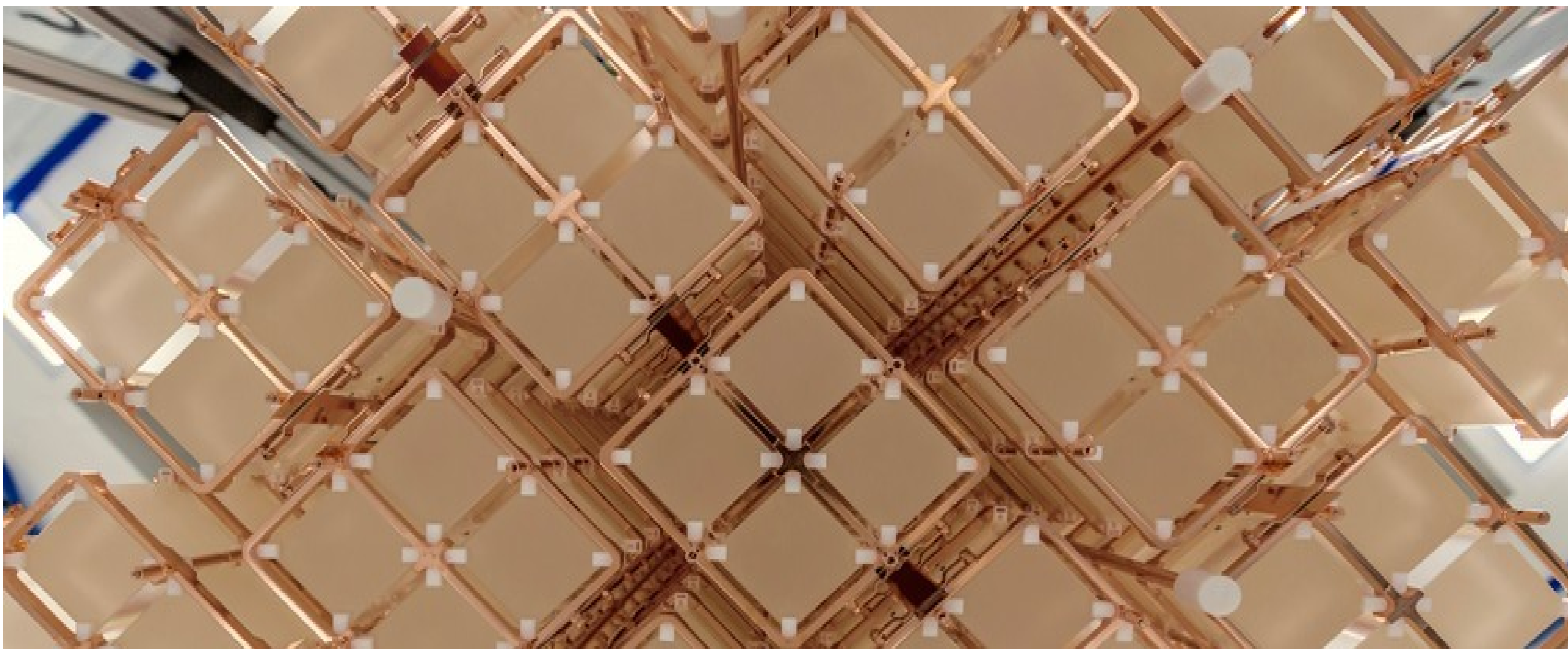
The CUORE experiment at LNGS

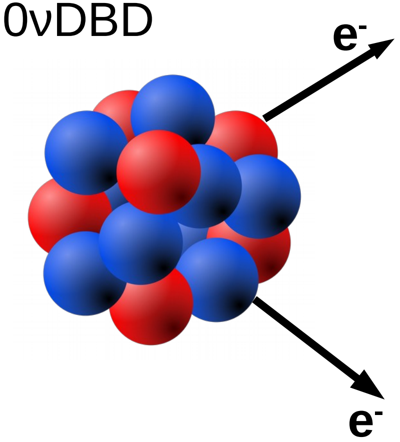
Sergio Di Domizio
Università di Genova and INFN



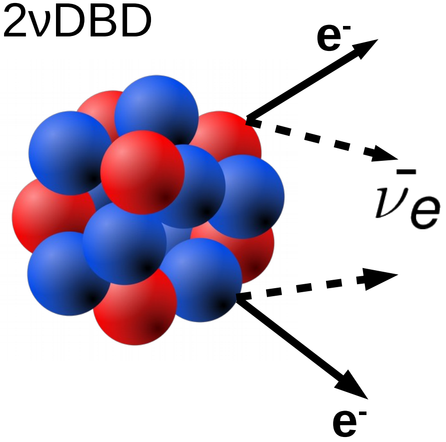
XVI Incontri di Fisica delle Alte Energie – Trieste, April 19-21 2017

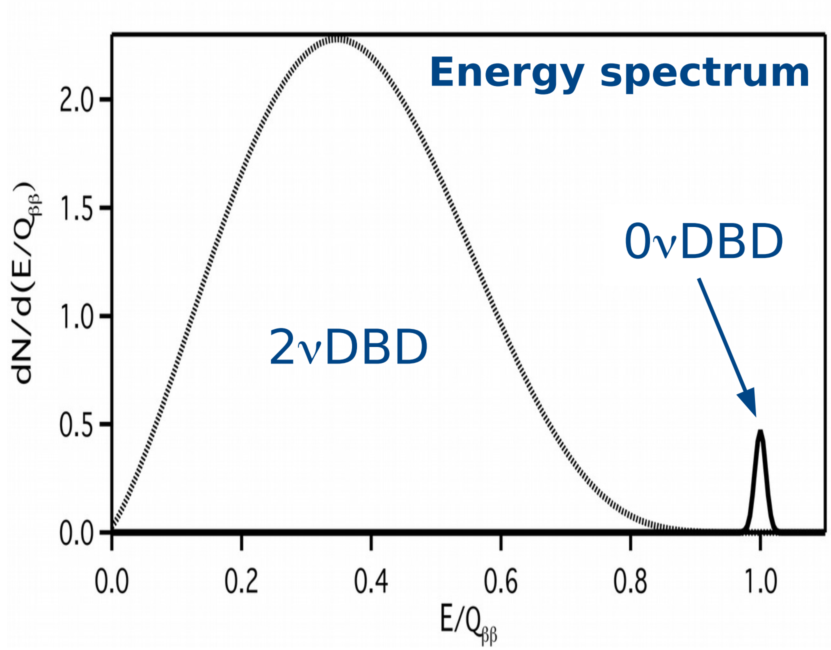
Neutrinoless double beta decay

0νDBD



2νDBD





$$(A, Z) \rightarrow (A, Z+2) + 2e^- \, (+2\bar{\nu}_e)$$

Decay: allowed in some even-even nuclei
Signature: 2 electrons with fixed sum energy in the 2 – 5 MeV region
Implications: ΔL=2, Majorana neutrinos

Faint peak
- Large source mass
- Low background
- Good energy resolution

Never observed to date
Current 0νDBD half-life lower limits are in the range 10^{22} – 10^{26} y

Light majorana neutrino exchange

decay half life
(from experiments)

Nuclear physics
(from theory)

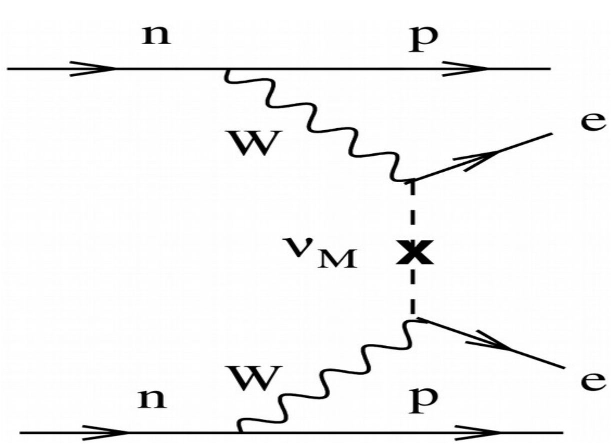
matrix element

phase space

effective Majorana mass
(neutrino physics)

