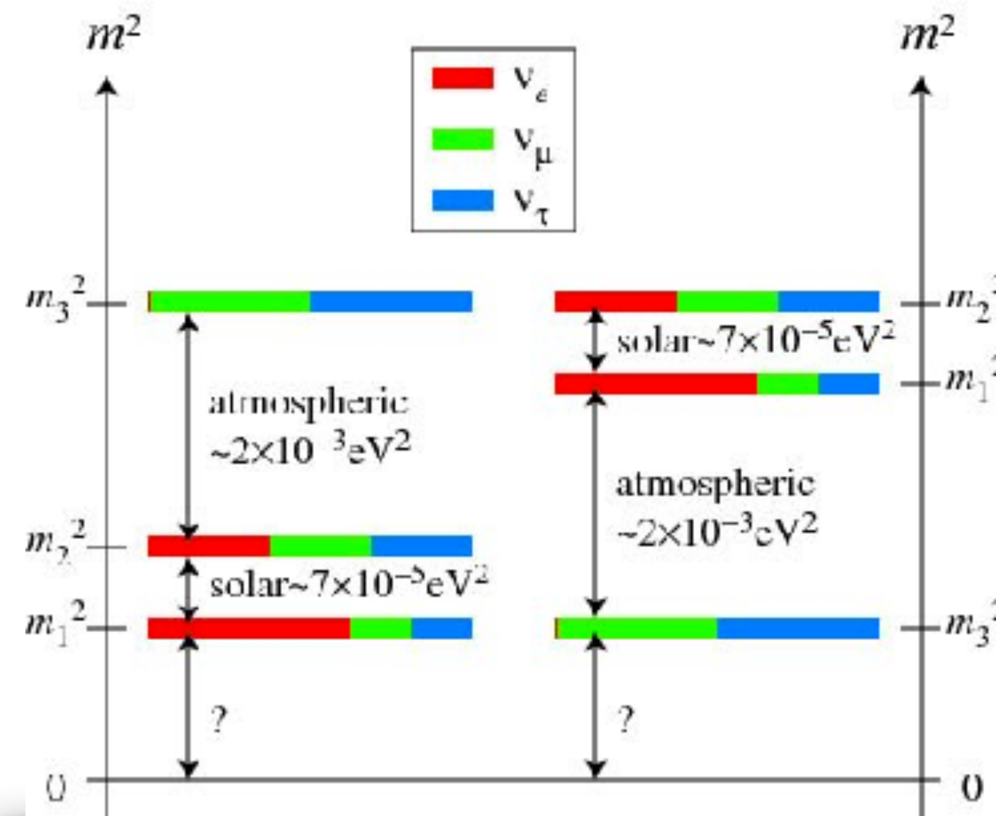
- Sum energy of emitted electrons: Peak at Q value of the decay.

Sensitivity of the search

$$T_{1/2}^{0\nu}(n_\sigma) = \frac{ln2}{n_\sigma}\frac{N_A\, i\, \varepsilon}{A} f(\Delta E)\sqrt{\frac{M\, t}{B\, \Delta E}}$$

IMPLICATIONS

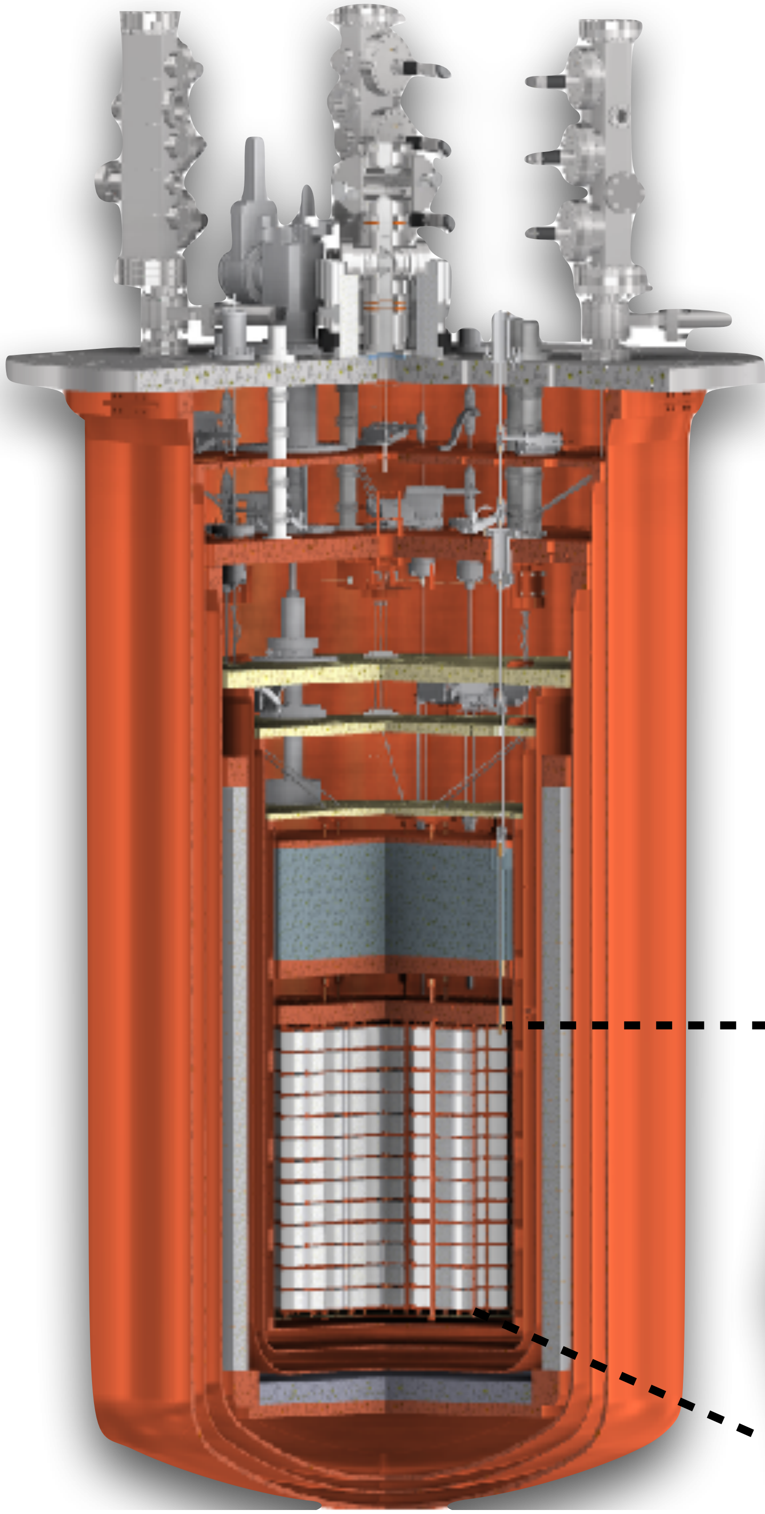


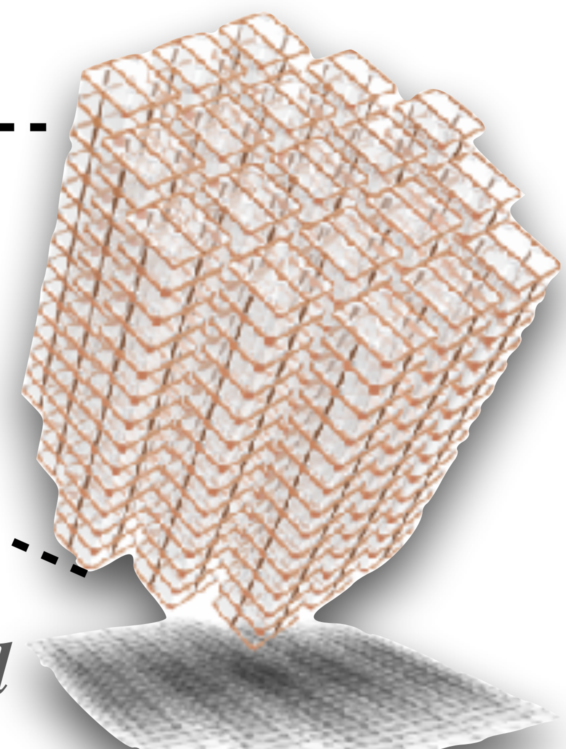


- Neutrinos are Majorana fermions.
  - Physics beyond standard model.
- Constraints on absolute mass scale.
  - Probes the mass hierarchy of the neutrinos.
- Constraints on CP violating phases?

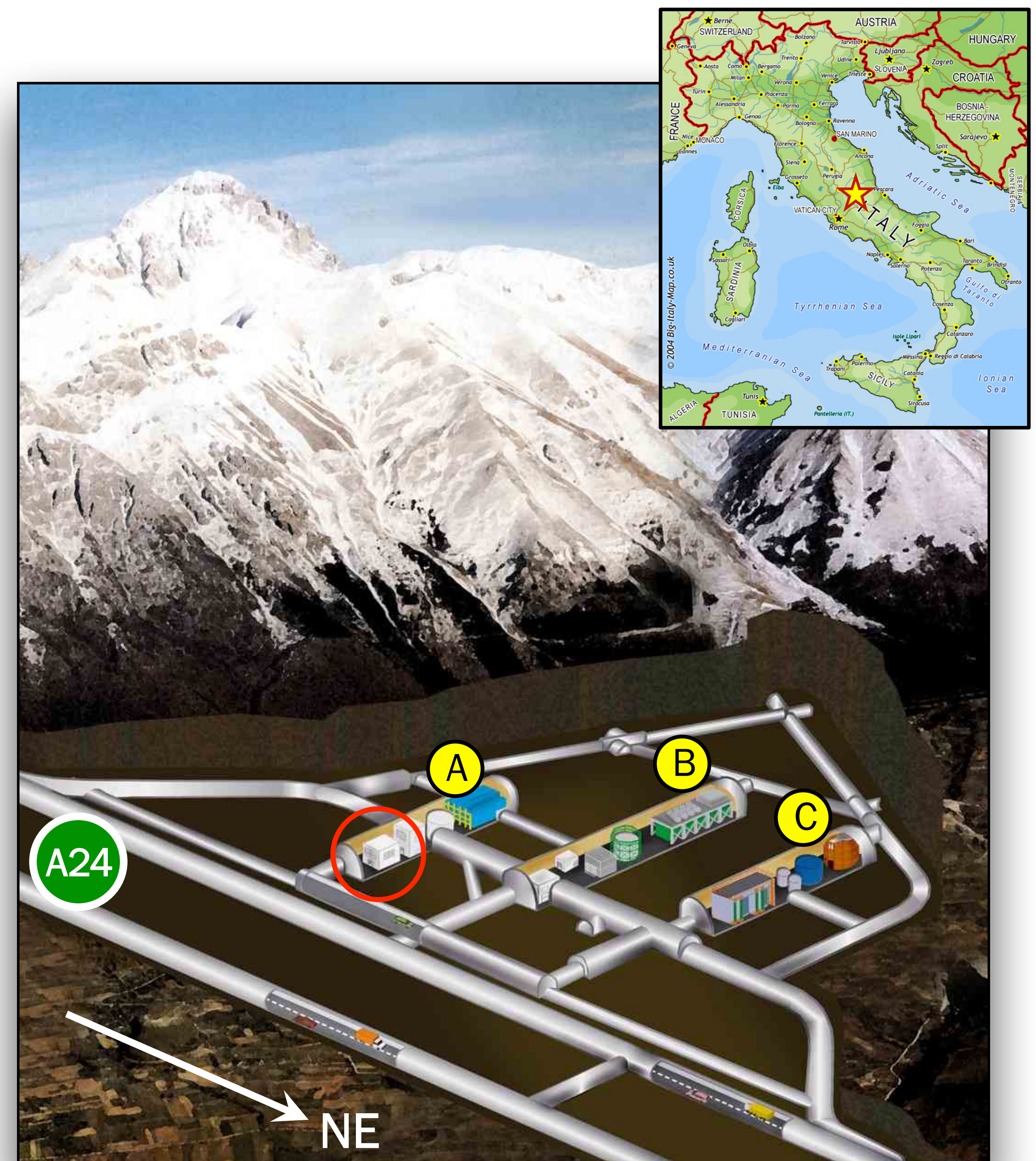
CUORE

- Search for $0\nu\beta\beta$ in ^{130}Te at LNGS, Italy (depth ~ 3600 m.w.e)

