Neutrinoless double beta decay results from CUORE-0 and status for CUORE experiment

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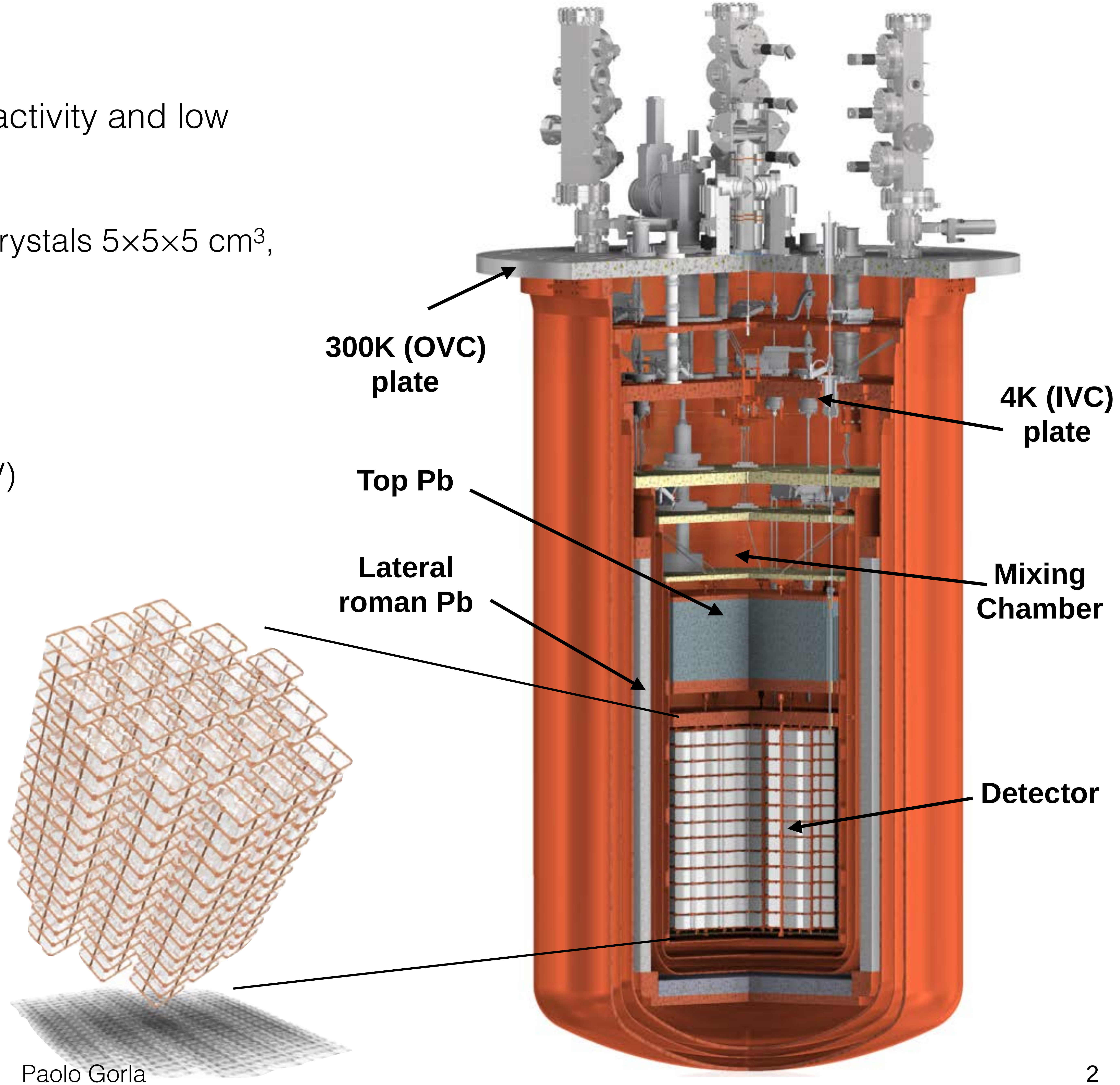
Moriond EW 2016