$$\langle m_{\beta\beta}\rangle = \left|\sum_{i=1,2,3} U_{ei}^2 m_i\right|$$

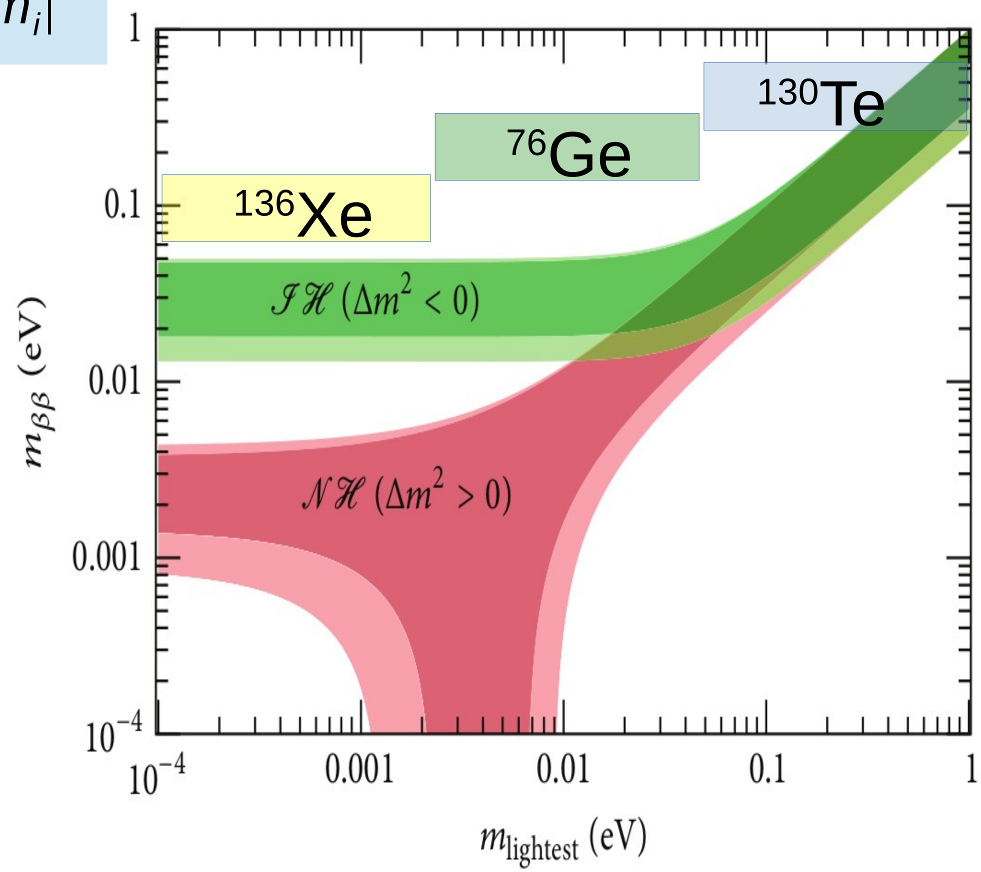
$$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}\,|M^{0\nu}|^2\,\frac{\langle m_{\beta\beta}\rangle^2}{m_e^2}$$



Xe-136: Phys. Rev. Lett. 117 (2016), 109903

Ge-76: Nature 544 (2017), 47–52

Te-130: Phys. Rev. Lett. 115 (2015), 102502



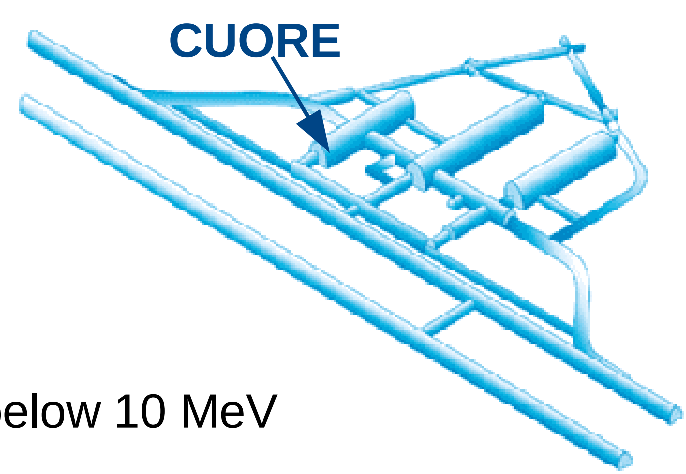
To compare different isotopes some assumptions must be made on the decay mechanism

CUORE

- An array of 988 TeO_2 bolometers operated at 10 mK
- Arranged in 19 towers
- Will search for 0νDBD of Te-130 (Q = 2527.5 keV)
- Mass: 742 kg of TeO_2 (206 kg of ^{130}Te)
- Background goal: 0.01 counts/(keV·kg·y)
- Energy resolution goal: 5 keV FWHM

Built with few selected ultra-clean low-radioactivity materials

Located underground in the hall A of Laboratori Nazionali del Gran Sasso (3600 m w.e. overburden)



γ: 0.73/(cm^2 s)
μ: $3 \cdot 10^{-8}$/(cm^2 s)
n: < $4 \cdot 10^{-6}$/(cm^2 s) below 10 MeV

Adv. High En. Phys. 2015 (2015), 879871

CUORE half-life sensitivity

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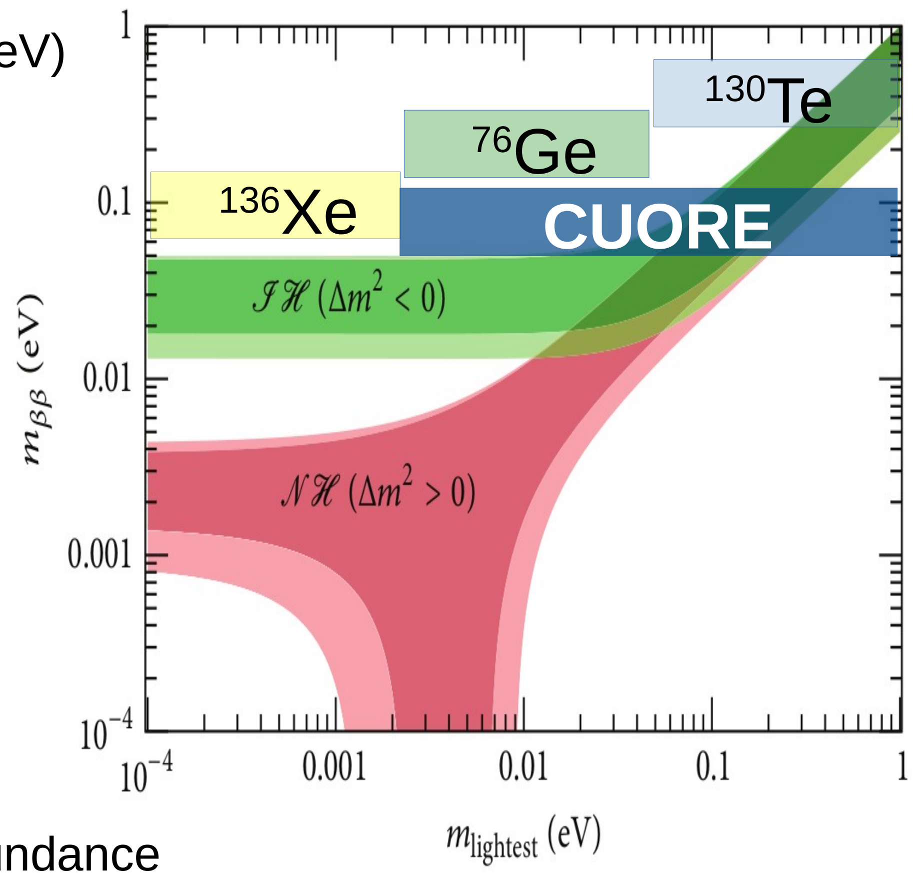


CUORE sensitivity in 5 y

$S^{0\nu}(^{130}Te)$ = 9.5 x 10^{25} y (90% CL)

translates into $m_{\beta\beta}$ < 50 – 130 meV

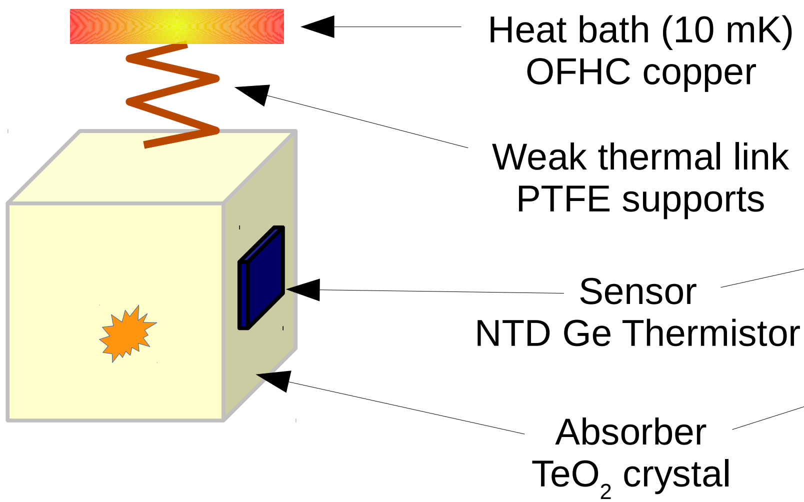
$$S^{0\nu} \propto \eta \sqrt{\frac{M \cdot t}{b \cdot \Delta E}}$$