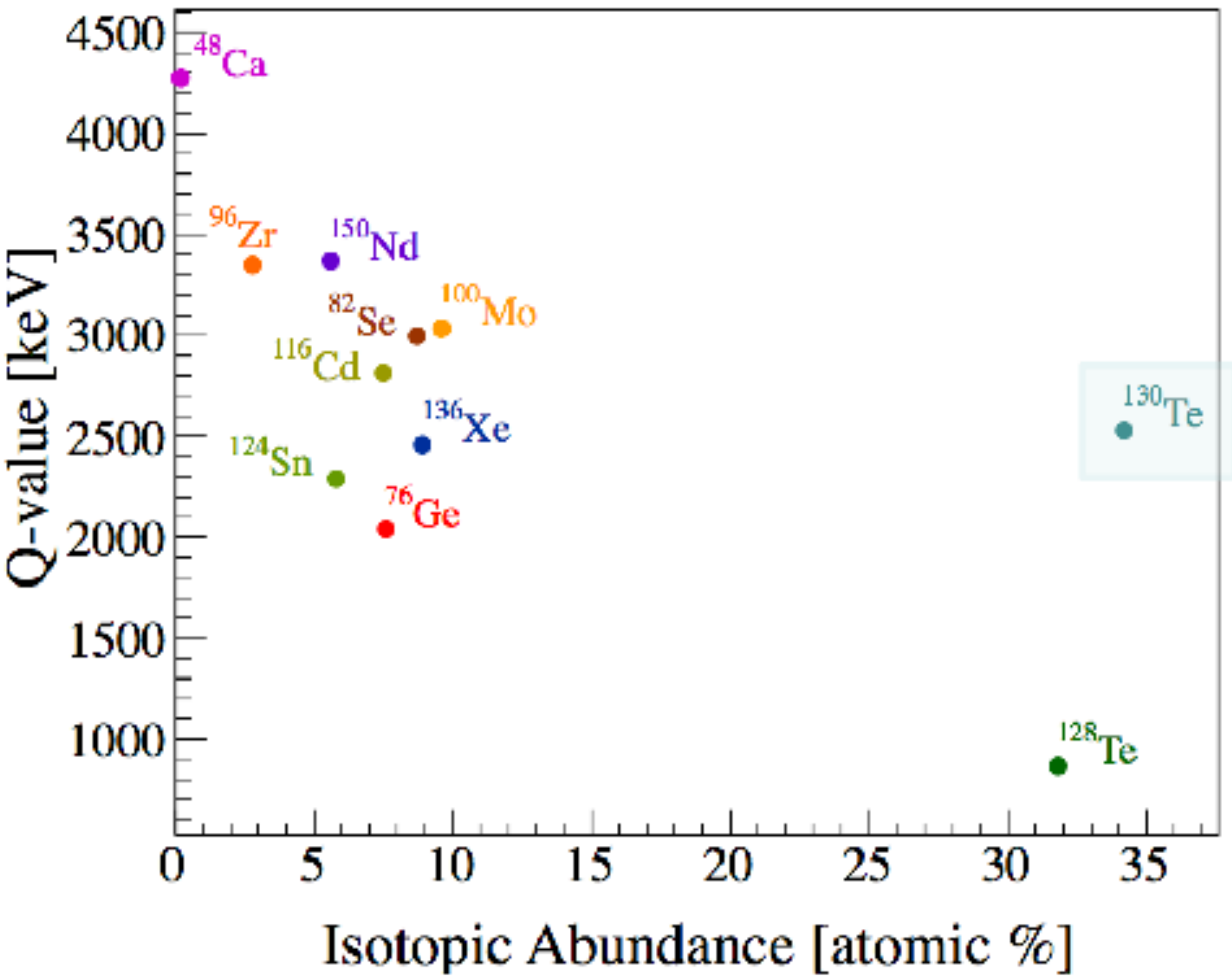




*The **C**ryogenic **U**nderground **O**bservatory for **R**are **E**vents*



CUORE



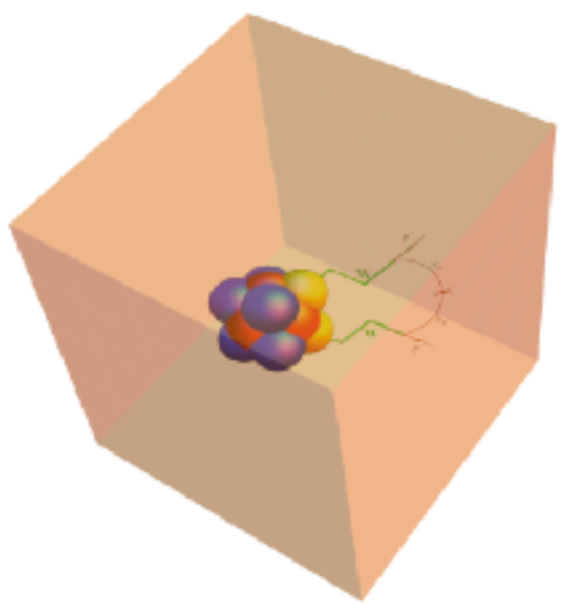
$$T^{0\nu}_{1/2}(n_\sigma) = \frac{ln2}{n_\sigma}\frac{N_A\, i\, \varepsilon}{A} f(\Delta E)\sqrt{\frac{M\, t}{B\, \Delta E}}$$

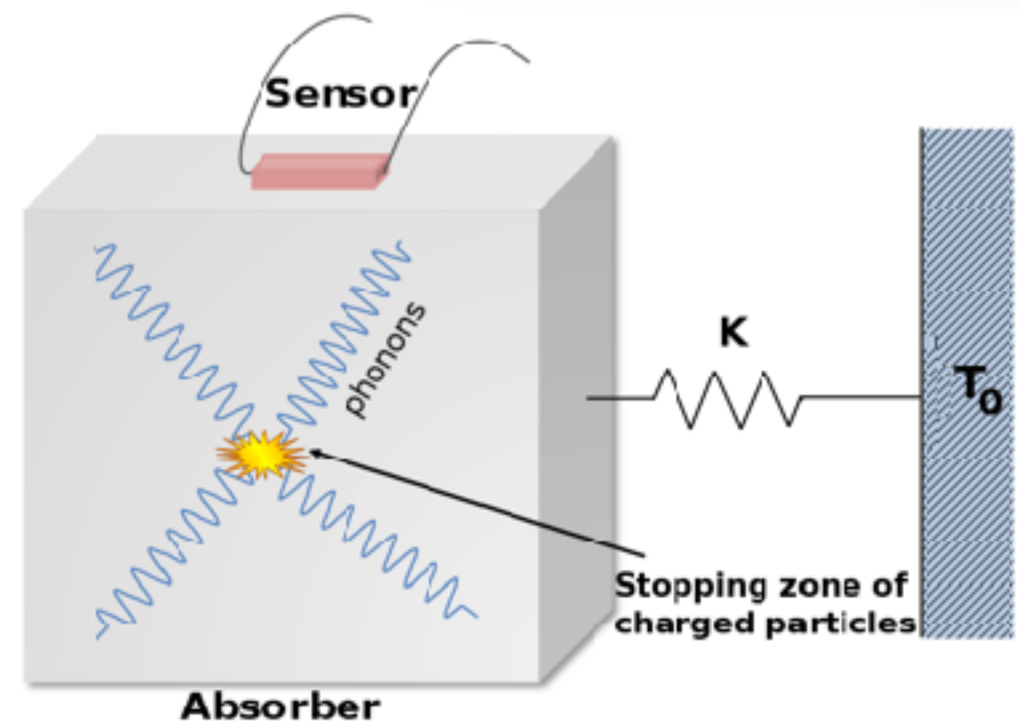
- $Q_{\beta\beta}$ = 2528 keV
- Isotopic mass of ^{130}Te : 206 kg
- 988 TeO_2 crystals (arranged in 19 towers with 13 floors each)
- Massive thermal calorimeters operated at ~10 mK
- Goal:
  - $\triangle E_{FWHM} \leq 5$ keV @ 2615 keV
  - B = 0.010 cnts/(keV·kg·yr)
  - $T_{1/2}$ (90% C.L.) > 9.5 x 10^{25} y (5 yrs of live time ; $<m_{\beta\beta}>$ ~ 50 - 130 meV)

DETECTOR PRINCIPLE : THERMAL CALORIMETERS

$$\Delta E_{TFN} = \sqrt{k_B T^2 C(T)}$$

Source = Detector

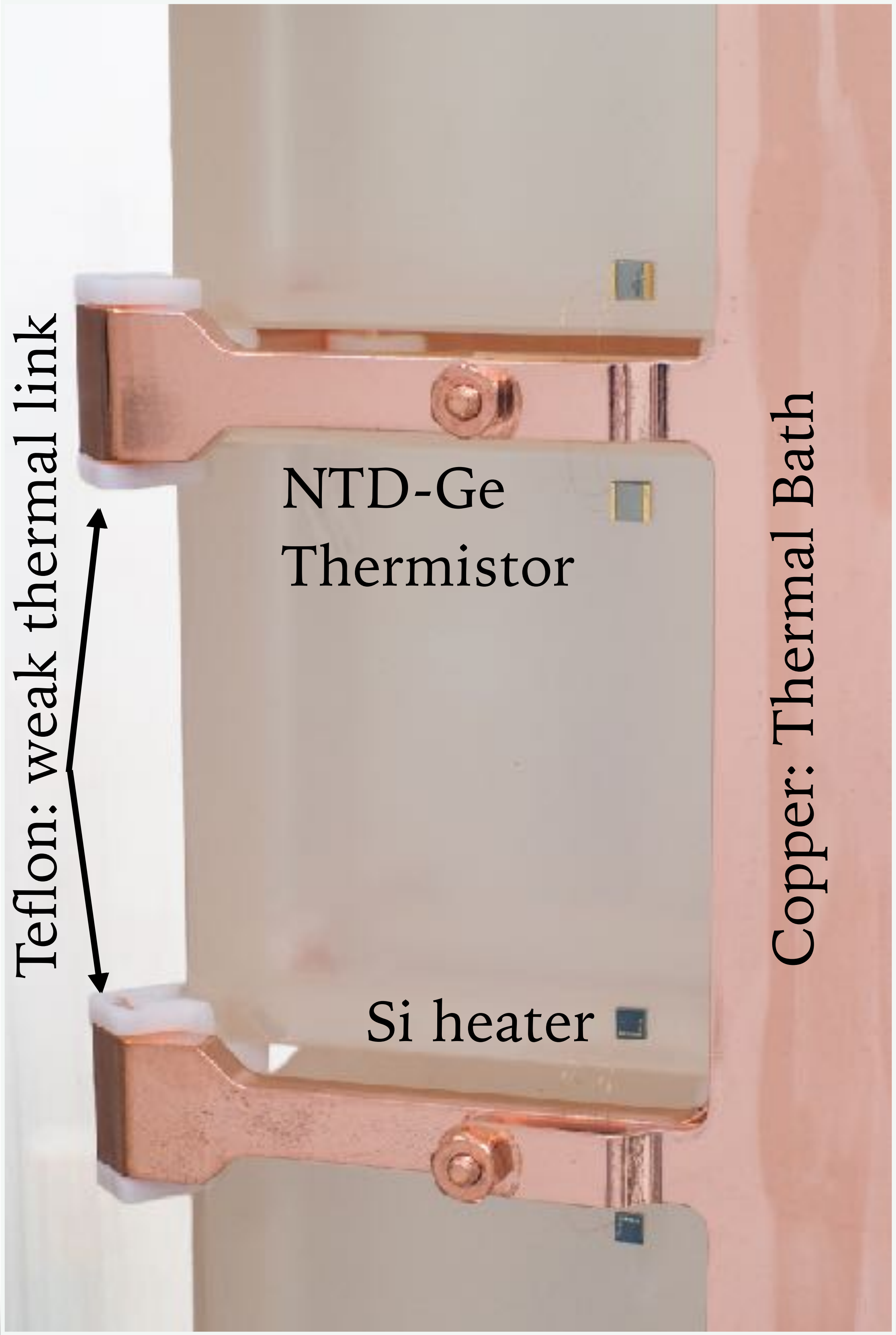




$$< \Delta E_{FWHM} >^2 = < \Delta E_{TFN} >^2 + < \Delta E_{electronics} >^2 + < \Delta E_{vibration} >^2 + \ldots$$

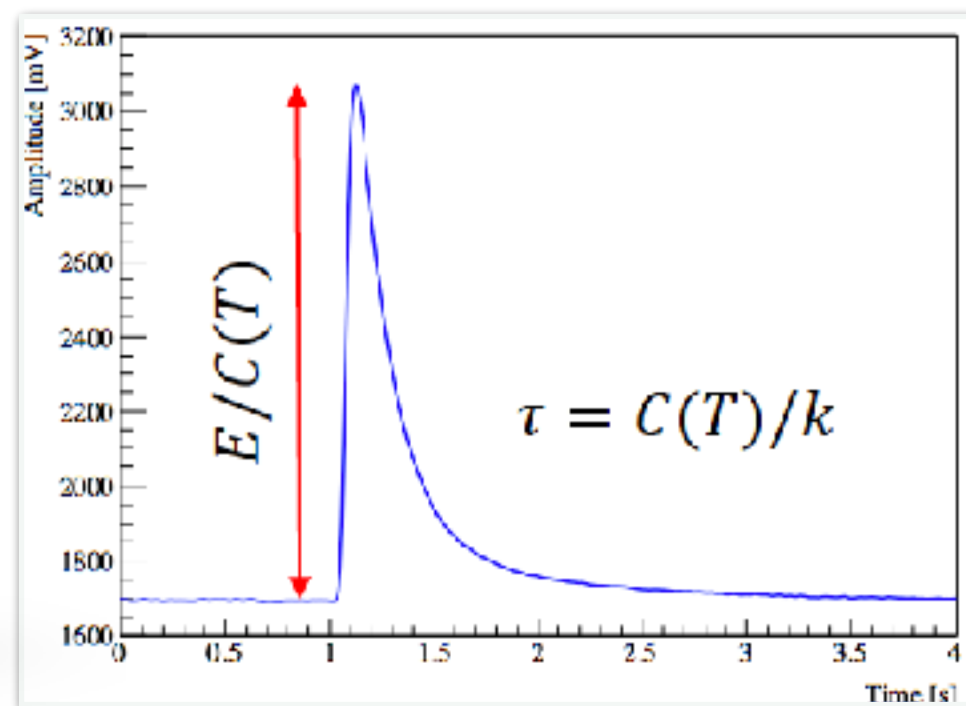
- Electron events mostly contained in the bulk : Large detection efficiency.
- The calorimeter cannot discriminate background from signal events easily.

- Thermodynamic limit for energy resolution can be made small by operating the detectors at a very low temperature.
- Requires ultra-low temperature facility with ultra-stable operating conditions.



DETECTOR PRINCIPLE

- 750 g (5x5x5 cm^3) crystal
- $\triangle T \sim 100\ \mu K$ for 1 MeV energy deposit
- NTD-Ge thermistor read out
  - $R(T) \sim R_0 \exp[(T_0/T)^{1/2}]$ (large sensitivity at low T)
- Energy response calibrated using known gamma sources
- Note:
  - Signal ➛ thermal channel only
  - No active background rejection