The CUORE challenge

Operate a huge bolometric array, in an extremely low radioactivity and low vibrations environment, to detect 0vDBD of ^{130}Te

- Closely packed array of 988 TeO_2 crystals (19 towers of 52 crystals 5×5×5 cm^3, 0.75 kg each)
- Mass of TeO_2: 741 kg (~206 kg of ^{130}Te)
- Energy resolution: 5 keV @ 2615 keV [FWHM] ($Q_{\beta\beta}$=2527 keV)
- Stringent radiopurity controls on materials and assembly
- Operating temperature: ~ 10 mK
- Mass to be cooled < 4 K: ~ 15 tons (lead, copper and TeO_2)
- Background aim: 10^{-2} c/keV/kg/year
- $T_{1/2}$ sensitivity in 5 years (90% C.L.): ~ 9.5 x 10^{25} yr



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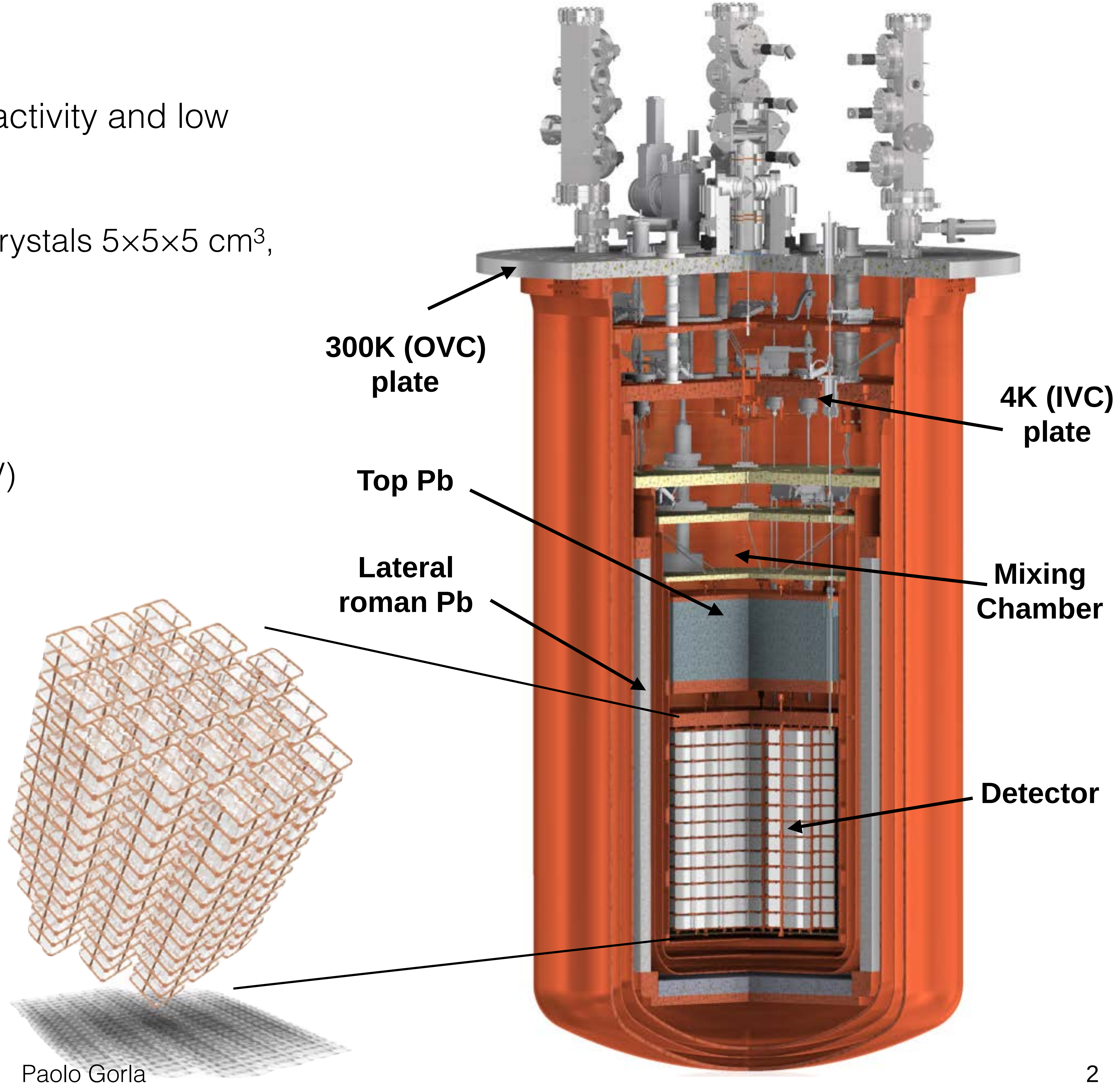