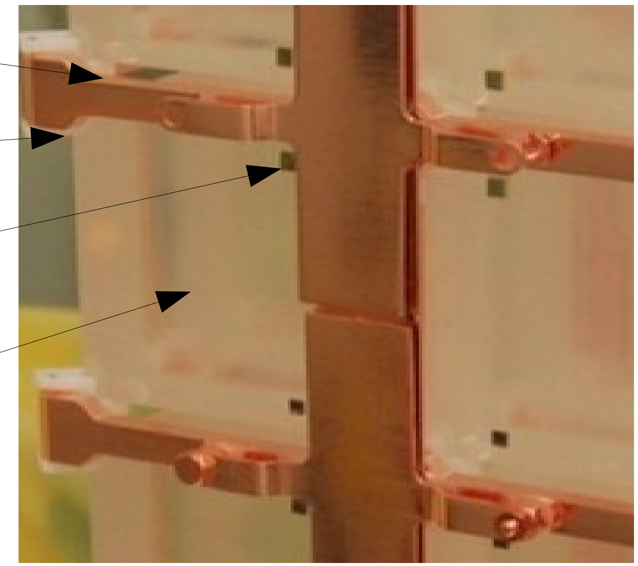
η: isotopic abundance
M: detector mass
t: measurement time
b: background index
ΔE: energy resolution

Adv. High En. Phys. 2015 (2015), 879871

CUORE bolometers

Measure the temperature rise of the absorber crystal: $\Delta T = \frac{E}{C}$



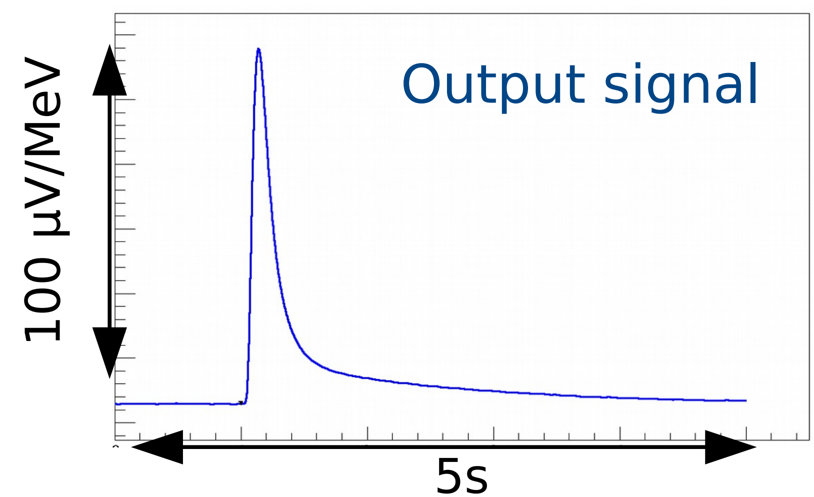


Absorber

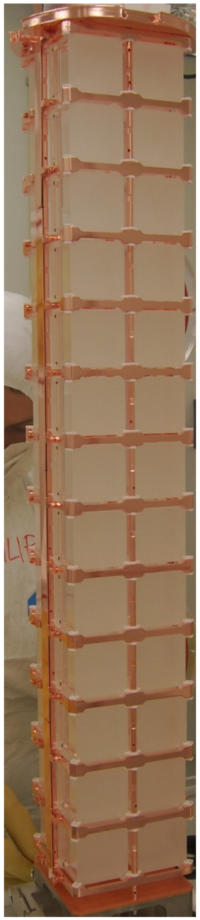
- Dimension: 5x5x5 cm^3
- Mass: 0.75 kg
- Heat capacity: 2x10^{-9} J/K
- ΔT/ΔE ~ 10 – 20 μK/MeV

Sensor

- R = R0 exp$[(T_0/T)^{1/2}]$
- R ~ 100 MΩ
- ΔR/ΔE ~ 3 MΩ/MeV



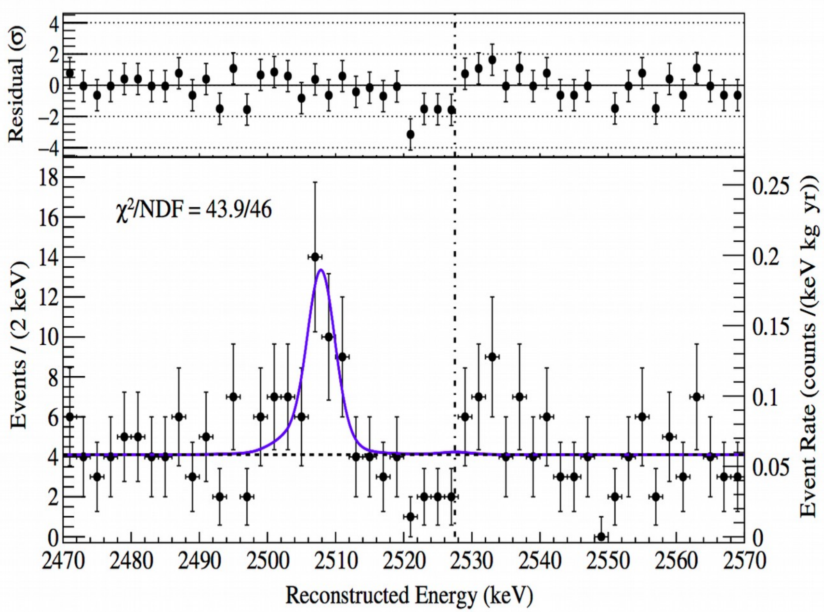
Pilot experiment: CUORE-0

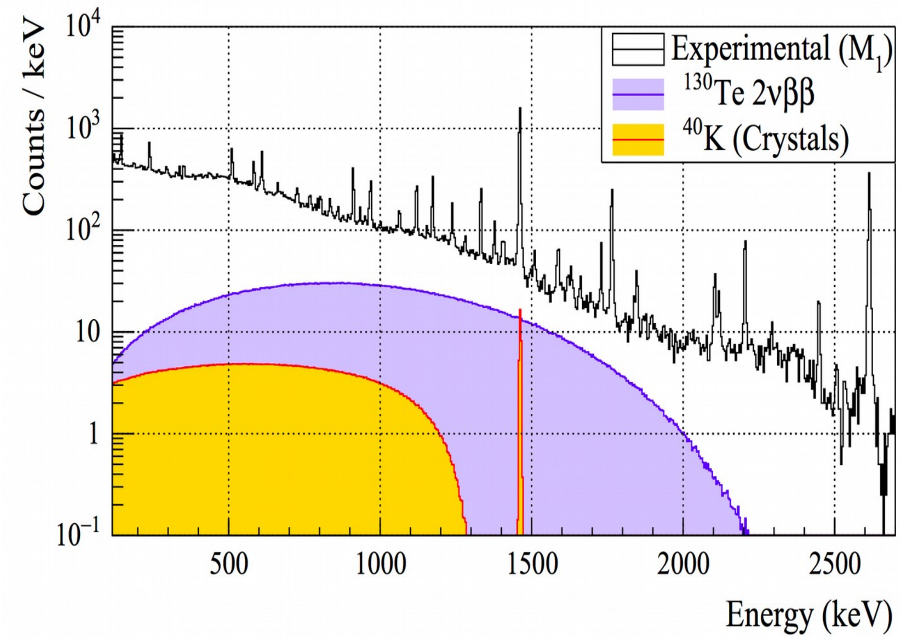


- A single CUORE-like bolometer tower
- 52 crystals, 11.3 kg of ^{130}Te
- Took data from 2013 to 2015 at LNGS
- Proved that the target parameters for CUORE are within reach
  - Energy resolution: 5 keV FWHM at 2.6 MeV
  - Background induced by α particles: 0.016 ± 0.001 counts/(keV·kg·y)

$T_{1/2}$ (2ν) = (8.2 ± 0.2 (stat) ± 0.6 (sys)) x 10^{20} y

$T_{1/2}$ (0ν) > 4.0 x 10^{24} y @90%C.L. (combined with Cuoricino)