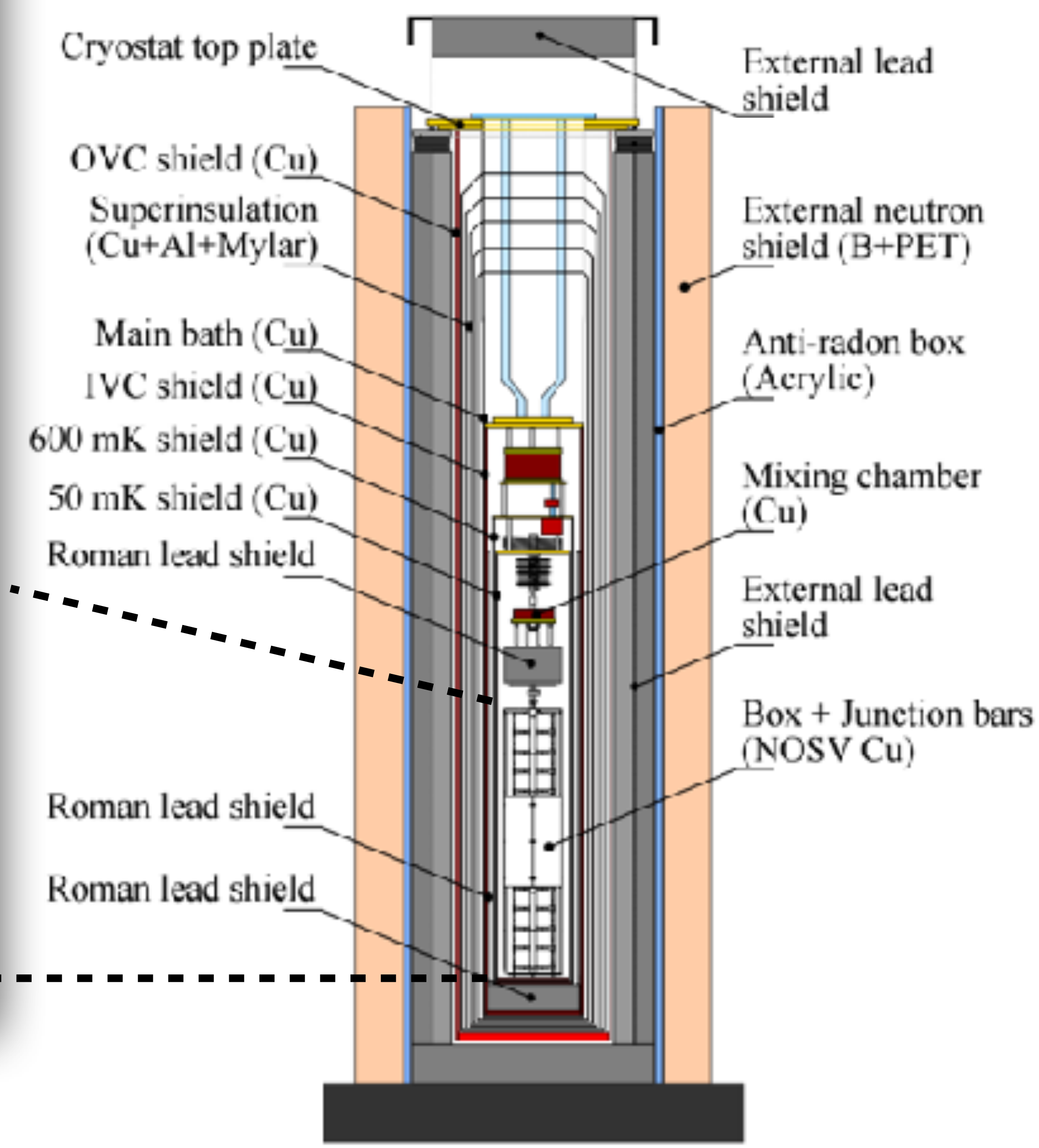


CUORE-0 : PRECURSOR OF CUORE

- Validation of assembly procedure for CUORE : first tower out of the assembly line
  - Strict material selection
  - Stringent surface cleaning procedures for detectors and materials nearby the detectors
  - Glovebox assembly to minimize Radon contamination
- 52 TeO_2 5x5x5 cm^3 crystals with a total mass of 39 kg; mass of ^{130}Te = 10.9 kg)
- ^{130}Te exposure = 9.8 kg yr

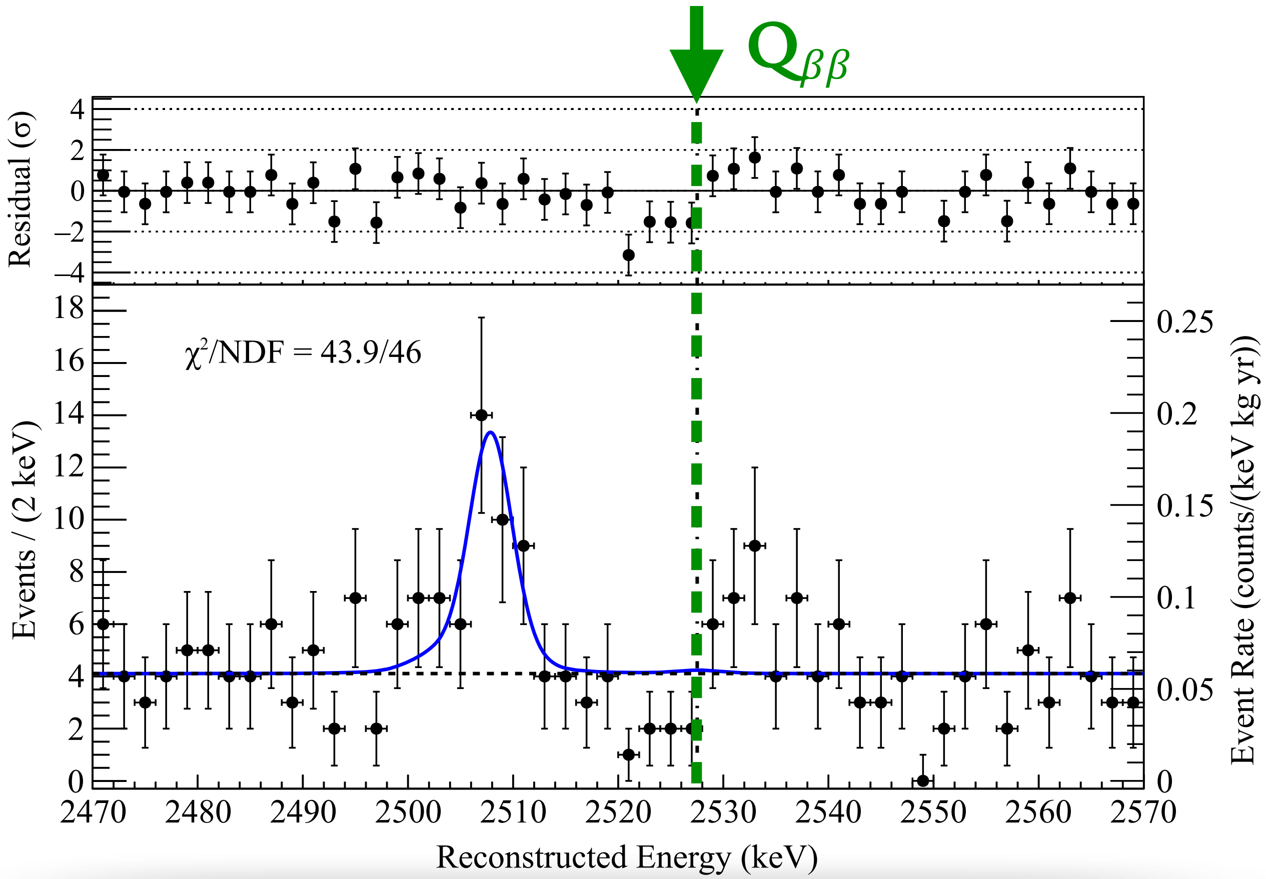
JINST 11 (2016) P07009

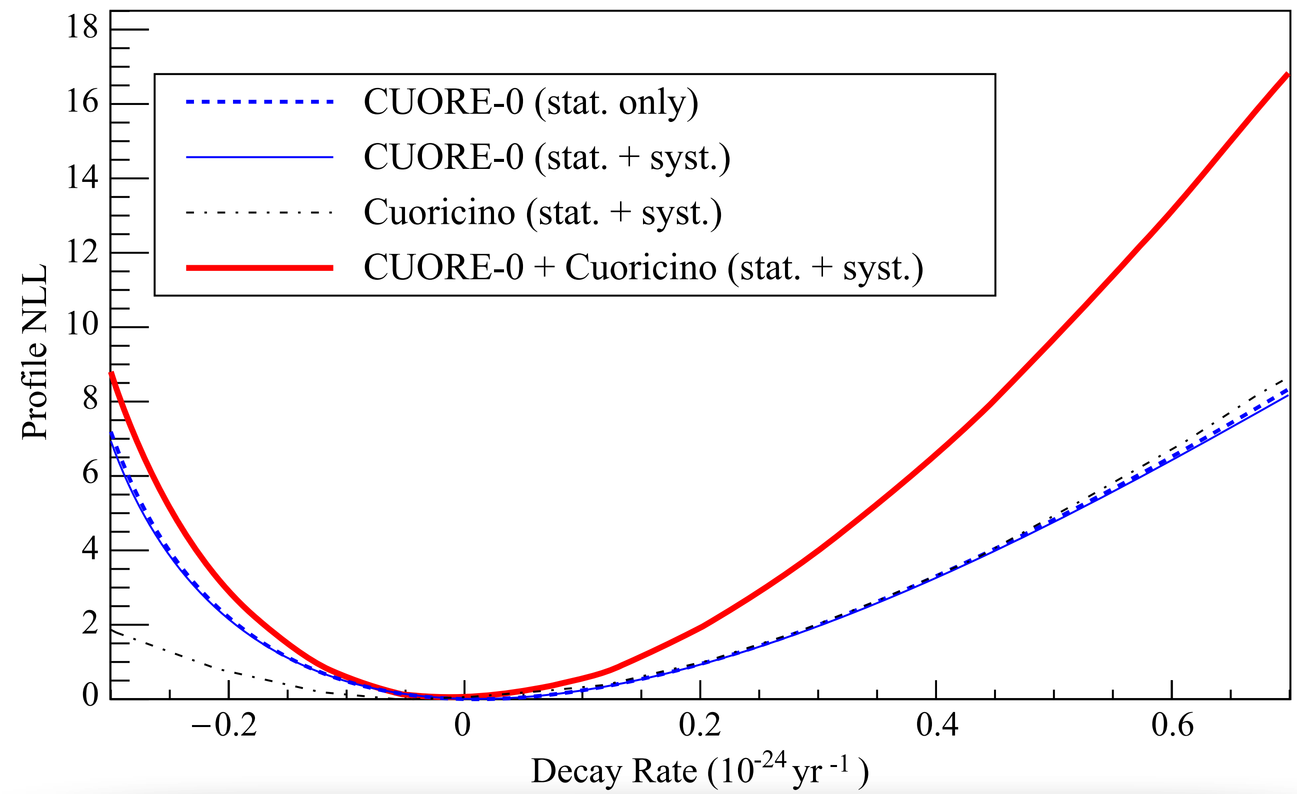
Same cryostat as Cuoricino, but not CUORE



CUORE-0 : $0\nu\beta\beta$ RESULTS

Phys. Rev. Lett. 115 (2015) 10, 102502
Phys. Rev. C 93 (2016) 045503





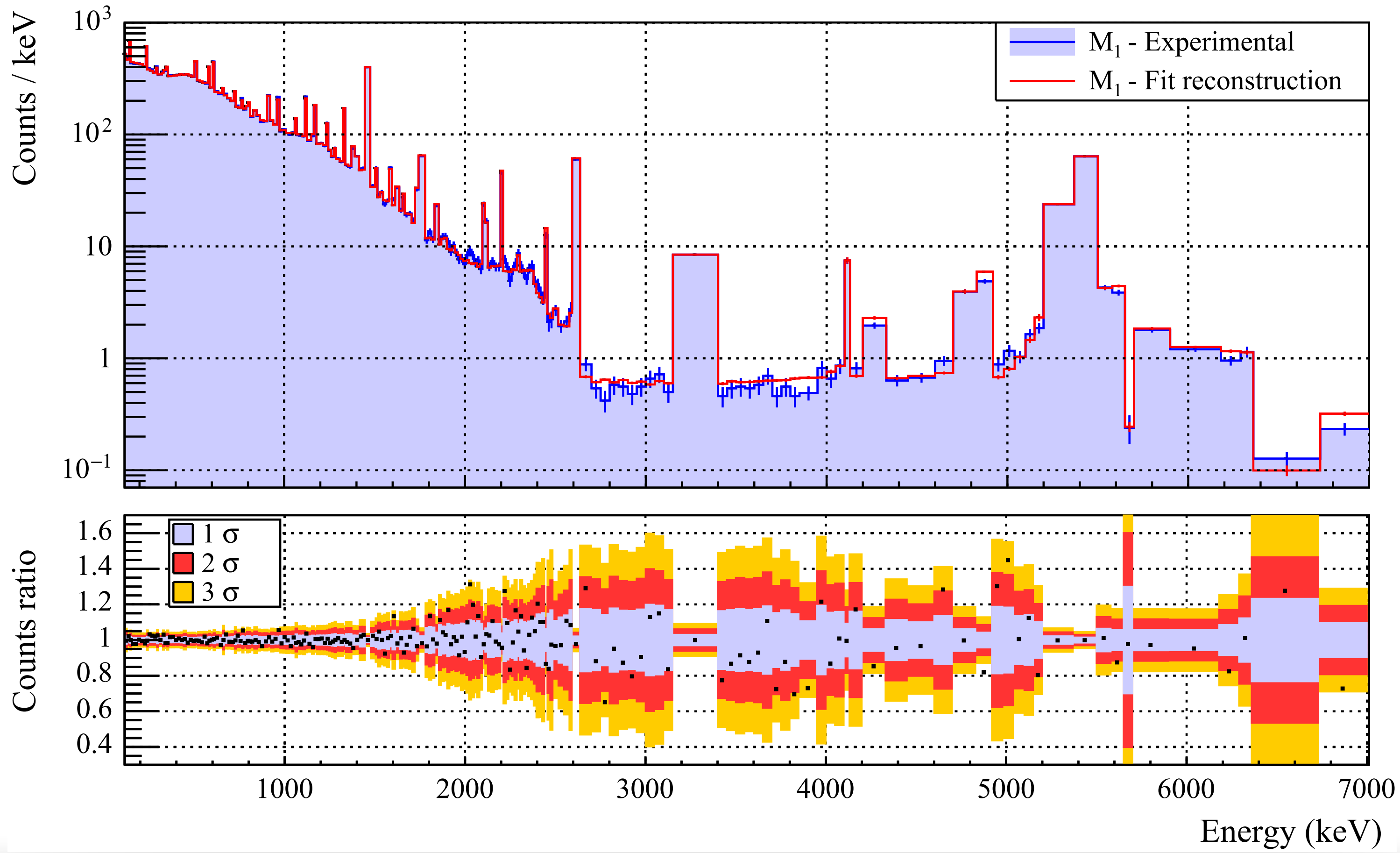
- $\triangle E_{FWHM}$ = 5.1±0.3 keV @2528 keV
- Background (cnts/(keV·kg·yr)): 0.058 ± 0.004 (stat.) ± 0.002 (syst.)
- CUORE-0 limit (90% C.L.):

  $T_{1/2} > 2.7 \times 10^{24}$ yr

Combining the limit with Cuoricino result (90% C.L.):
$T_{1/2} > 4.0 \times 10^{24}$ yr