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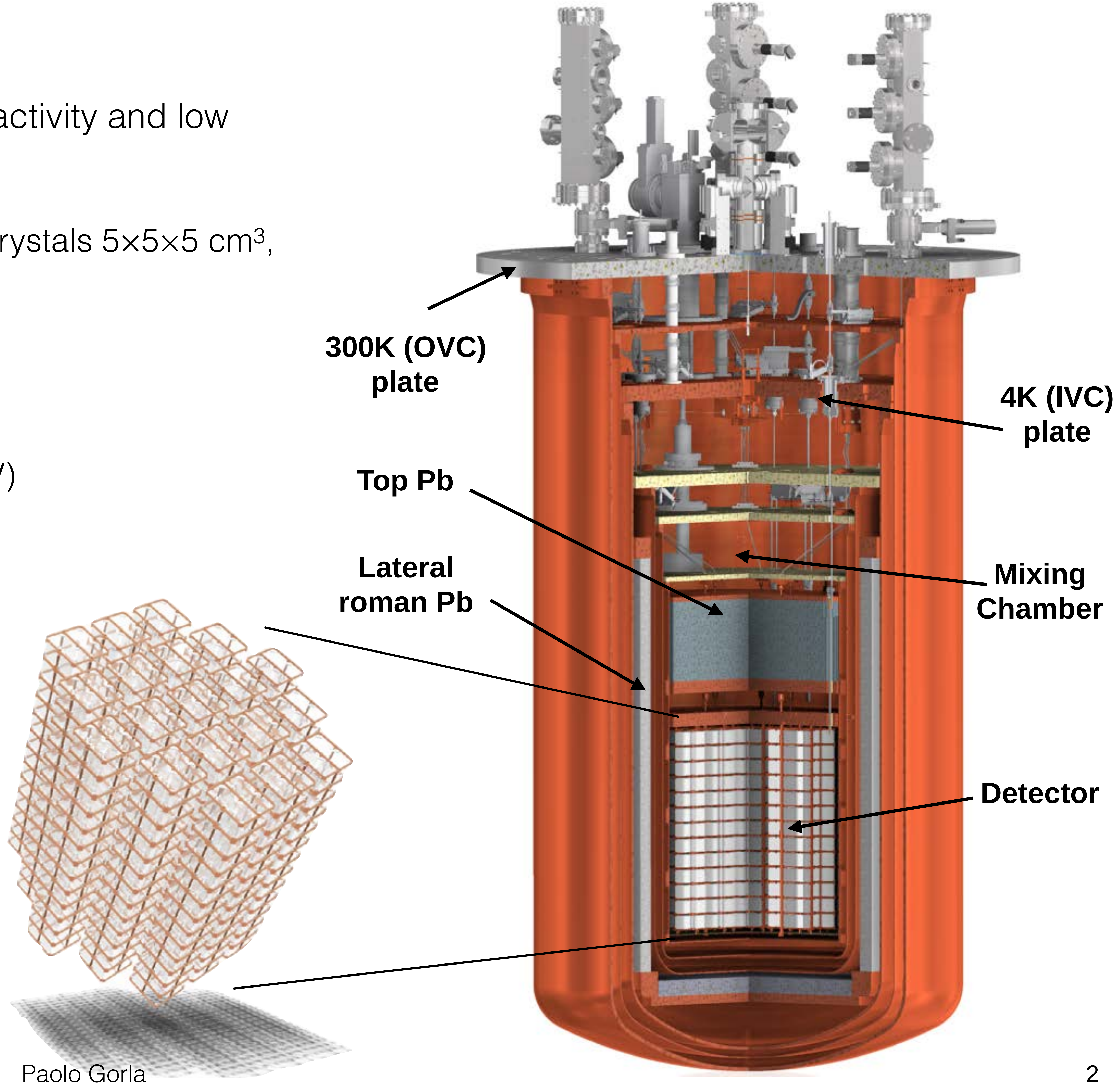
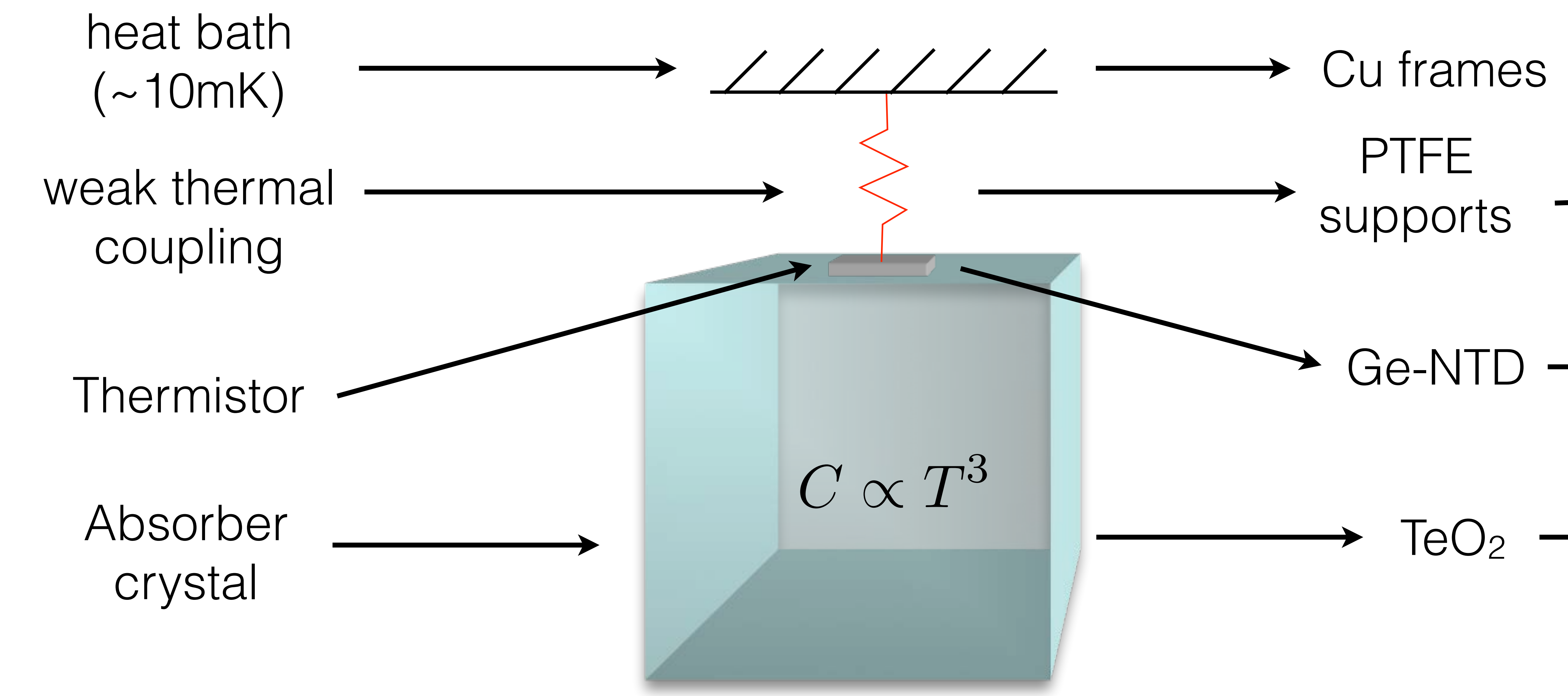
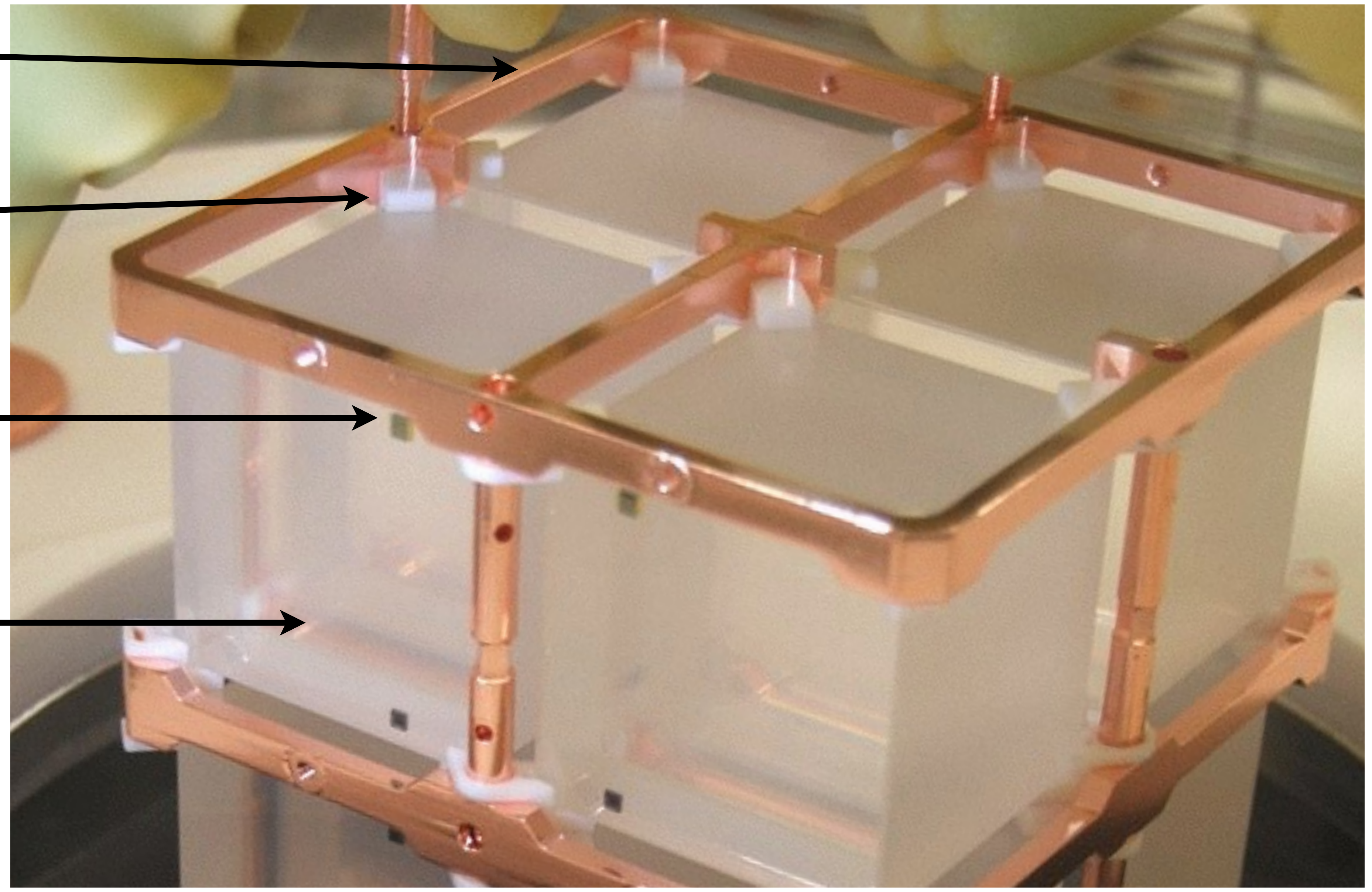
  - CUORE-0 results