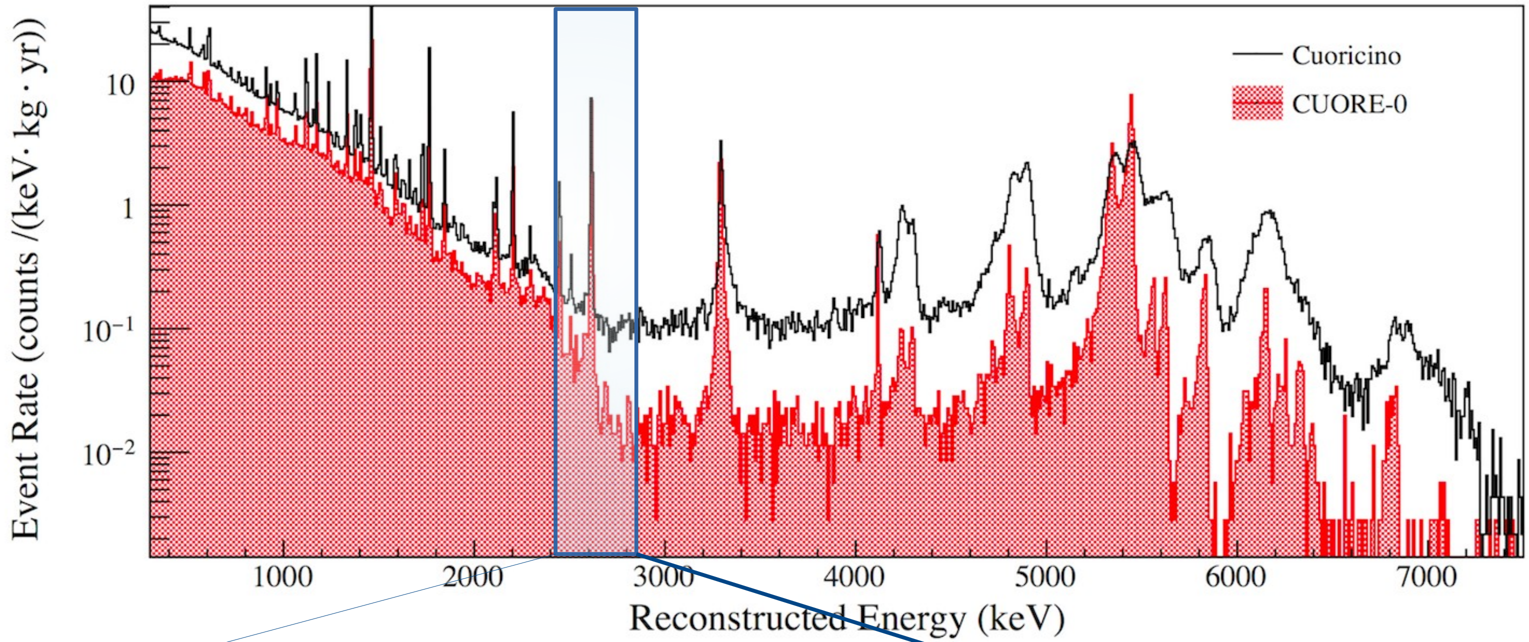
Half-life limit: Phys. Rev. Lett. 115 (2015) 102502

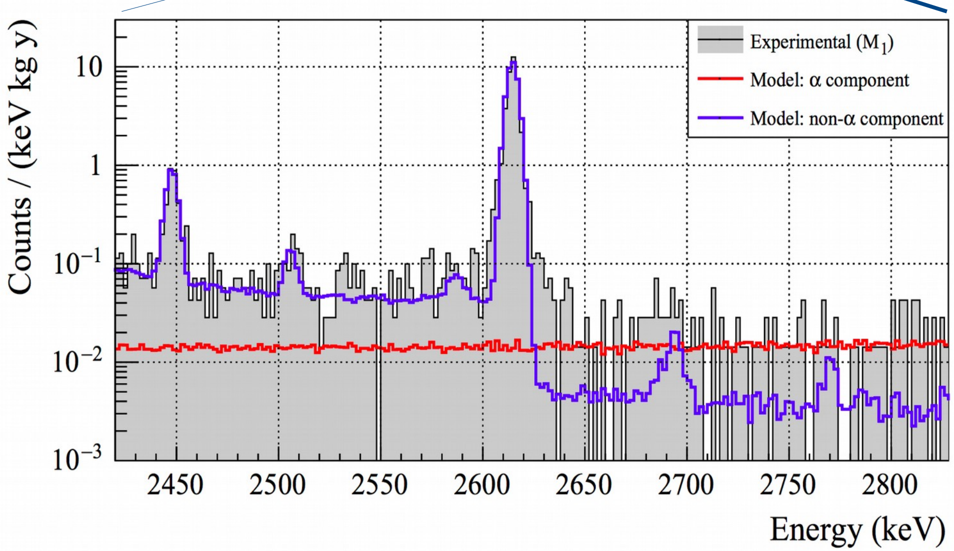
Analysis paper: Phys. Rev. C 93 (2016) 045503

2νDBD measurement: Eur. Phys. J. C (2017) 77:13

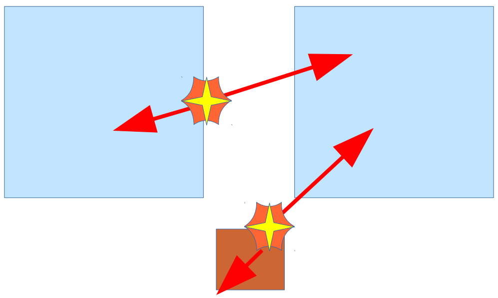
Detector description: JINST 11 (2016) P07009

CUORE-0 background

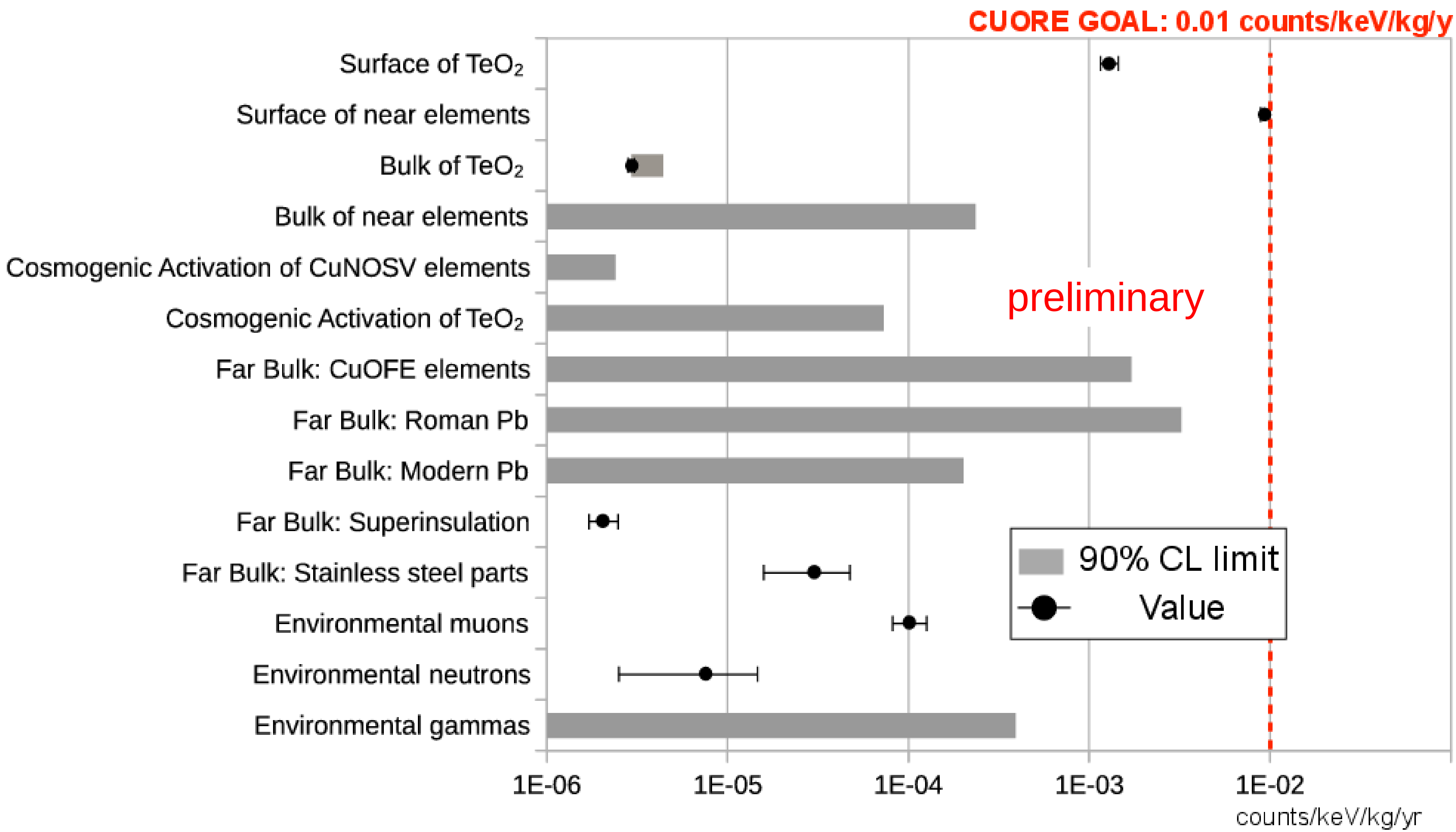




Main bkg expected in CUORE
degraded alpha particles from materials facing the detectors