CUORE-0 : $2\nu\beta\beta$ RESULTS

Eur. Phys. J. C 77 (2017) 13



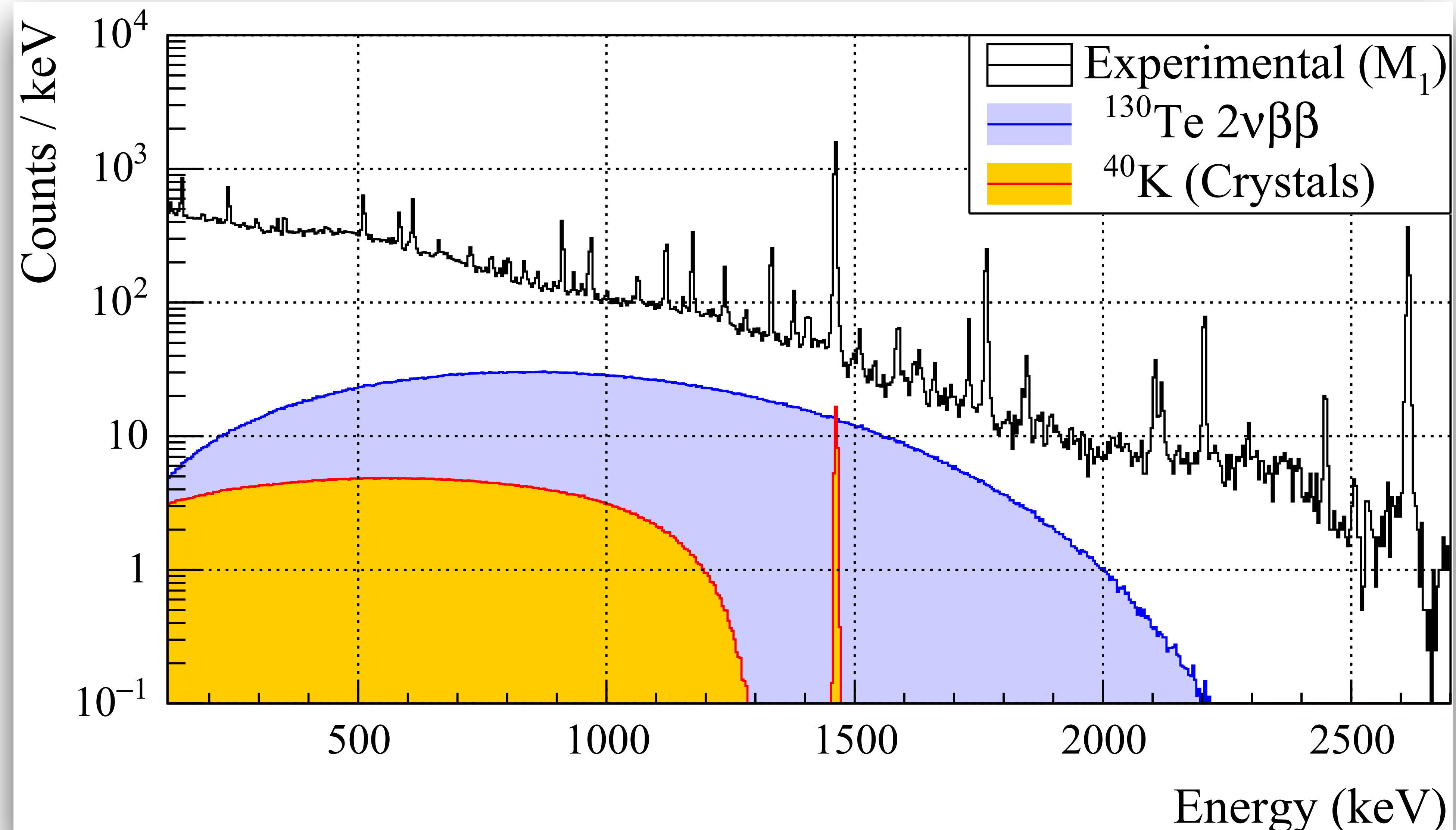
Background sources identified and ascribed to different locations in the experimental setup using

- Coincidence analysis
- Gamma peaks
- Alpha peaks
- Radio-assay measurements
- Data from neutron activation

Excellent agreement of the data with the background model with $2\nu\beta\beta$

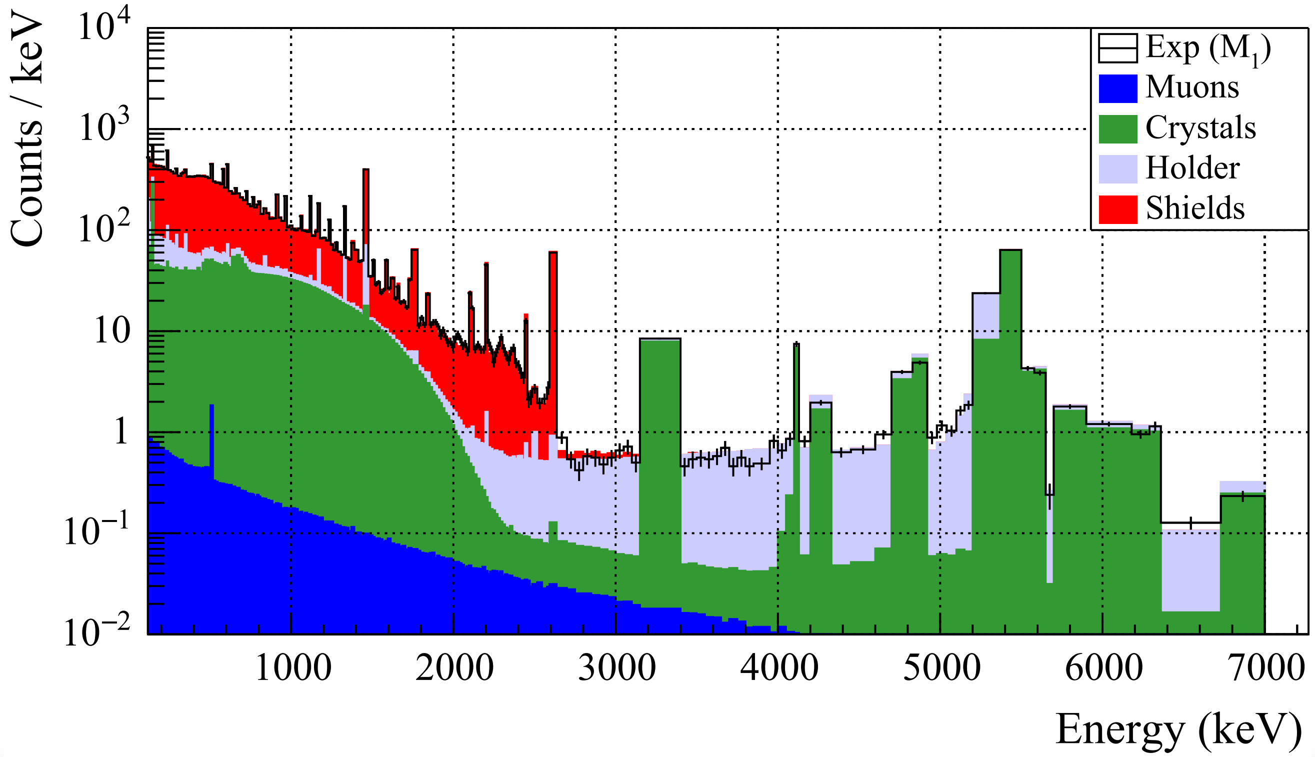
CUORE-0 : $2\nu\beta\beta$ RESULTS

Eur. Phys. J. C 77 (2017) 13



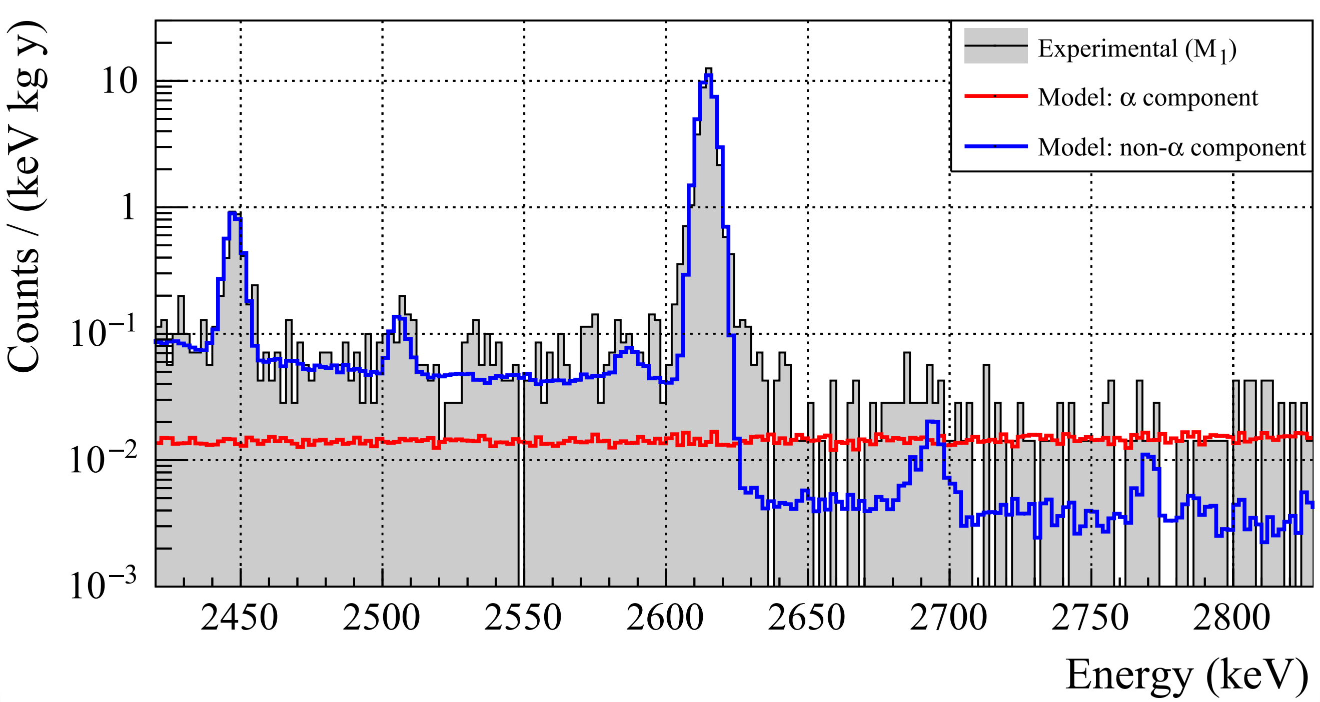
- CUORE-0: $T_{1/2}$ = [8.2 ± 0.2 (stat.) ± 0.6 (syst.)] × 10^{20} y
- NEMO: $T_{1/2}$ = [7.0 ± 0.9 (stat.) ± 1.1 (syst.)] × 10^{20} y
- MiDBD: $T_{1/2}$ = [6.1 ± 1.4 (stat.) $^{+2.9}{}_{-3.5}$ (syst.)] × 10^{20} y

CUORE-0 : BACKGROUND ESTIMATES FOR CUORE



Component	Fraction [%]
Shields	74.4 ± 1.3
Holder	21.4 ± 0.7
Crystals	2.64 ± 0.14
Muons	1.51 ± 0.06

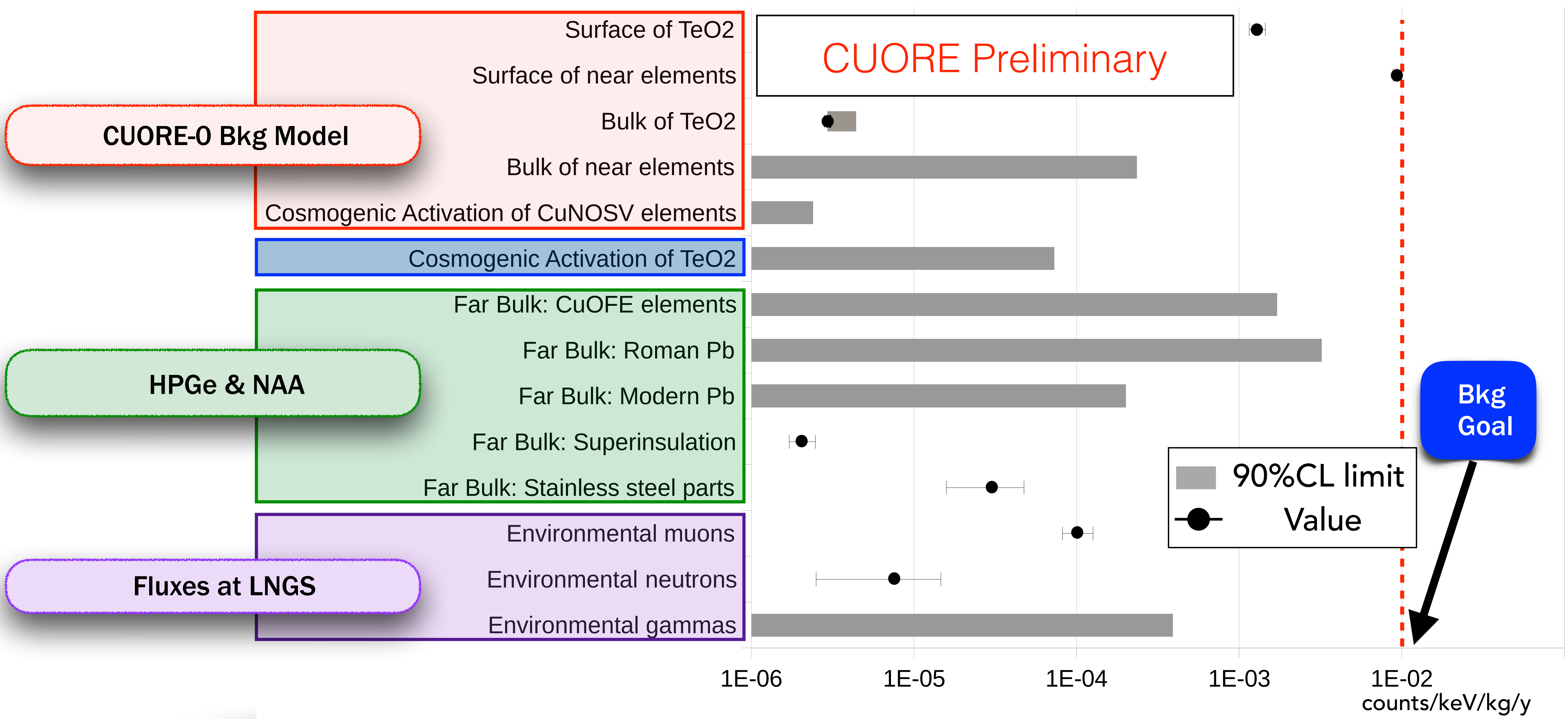
Events due to alpha particles (about 24% of the ROI background)



- *Shields of CUORE cryostat are significantly more radio-pure than CUORICINO.*
- *The granularity and self-shielding of the detector array will also help reduce the background.*

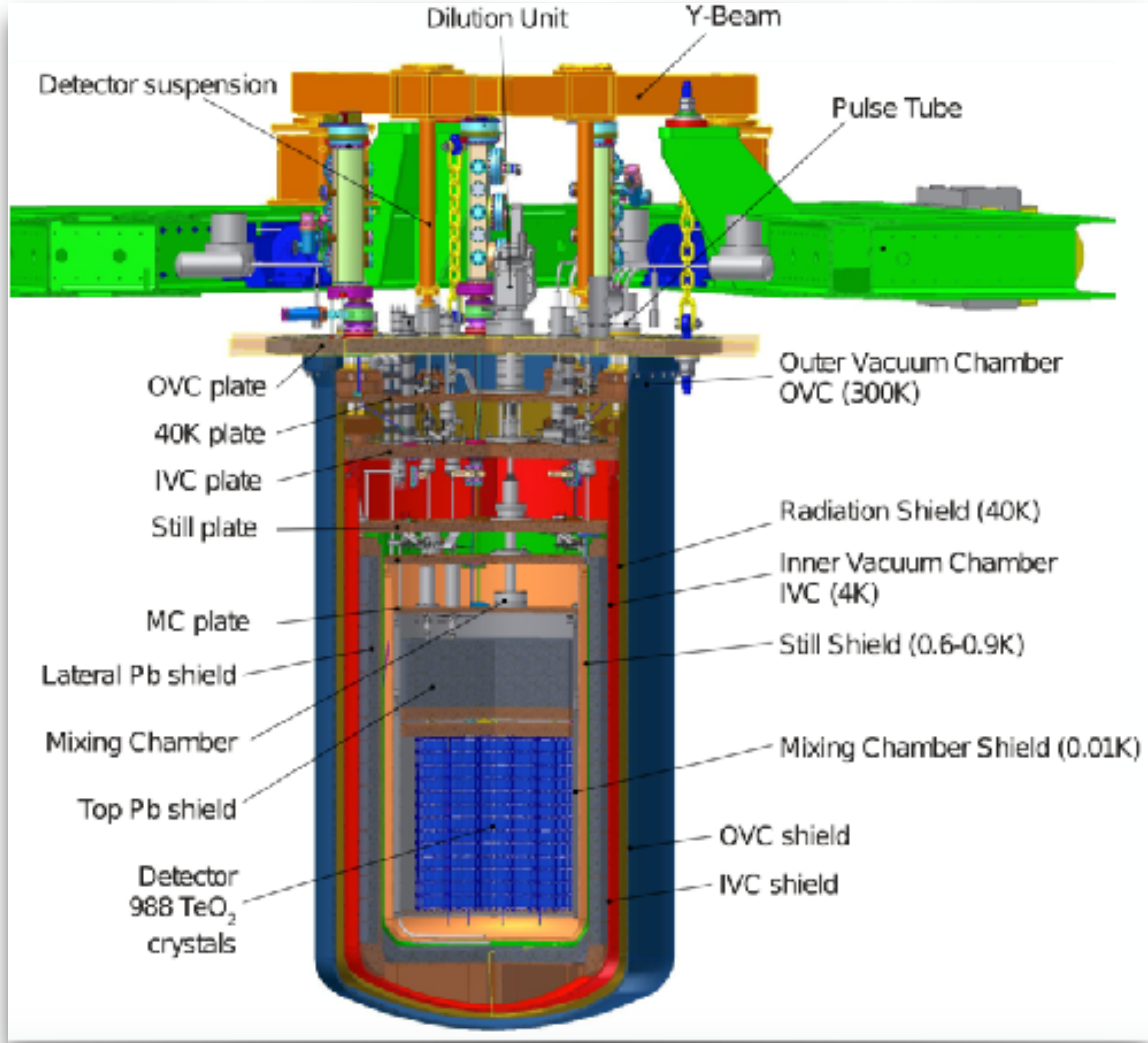
We expect a better background in the ROI.

CUORE: BACKGROUND BUDGET



Material choices strictly constrained by thermal properties, mechanical strength and radio-purity

CUORE: CRYOSTAT COMMISSIONING

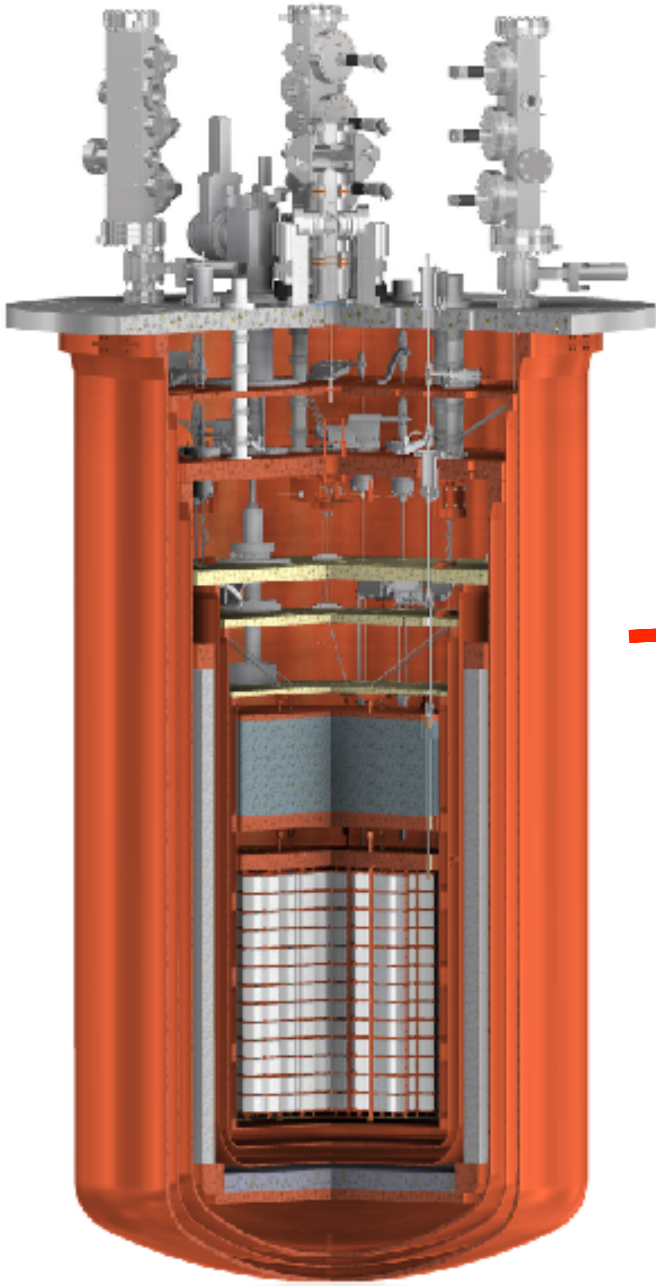


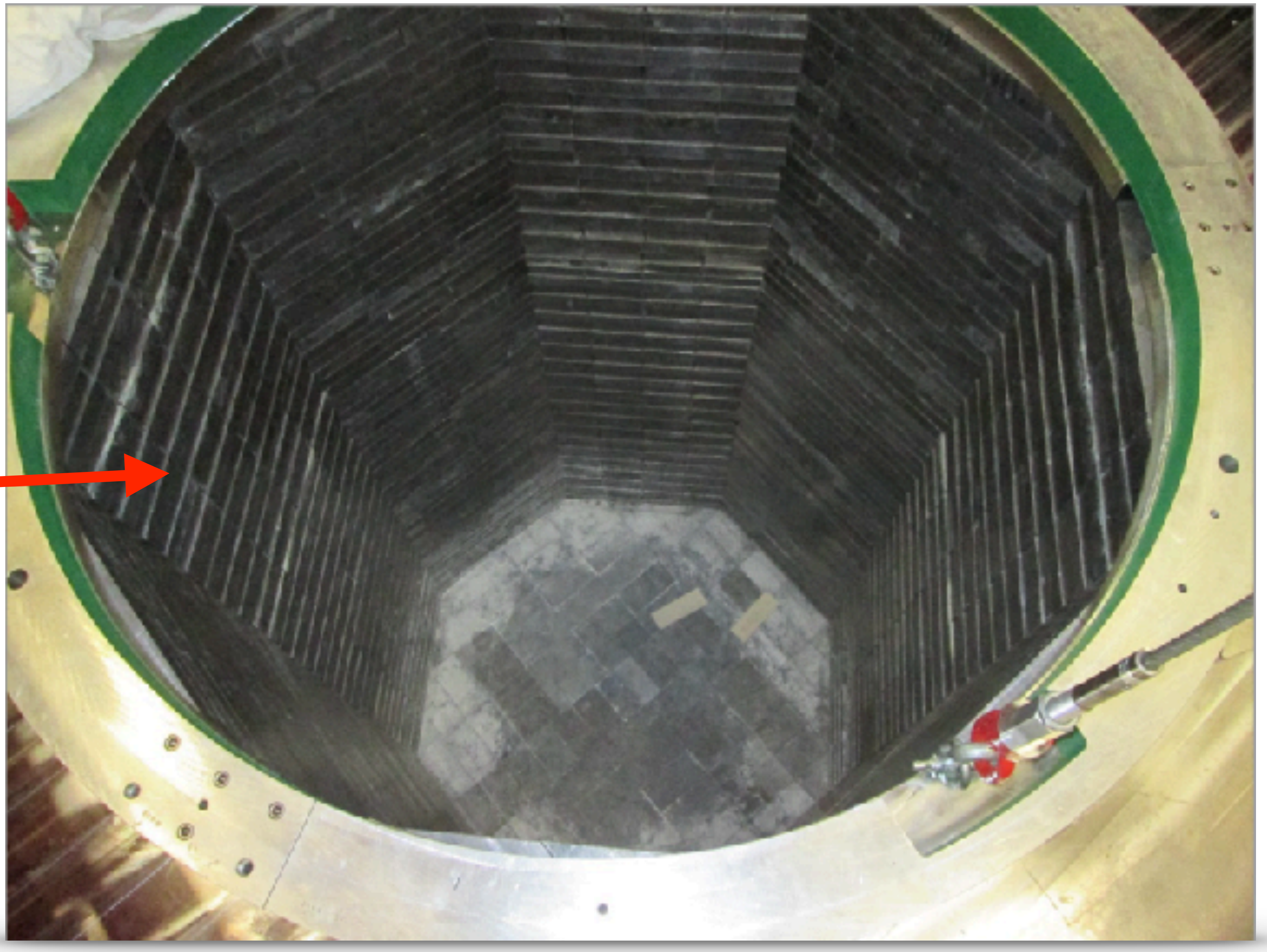
- Experimental Conditions
  - Low radioactivity environment
  - Stable ultra-low temperatures
  - Extremely low vibrations

30 cm of Pb Top Shield (2.5 tons@50 mK)

6 cm Roman Pb Shield (5 tons@4K)

EXTERNAL SHIELDING



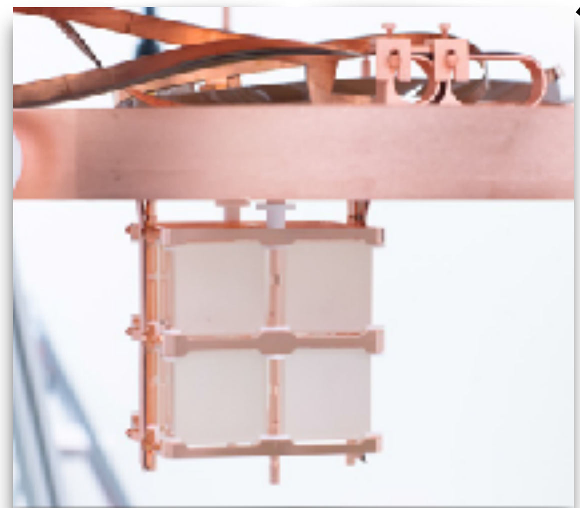


External lead: 25 cm thick

Neutron shield: 18 cm of PET + 2 cm of H_3BO_3

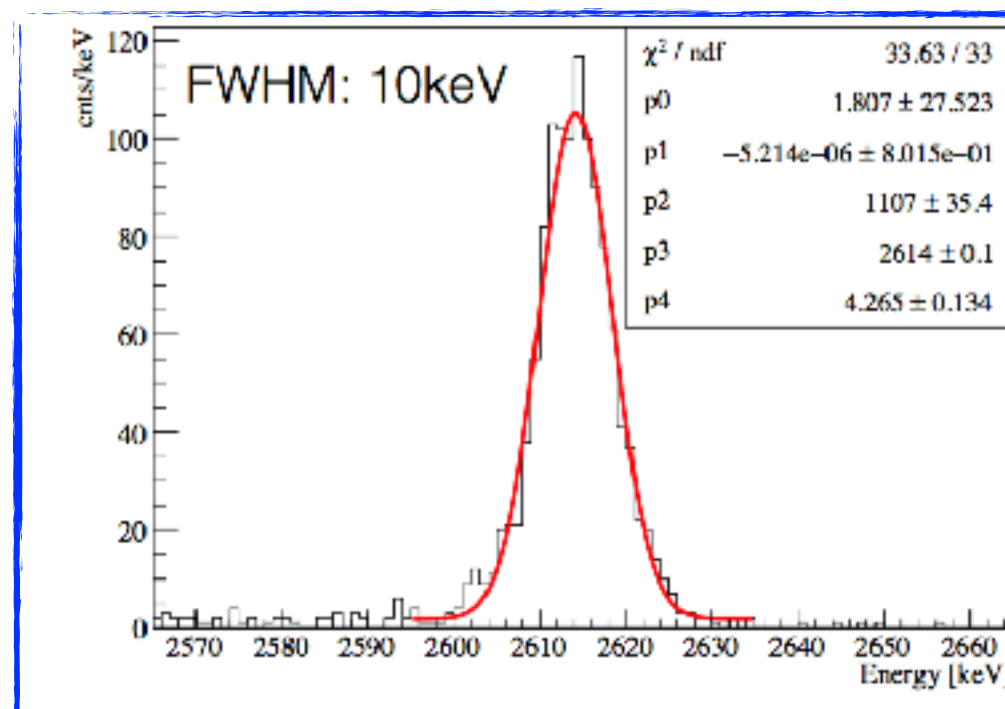
RESULTS: CRYOSTAT COMMISSIONING

- Commissioning completed in March'16.
- Stable base temperature ~ **6.3 mK**
- Proved nominal cooling power: **3 μW @ 10 mK**
- Successful test of the detector calibration system, electronics, DAQ and temperature stabilization system