CUORE background budget

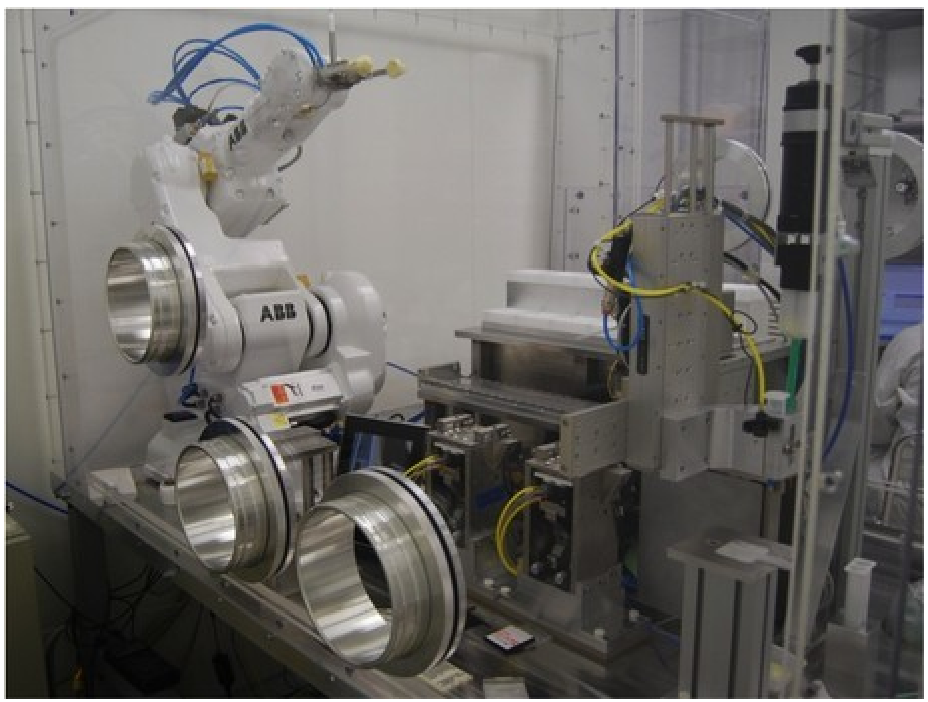


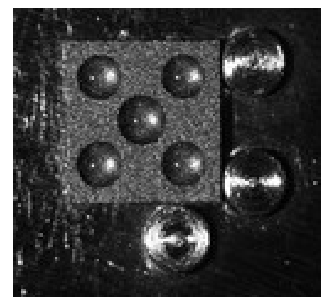
CUORE towers construction

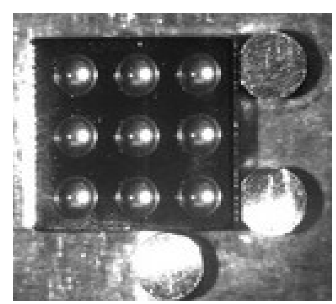
Consisted of 3 steps

1. Gluing

Semi-automatic absorber-sensor coupling system
- NTD sensors
- Joule heaters for thermal gain calibration





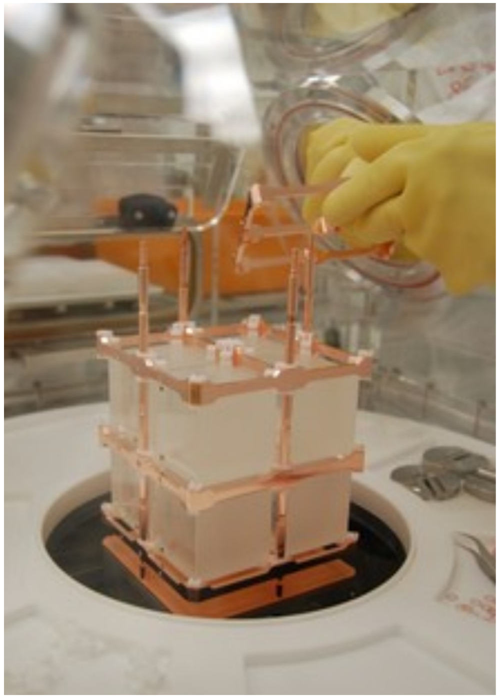


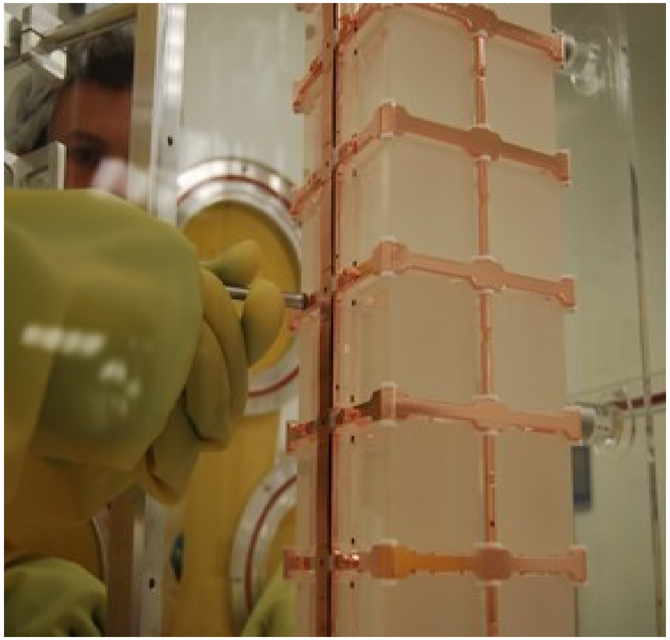
All operations performed in glove boxes to avoid radon recontamination

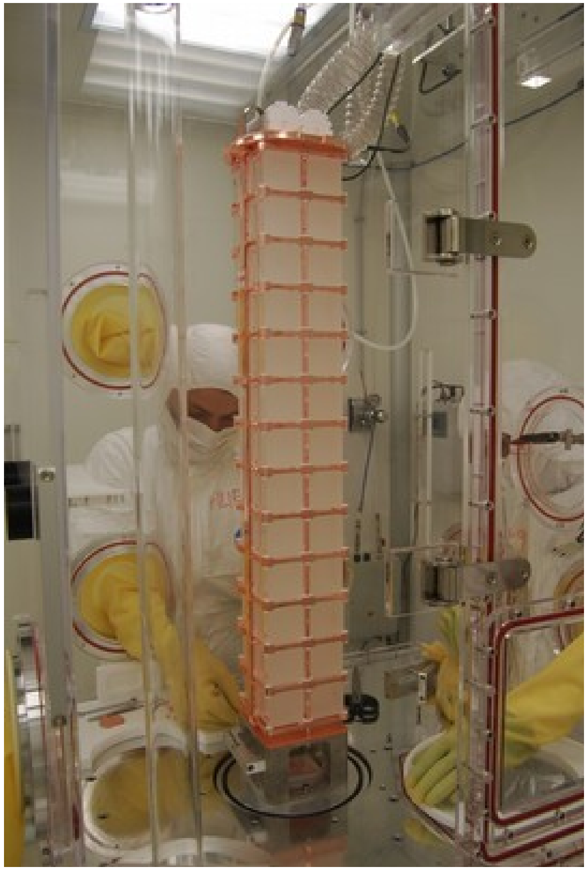
CUORE towers construction

Consisted of 3 steps

1. Gluing
2. Tower assembly







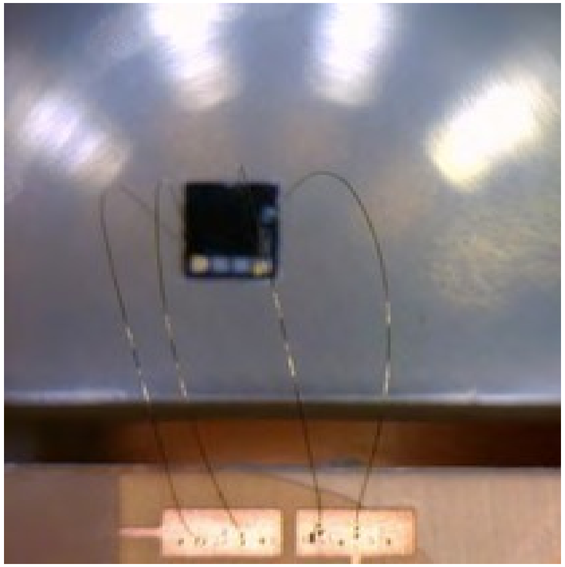
- Copper support structure
- Teflon supports
- Crystals
- tapes for signal readout