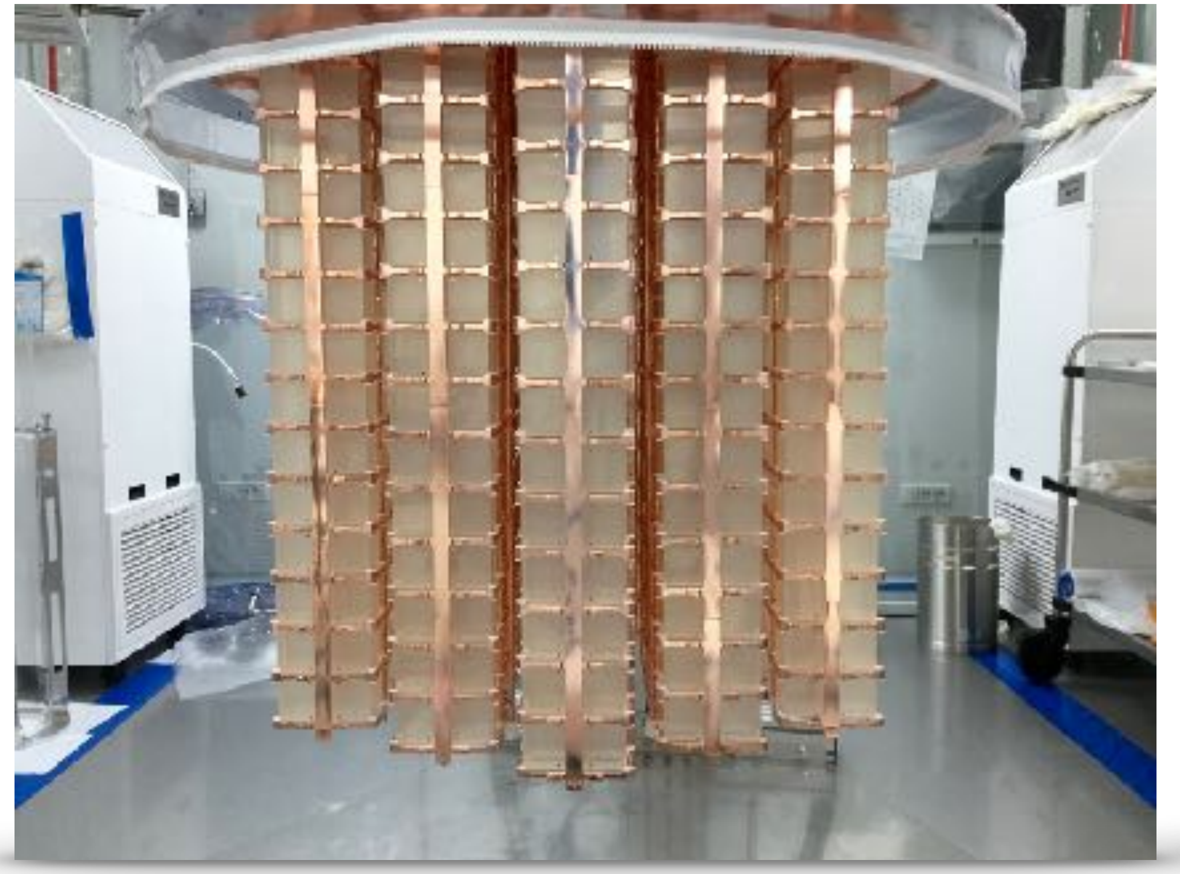


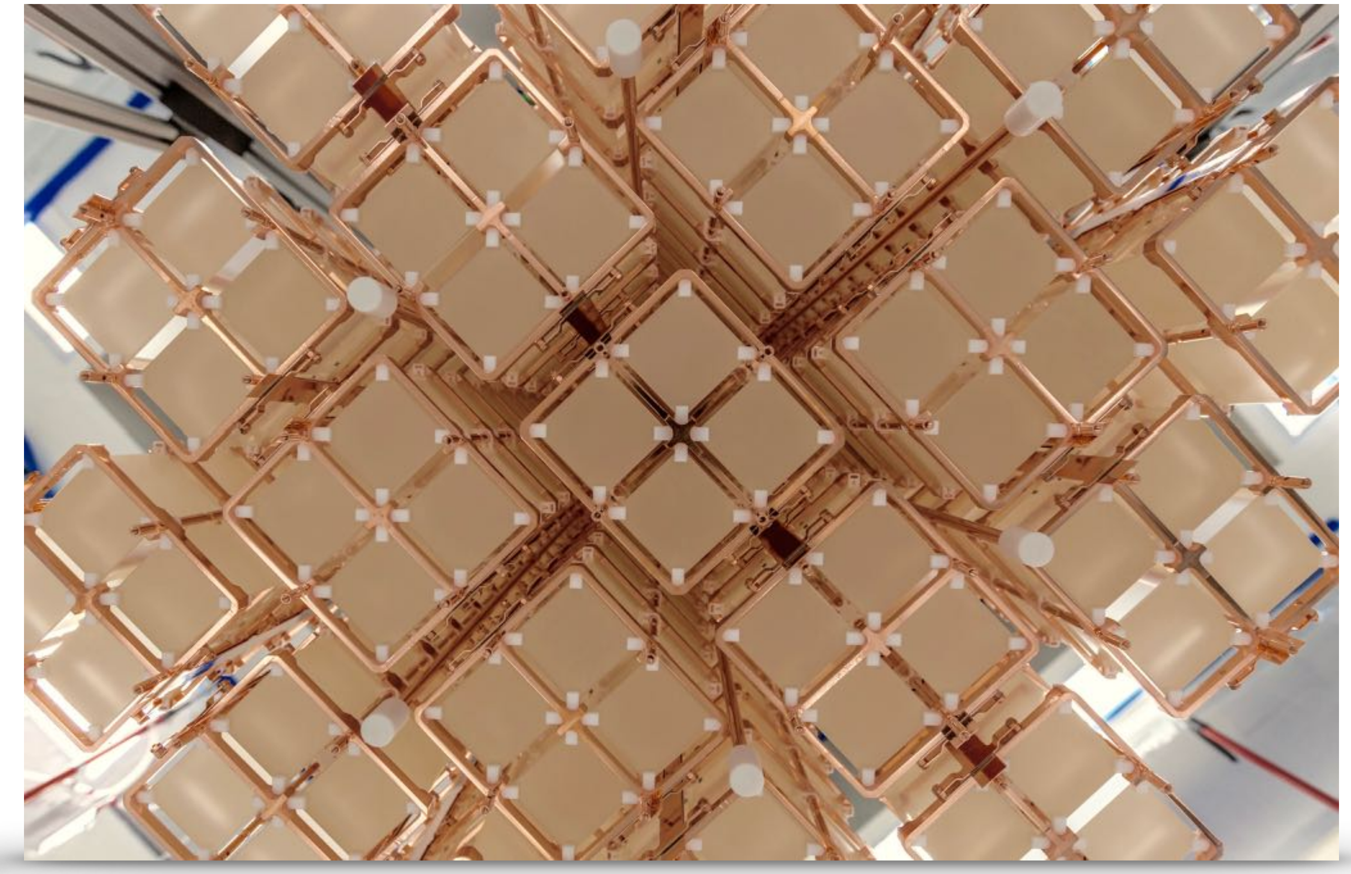
Mini-tower

- Encouraging detector performance on 8 detector array (Mini-tower)
- No indications of unaccounted for bkg sources



CUORE: DETECTOR INSTALLATION

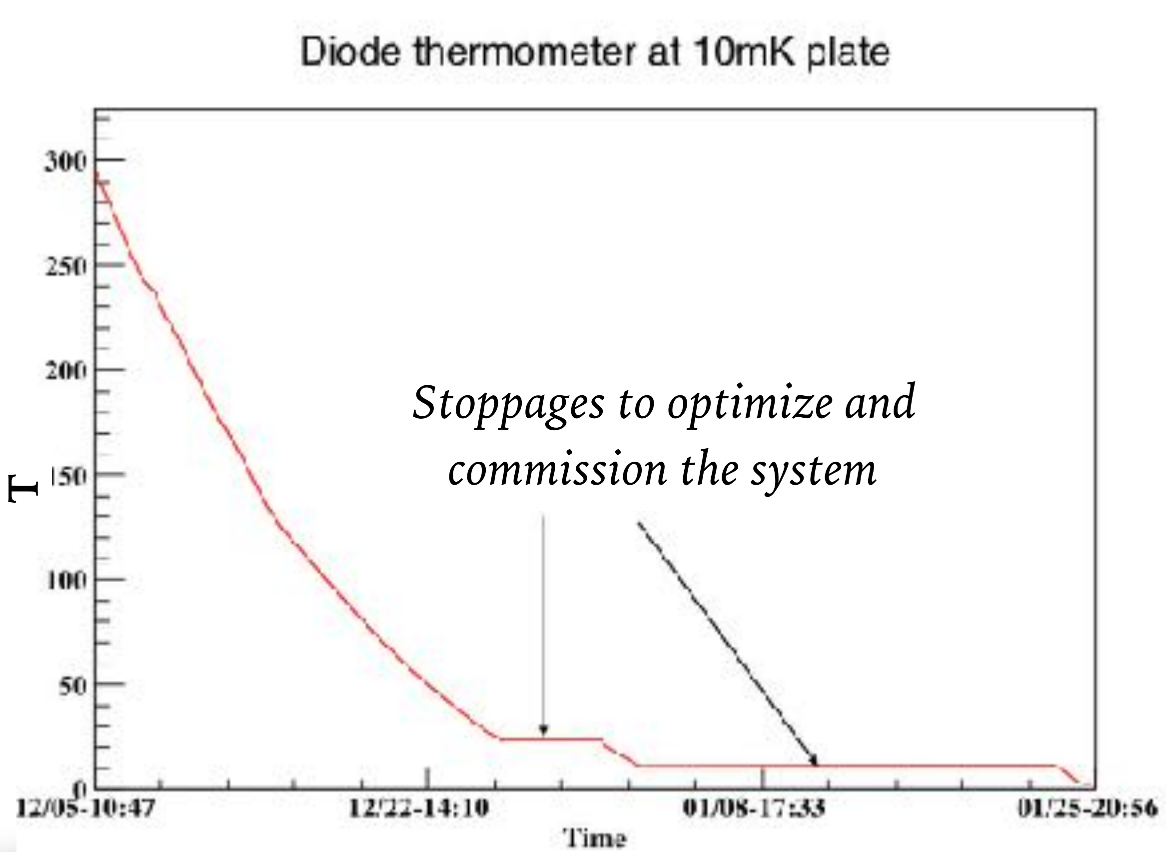


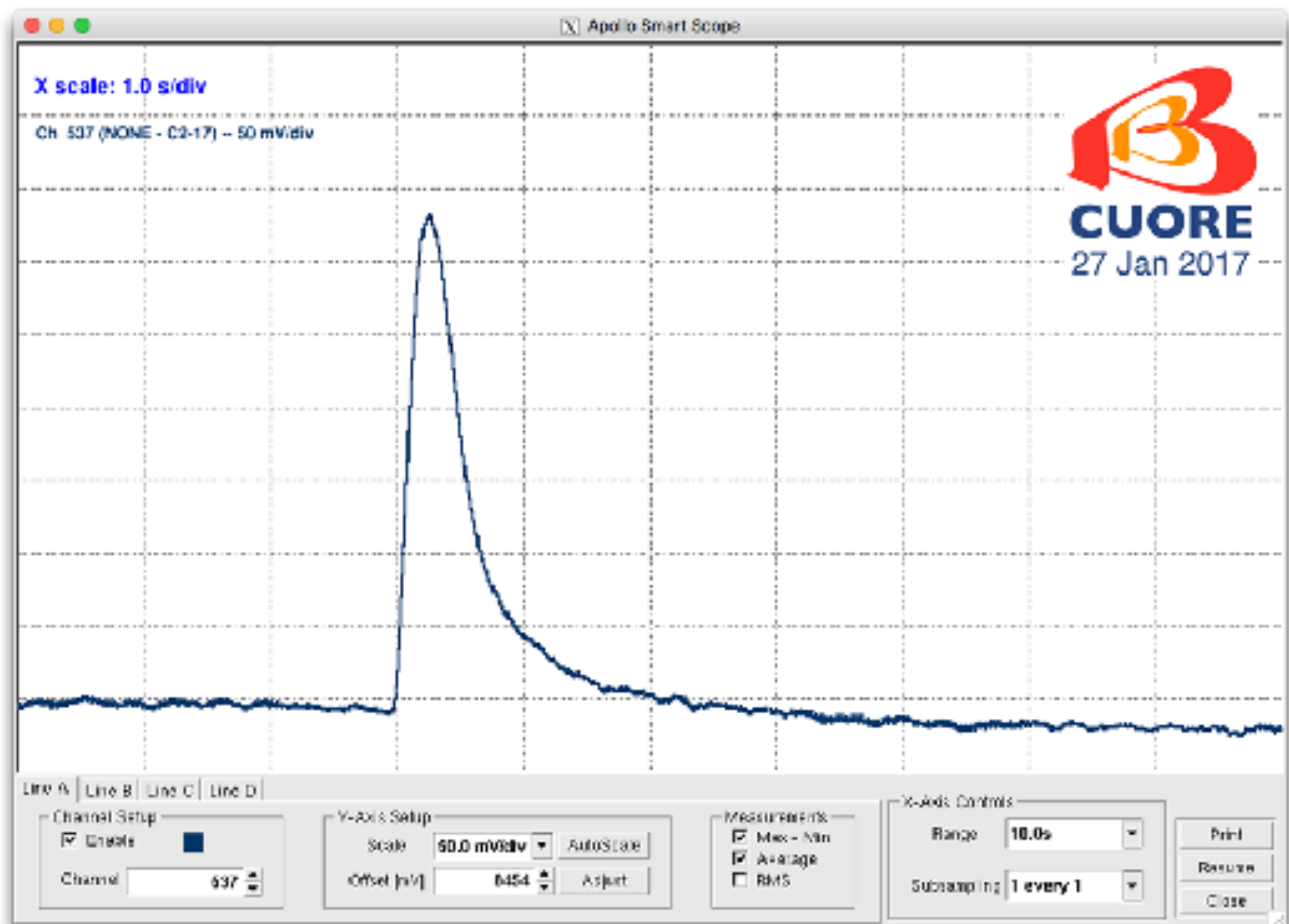


- *Detector installation was completed in a specially constructed cleanroom, constantly flushed with Radon free air.*
- *Electronics and DAQ installation complete.*

CUORE: COOLDOWN AND PULSES

- Reached base temperature in January 2017 after two months of cool-down from room temperature.
- Stable base temperature ~ **8 mK**
- First Pulses!

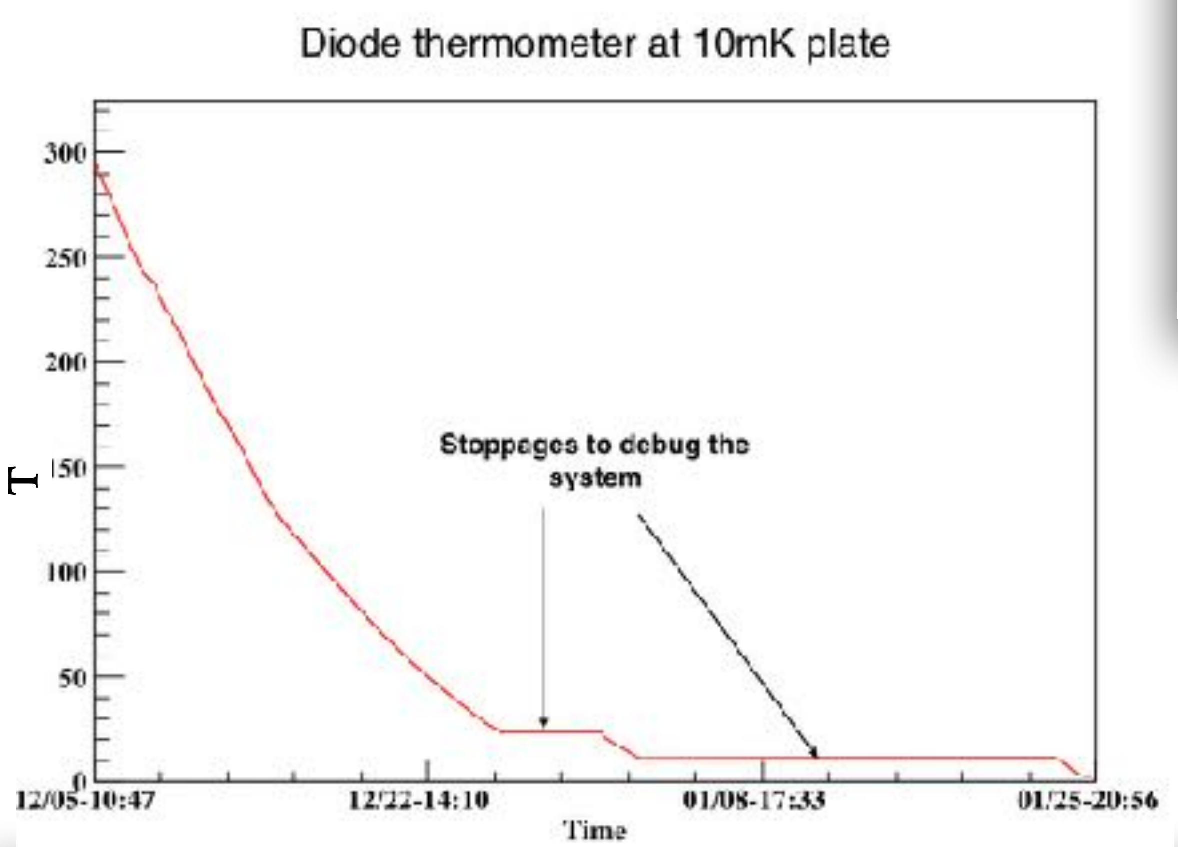




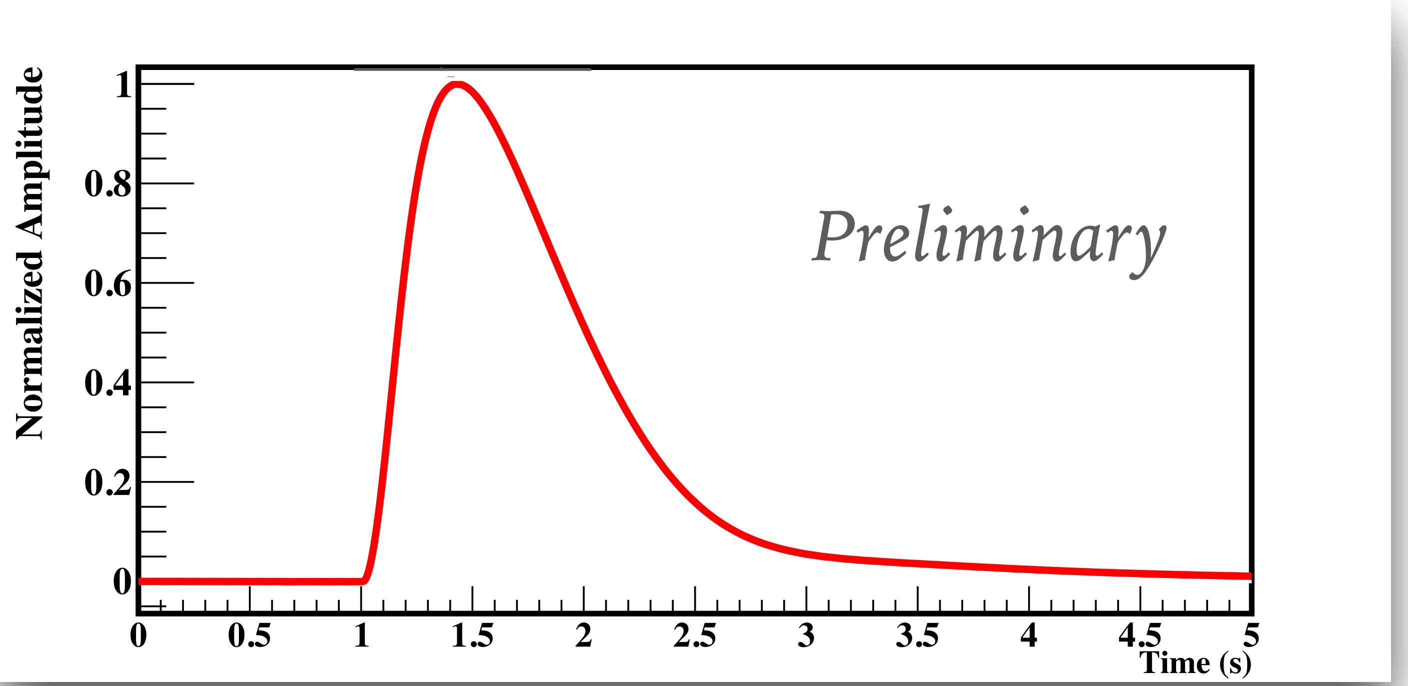
We are continuously improving on the vibrational and electronics noise.

CUORE: COOLDOWN AND PULSES

- Reached base temperature in January 2017 after two months of cool-down from room temperature.
- Stable base temperature ~ **8 mK**
- First Pulses!



Average pulse from heater on one of the channels

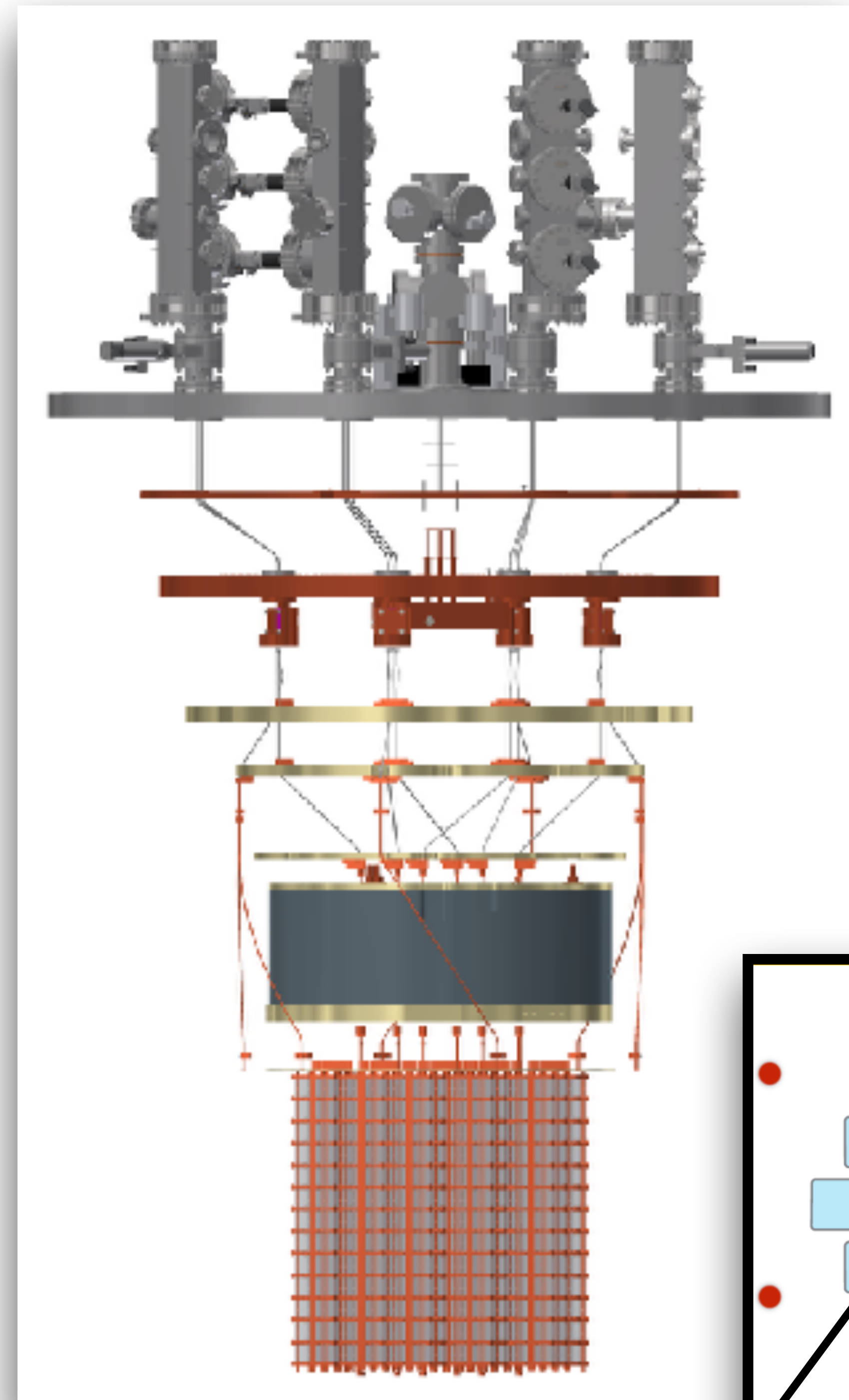


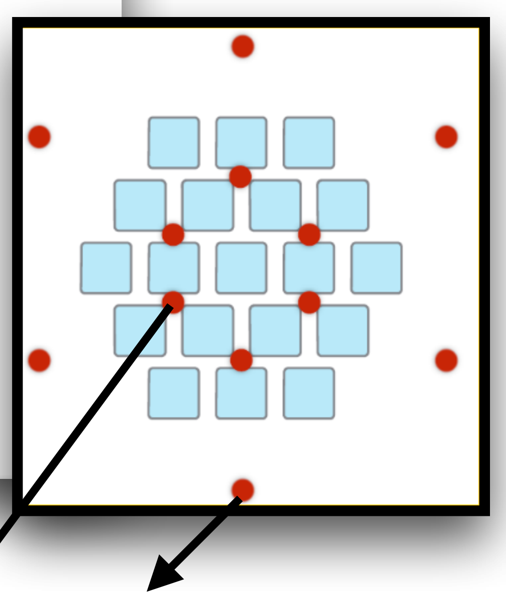
We are continuously improving on the vibrational and electronics noise.

Pulse shape parameters (rise time, decay time, etc.) will change as the detector commissioning continues

NEXT STEPS: CALIBRATION

Nucl. Instrum. Methods A 844 (2017) 32





3.5 Bq

19.4 Bq

- *In situ* energy calibration
- Low background contribution from calibration hardware (« 0.01 counts/keV/kg/year).
- 12 source strings to be lowered into the cryostat during calibration.
- Each source string contains 25 source capsules of thoriated tungsten wire (containing ^{232}Th)

Once we understand the energy scale and pulse shapes in the ROI we will be ready to take background data.

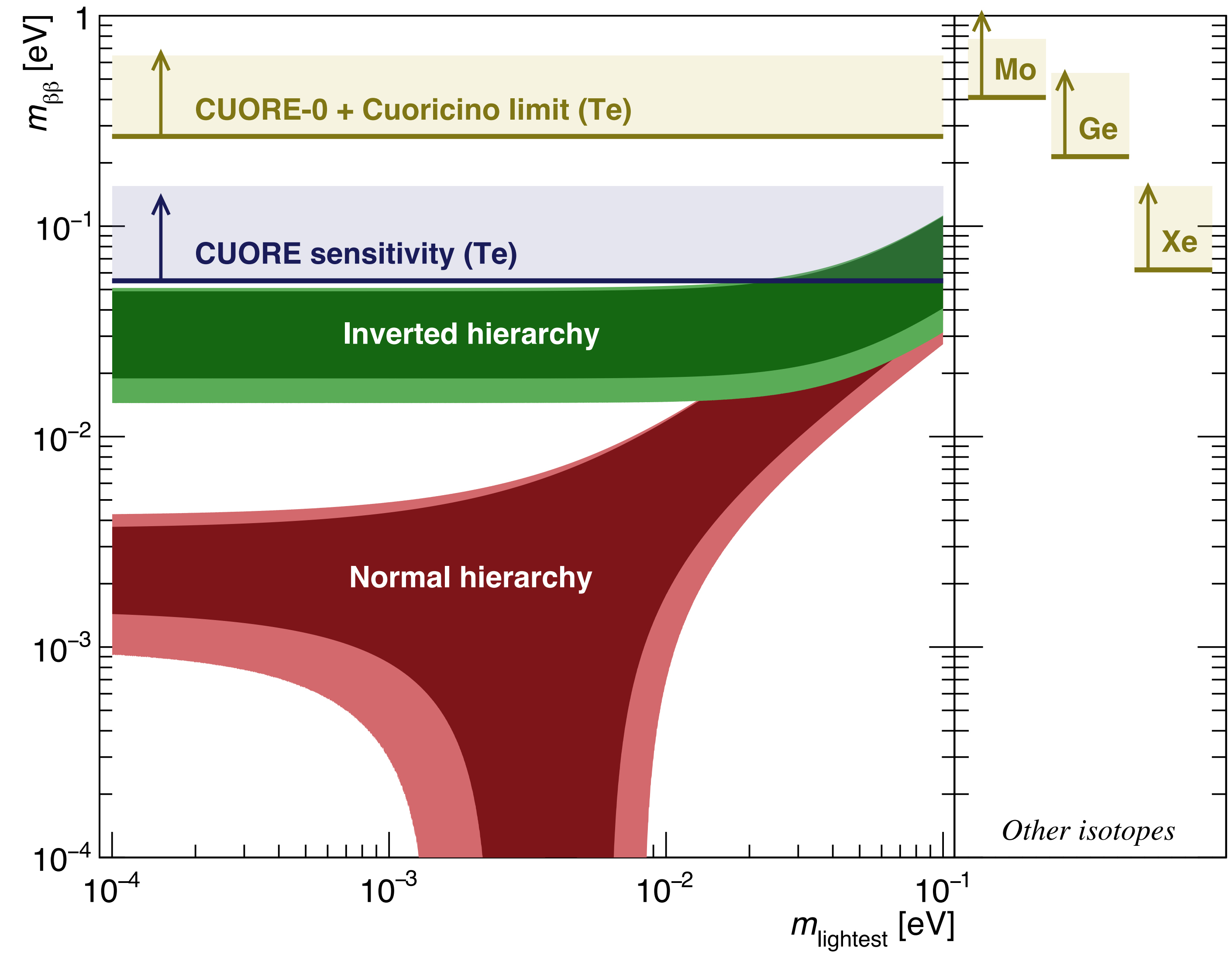
Stay tuned for Physics results soon !