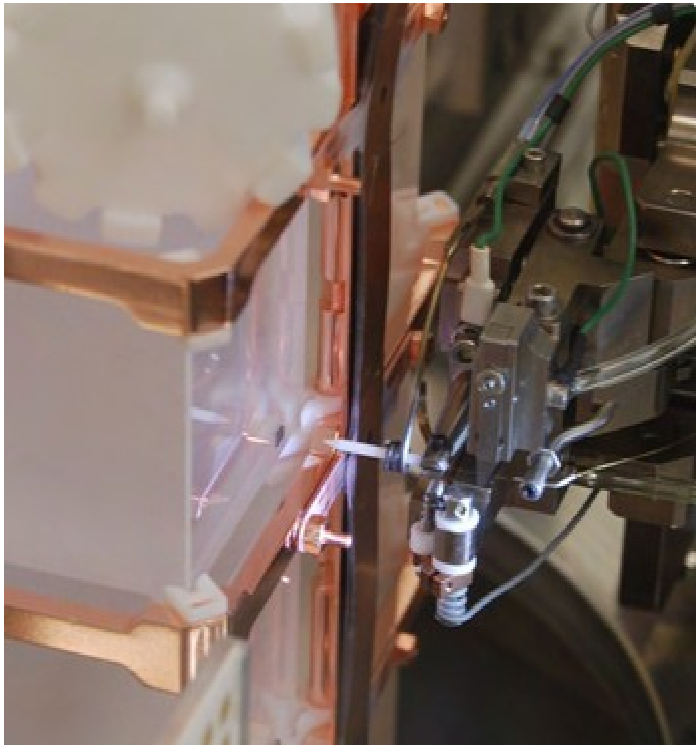
All operations performed in glove boxes to avoid radon recontamination

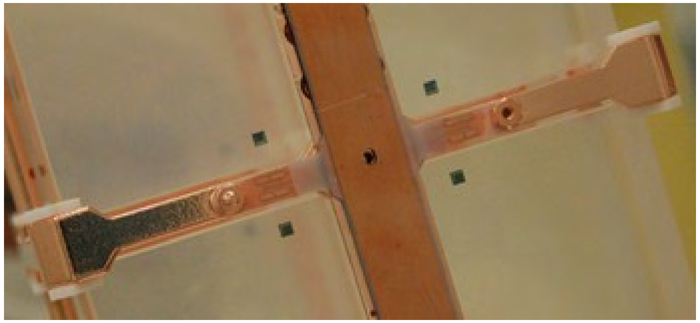
CUORE towers construction

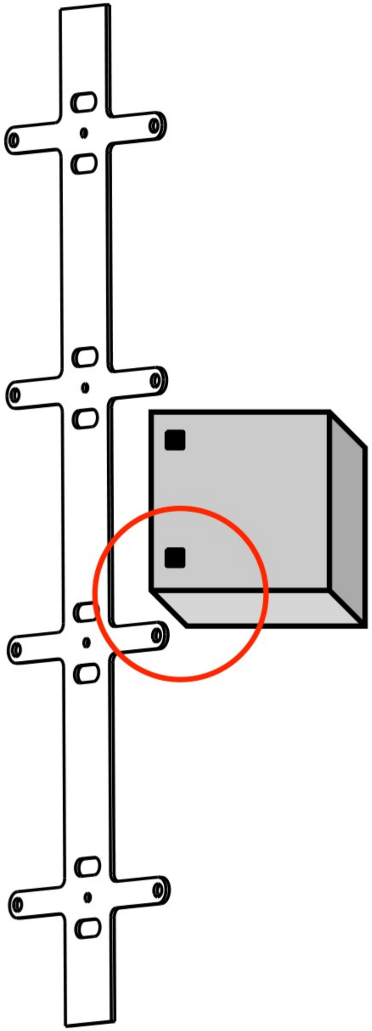
Consisted of 3 steps

1. Gluing
2. Tower assembly
3. Sensor bonding









All operations performed in glove boxes to avoid radon recontamination

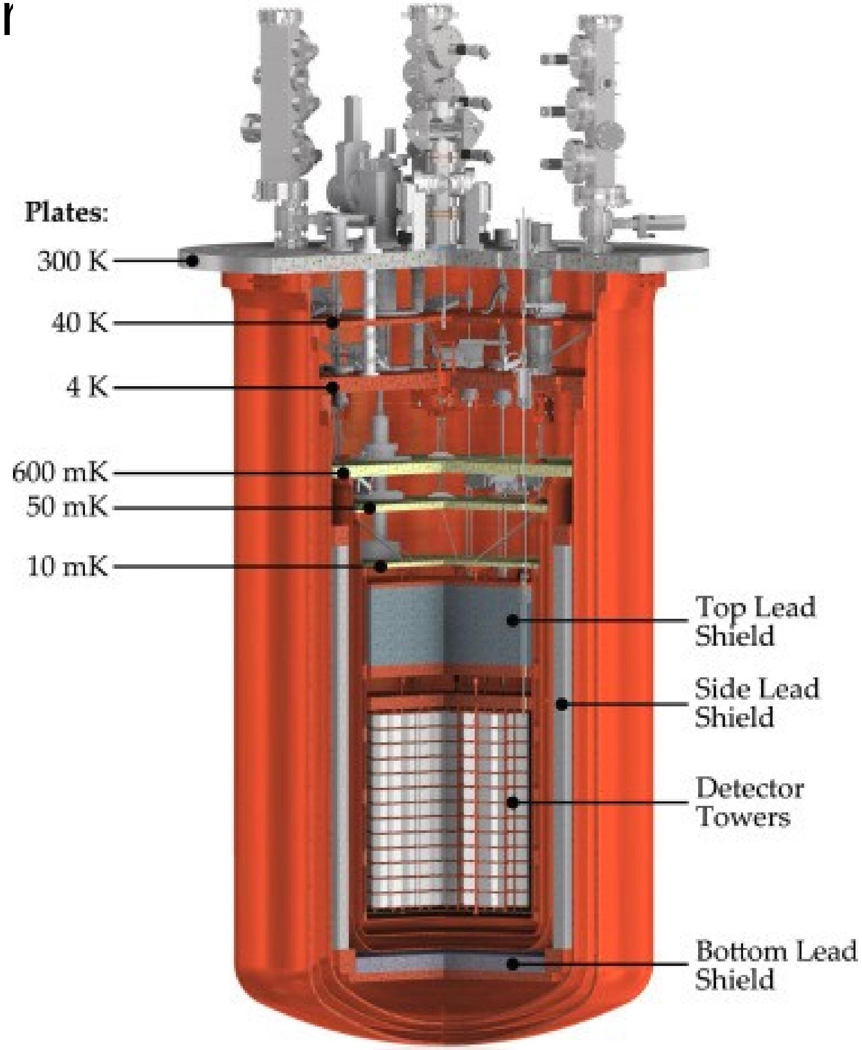
CUORE towers construction

Tower construction completed in June 2014

Then towers were stored in nitrogen atmosphere,
waiting to be installed in the cryostat

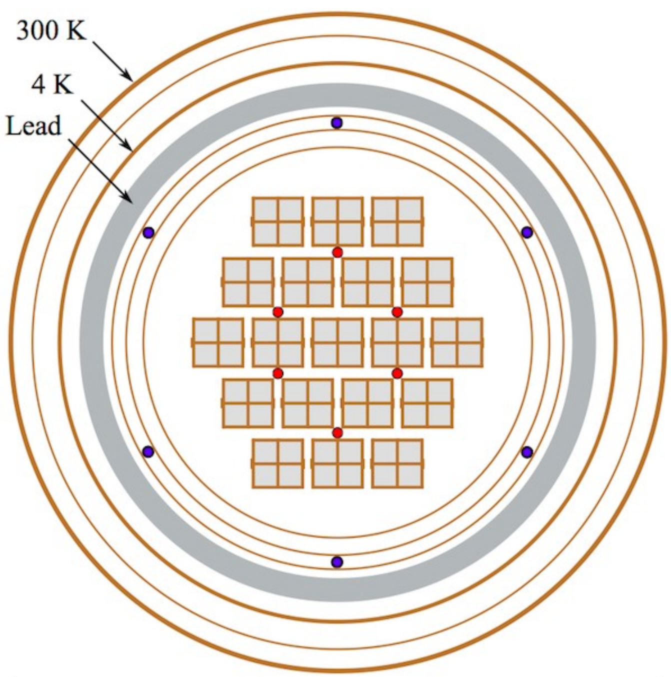
CUORE cryostat

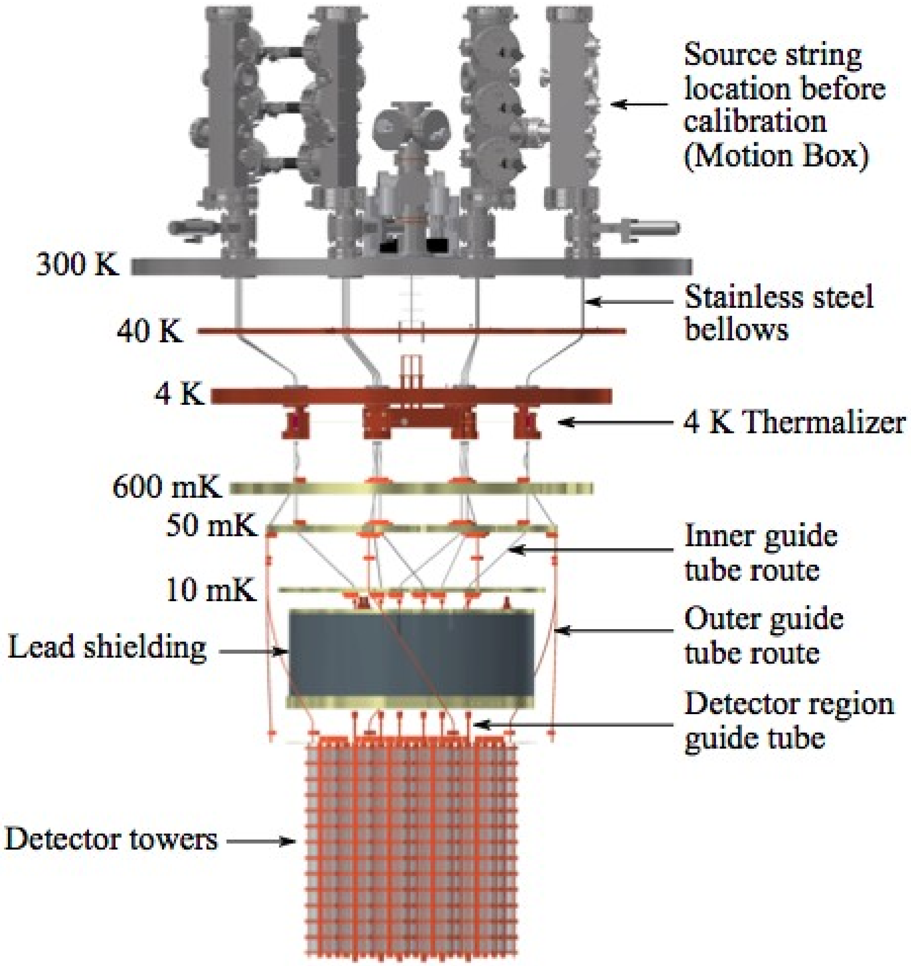
- Custom cryogen-free dilution refrigerator
  - ~1 ton of detectors at 10mK
  - ~20 tons cooled below room temperature
  - Multi-stage suspension system: mechanically decouple the detectors from the cryostat
- Commissioning completed in Mar 2016
  - base temperature: 6.3 mK
  - Long term stability demonstrated



Detector calibration

- 12 Thoriated tungsten source strings
- 6 strings deployed between CUORE towers to ensure uniform illumination
- Strings lowered and cooled to 10mK at each calibration cycle, then warmed up at room temperature after calibration

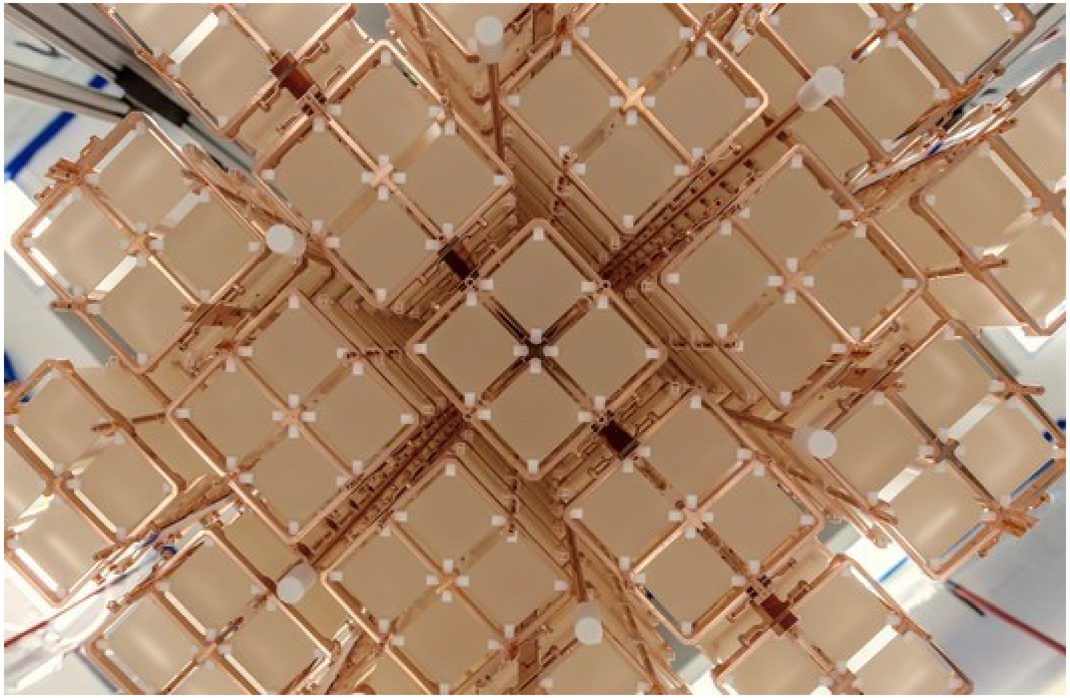


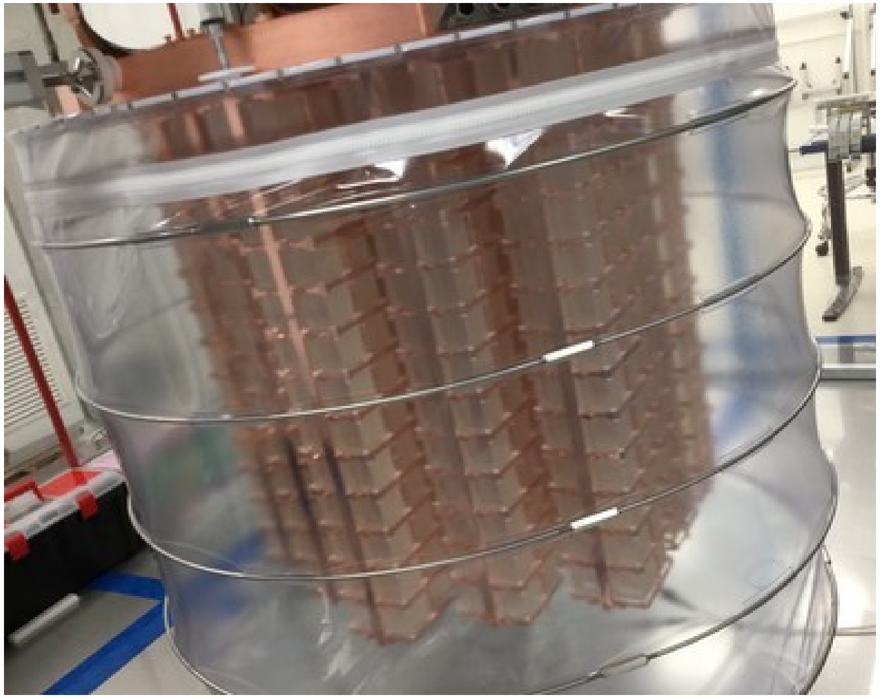


NIM A 844 (2017), 32–44

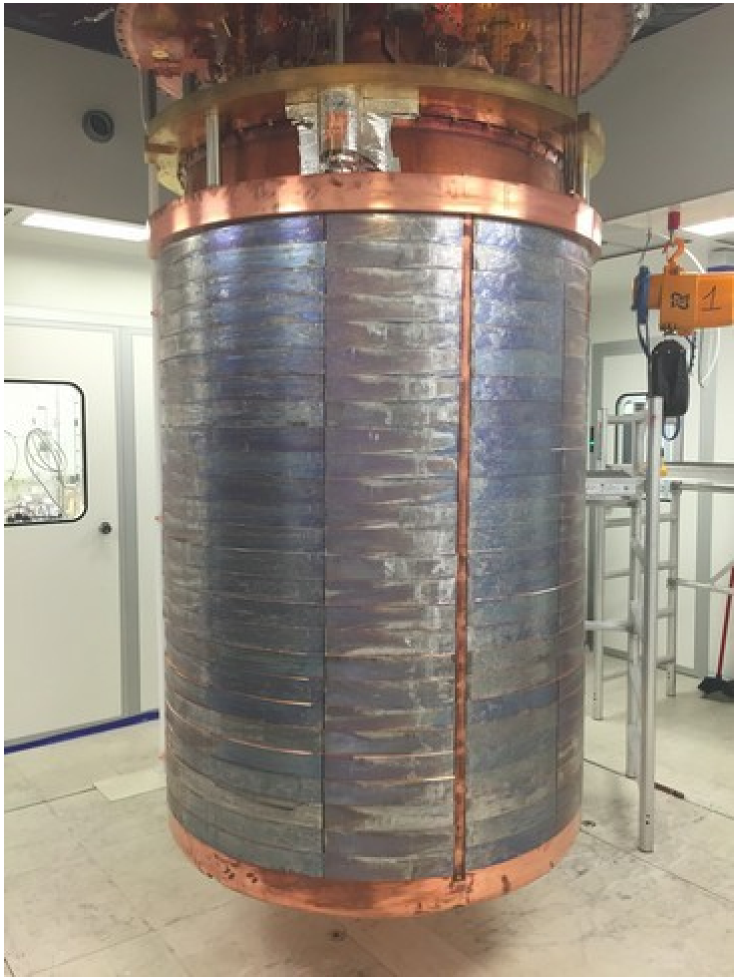
Towers installation

- Towers installed in August 2016
- 1 tower/day
- First and only time when the towers were exposed to air with reduced radon level