CUORE: SENSITIVITY

- 988 bolometers
- 5 years of live time
- ΔE = 5 keV FWHM
- B = 0.01 counts /(kg . keV . yr)

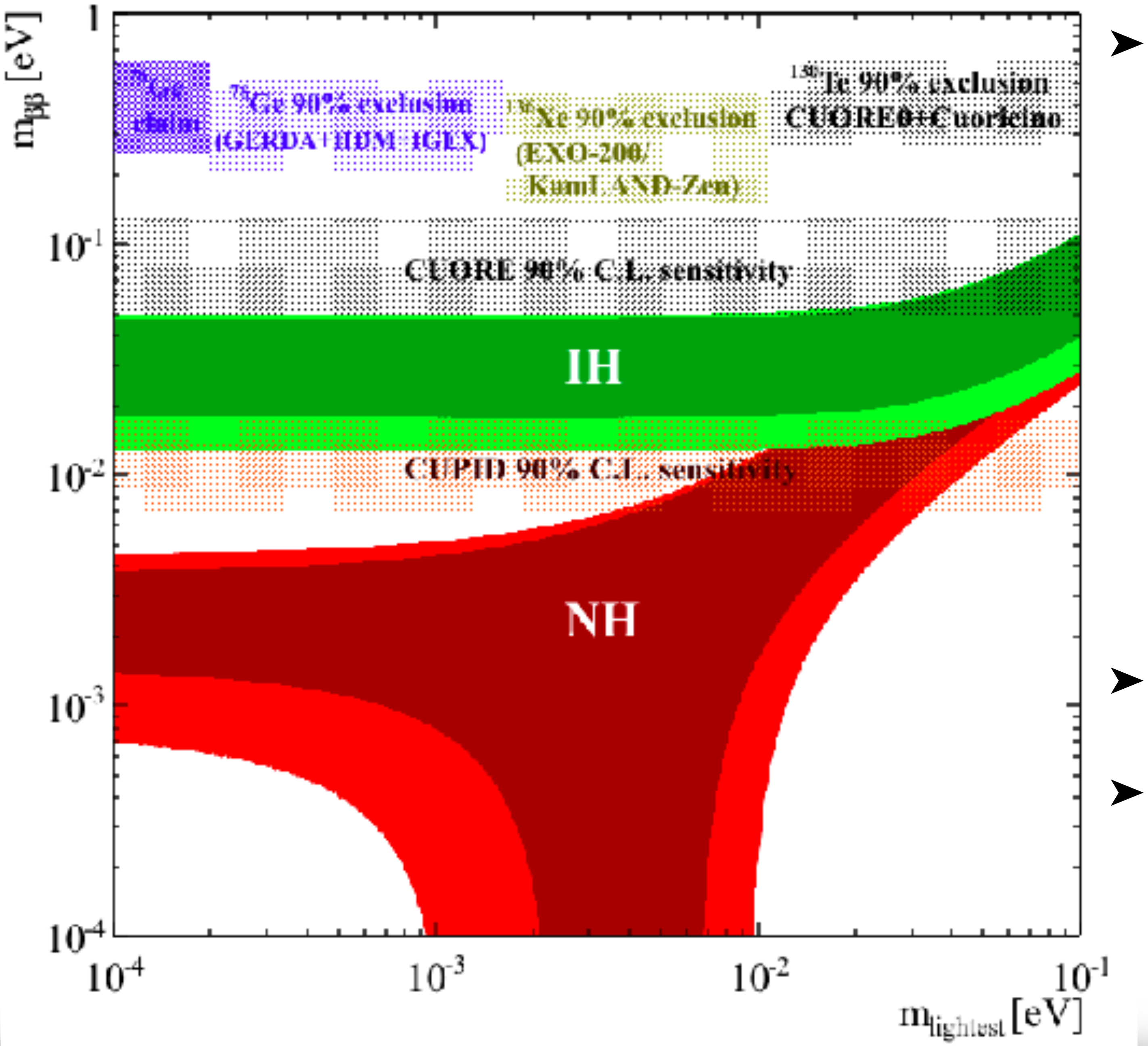
$$T^{0\nu}_{1/2} > 9.5 \text{ x } 10^{25}\ yr \quad (90\%\ CL)$$

CUORE may come close to start exploring the Inverted hierarchy region, depending on the NME



$$m_{\beta\beta} < (50 - 130\ meV)$$

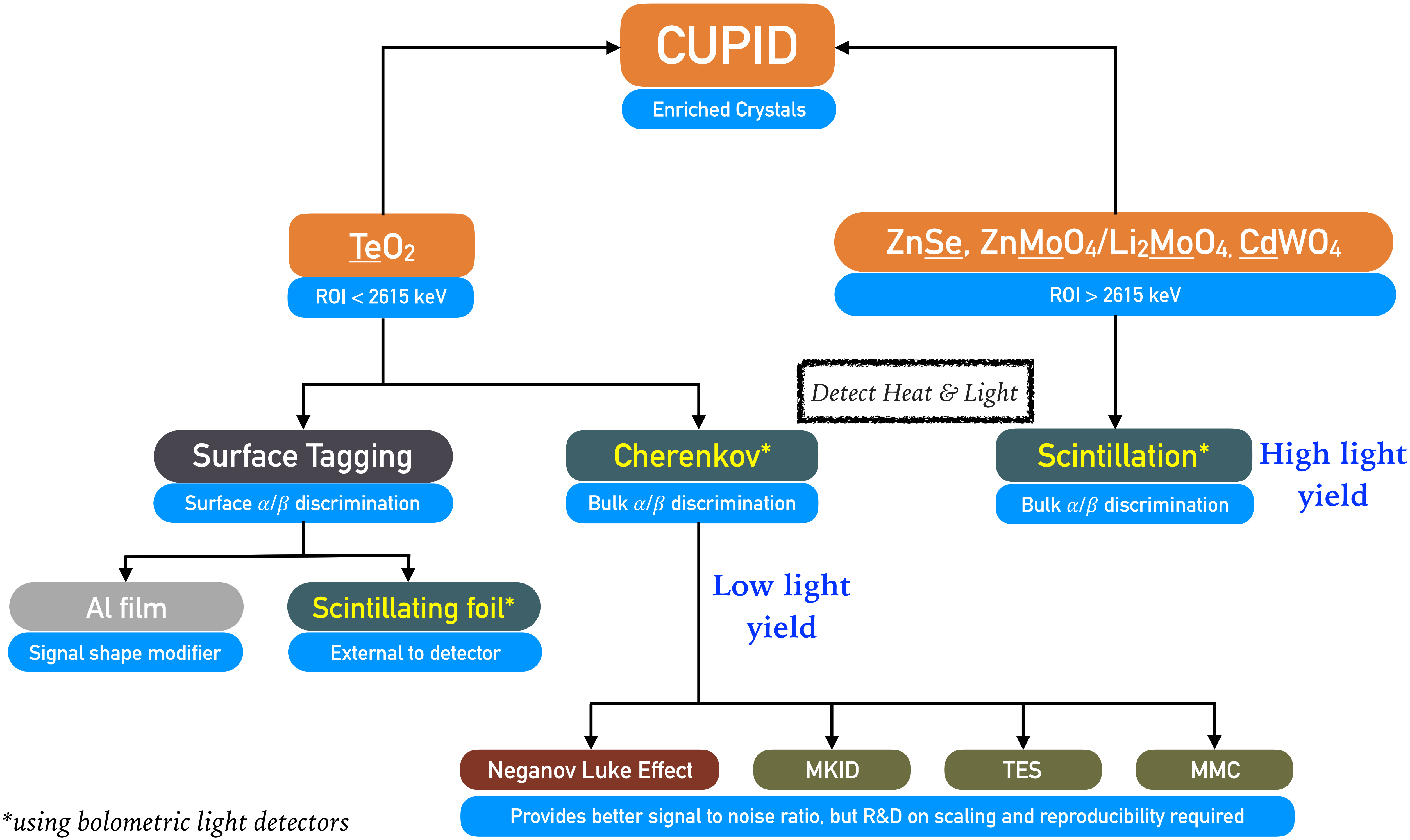
CUORE TO CUPID = CUORE UPGRADE WITH PARTICLE IDENTIFICATION



- Goal:
  - ➡ $\triangle E_{FWHM} \leq 5$ keV @ 2615 keV
  - ➡ B = 0.1 c/ton/y in ROI
  - ➡ $<m_{\beta\beta}> \sim$ 7 - 18 meV (10 yrs of live time)
- Increase Sensitive mass ☛ Enrichment
- Active background rejection method ☛ α / ($\beta^{-}\gamma$) separation

- Technology should be as compatible as possible with CUORE (mechanical coupling, cryogenics, etc)

R&D ACTIVITIES

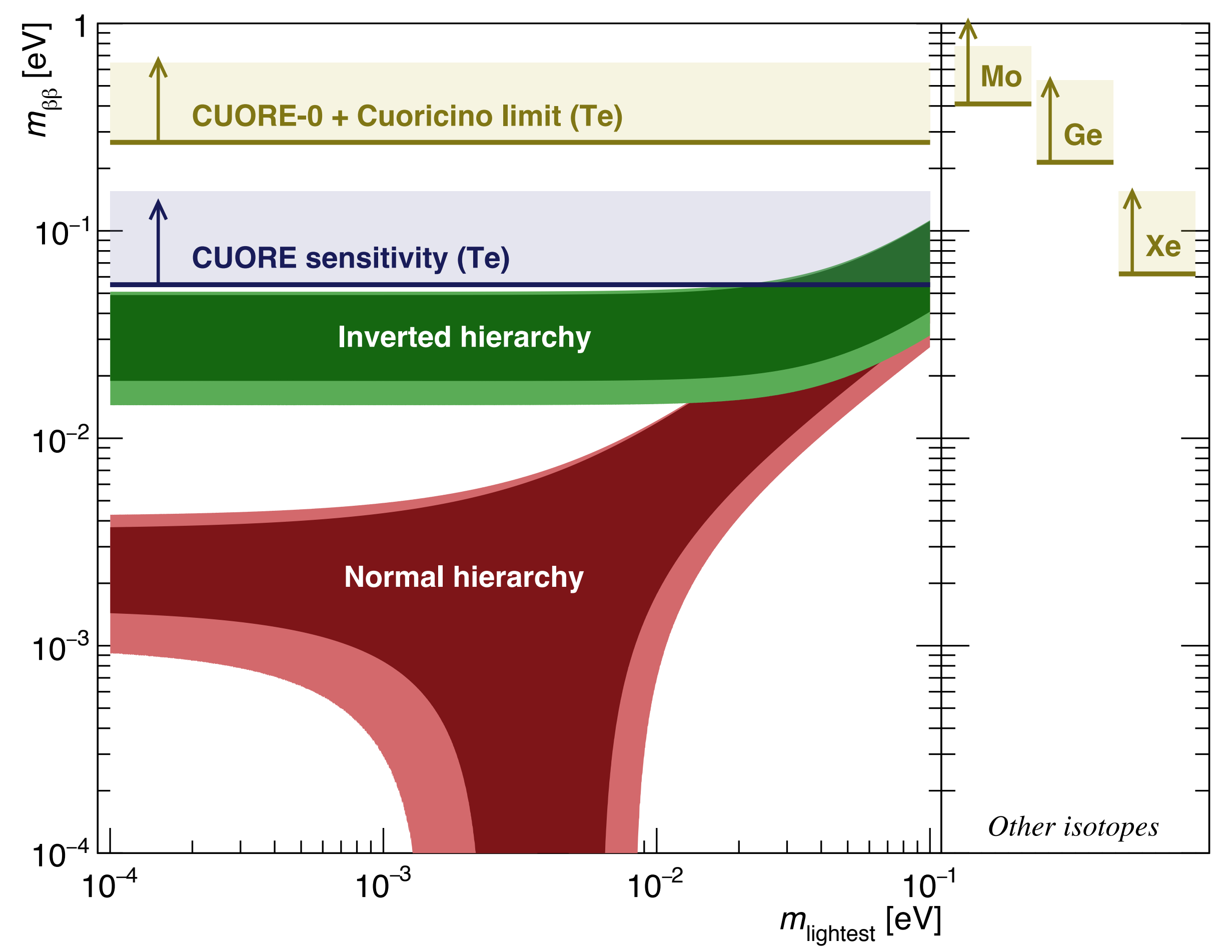


**using bolometric light detectors*

SUMMARY

- CUORE-0
  - Set the most stringent limit on the half-life of $0\nu\beta\beta$ in ^{130}Te
  - Made the most precise measurement of $2\nu\beta\beta$ half-life in ^{130}Te
  - Validated the assembly line production and the background model for CUORE

- CUORE
  - The cryostat has been successfully cooled down to ~ 8 mK, with all the detectors installed
  - We have started the detector operations; expect physics data soon.
  - Will pave the way for next generation large bolometric experiments.



COLLABORATION

CSNSM

Yale

Universitas Studii Paduani MCCXXII

INFN Istituto Nazionale di Fisica Nucleare

Berkeley Lab

Cal Poly San Luis Obispo

The University of California 1868

Massachusetts Institute of Technology

VirginiaTech Invent the Future®

Lawrence Livermore National Laboratory

Sapienza Università di Roma

Università degli Studi di Milano Bicocca

Shanghai Jiao Tong University 1896

Alma Mater Studiorum A.D. 1088

Università degli Studi di Cassino e del Lazio Meridionale Sol per noctem 1979

UCLA

SINAP

University of South Carolina 1801

CUORE

Funding and support

The CUORE Collaboration thanks the directors and staff of the Laboratori Nazionali del Gran Sasso and the technical staff of our laboratories. CUORE is supported by:

- The Istituto Nazionale di Fisica Nucleare (INFN)
- The National Science Foundation under Grant Nos. NSF-PHY-0605119, NSF-PHY-0500337, NSF-PHY-0855314, NSF-PHY-0902171, NSF-PHY-0969852, NSF-PHY-1307204, NSF-PHY-1314881, NSF-PHY-1401832, and NSF-PHY-1404205
- The Alfred P. Sloan Foundation
- The University of Wisconsin Foundation
- Yale University
- The US Department of Energy (DOE) Office of Science under Contract Nos. DE-AC02-05CH11231, DE-AC52-07NA27344, and DE-SC0012654
- The DOE Office of Science, Office of Nuclear Physics under Contract Nos. DE-FG02-08ER41551 and DE-FG03-00ER41138
- The National Energy Research Scientific Computing Center (NERSC)

THANK YOU