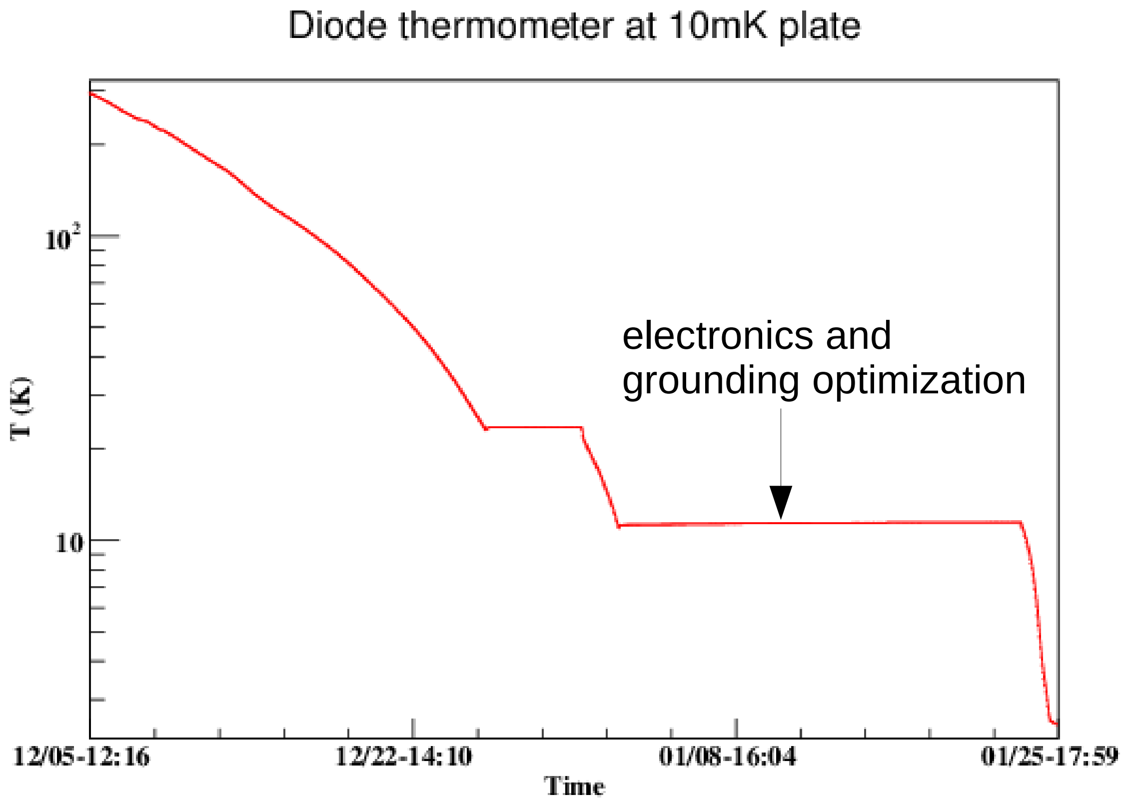




CUORE cool down



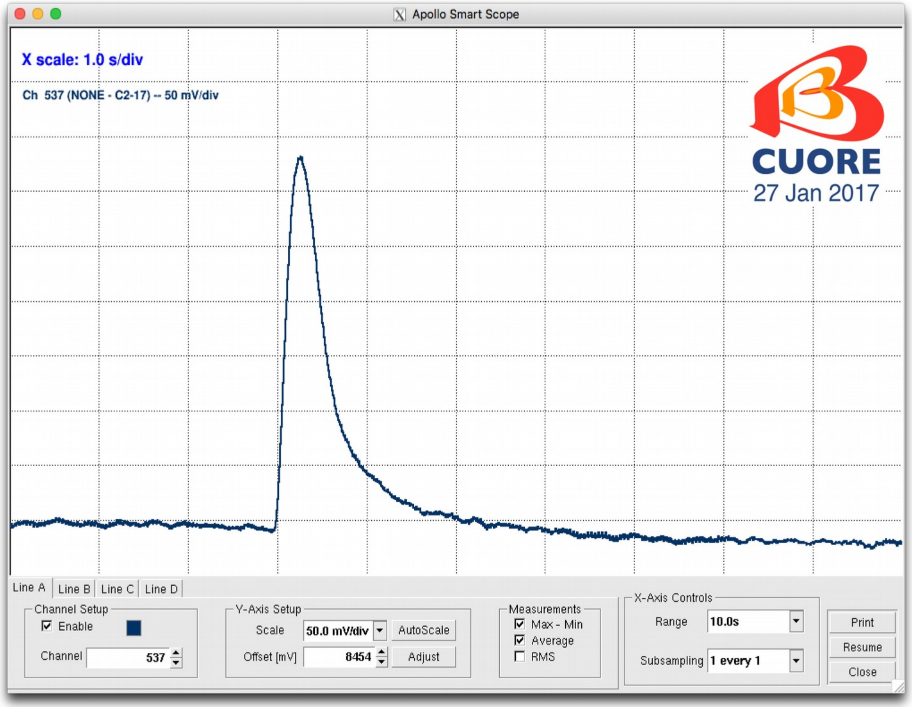
- Cryostat closed in fall 2016
- Cool down started in December 2016
- Base temperature reached in Jan 2017: 8 mK



CUORE operation

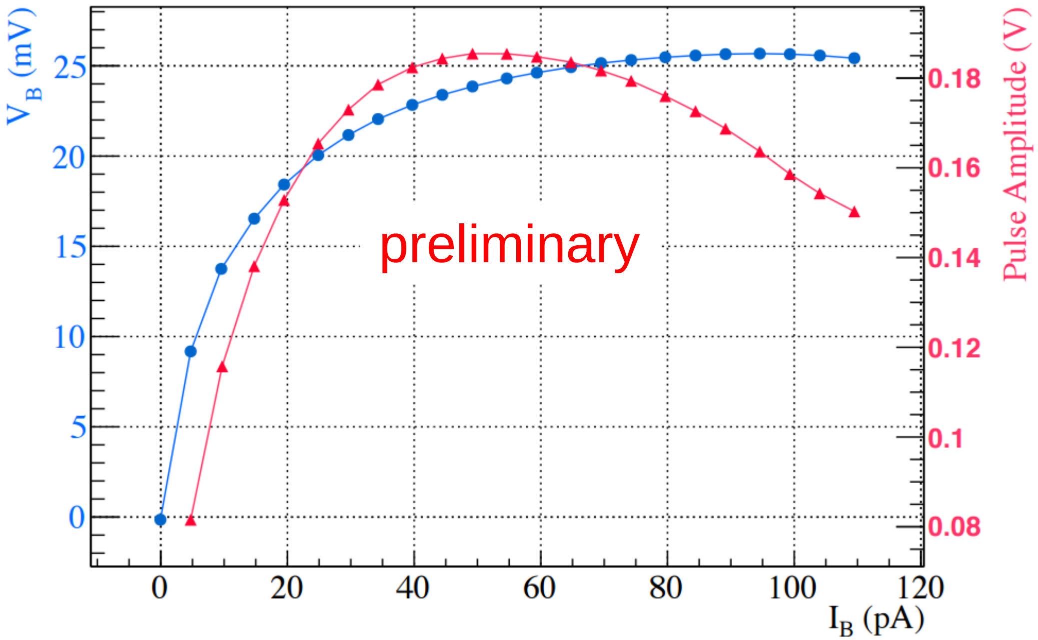
CUORE operation has started early this year

First CUORE pulse observed on Jan 27 2017



A lot of activities in the last months

- Electronics and DAQ debugging
- Noise and vibrations optimization
- Working point measurements at different temperatures
- External lead shield deployment
- Optimization of trigger thresholds



Conclusions

- CUORE is a ton-scale bolometer array searching for neutrinoless double-beta decay in Te-130
- The detector installation completed successfully in 2016
- The experiment reached base temperature in early 2017
- Detector operation has started
- Physics data to come soon!