  - CUORE commissioning



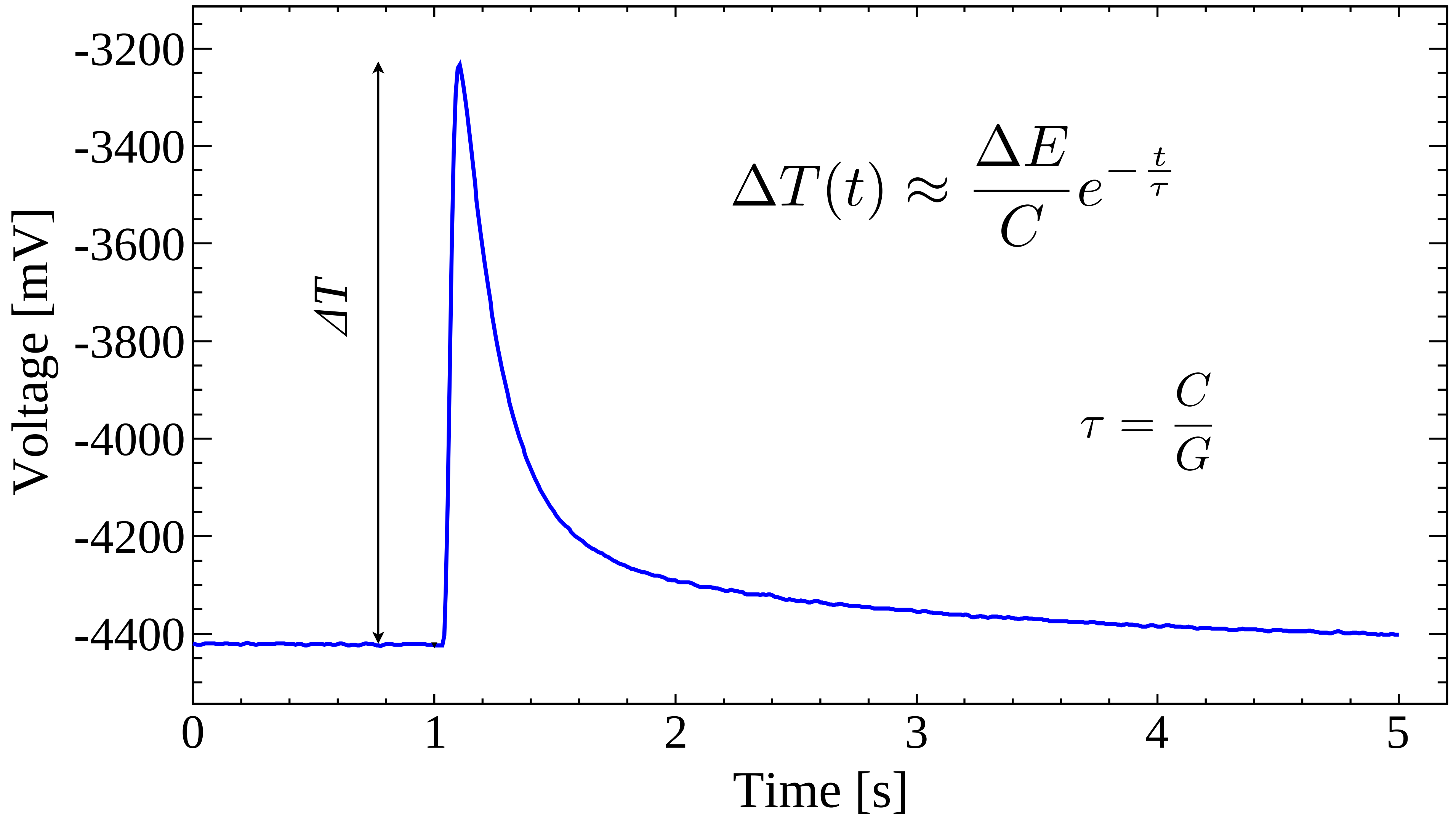
Thermal Detectors



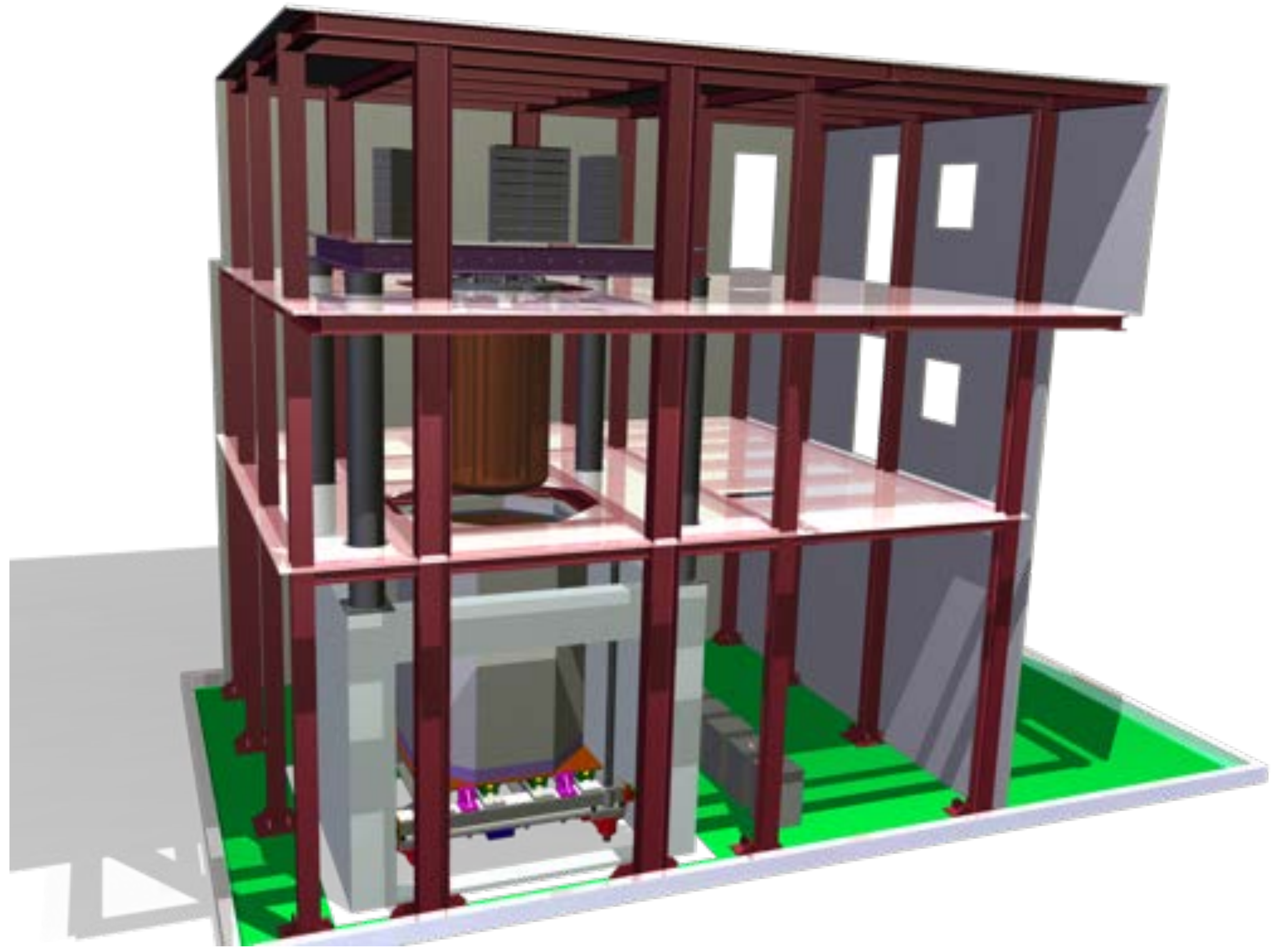


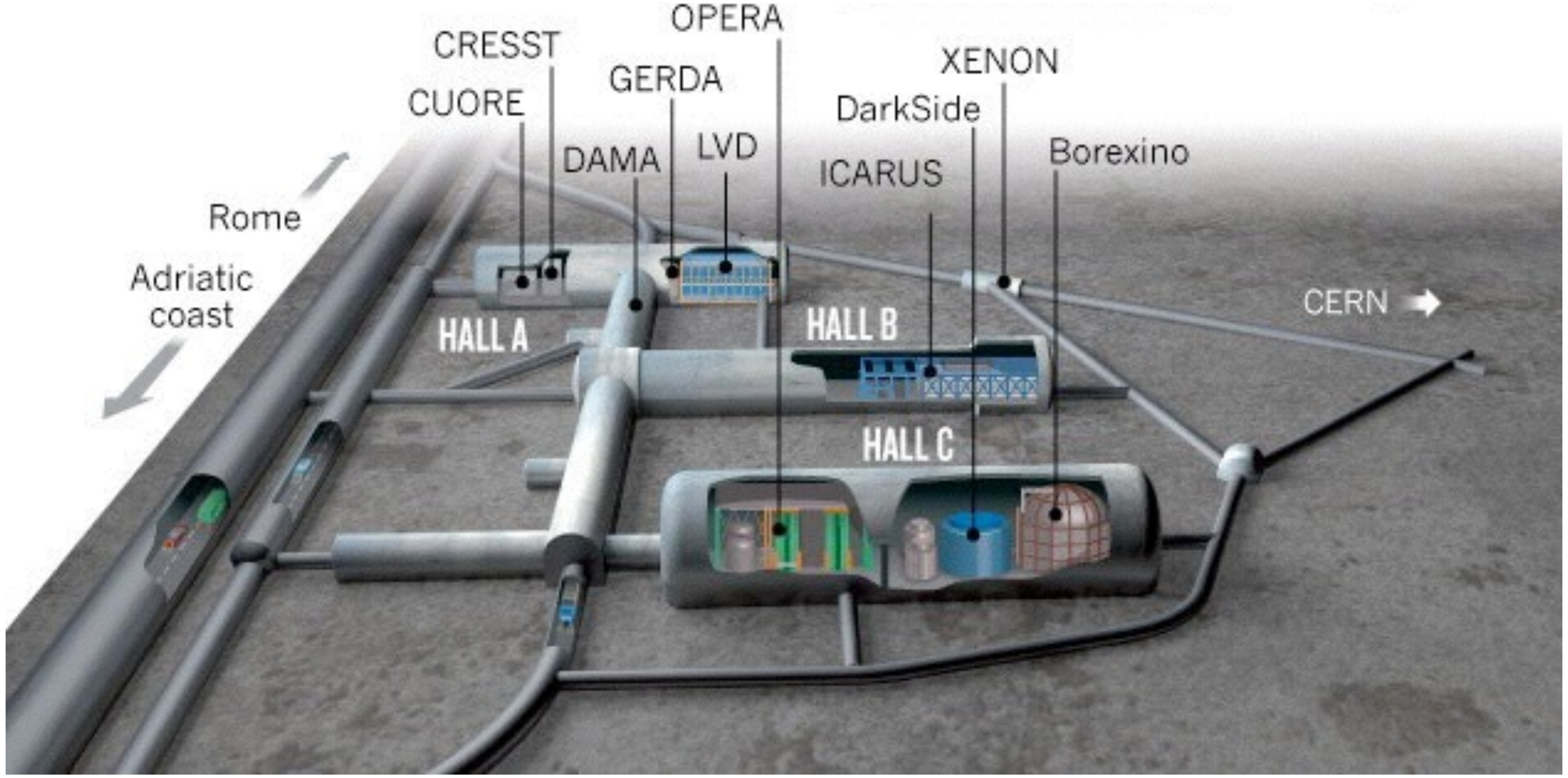
- low heat capacity @ T_{work}
- excellent energy resolution (~1 ‰ FWHM)

  huge number of energy carriers (phonons)
- equal detector response for different particles
- slowness (suitable for rare event searches)



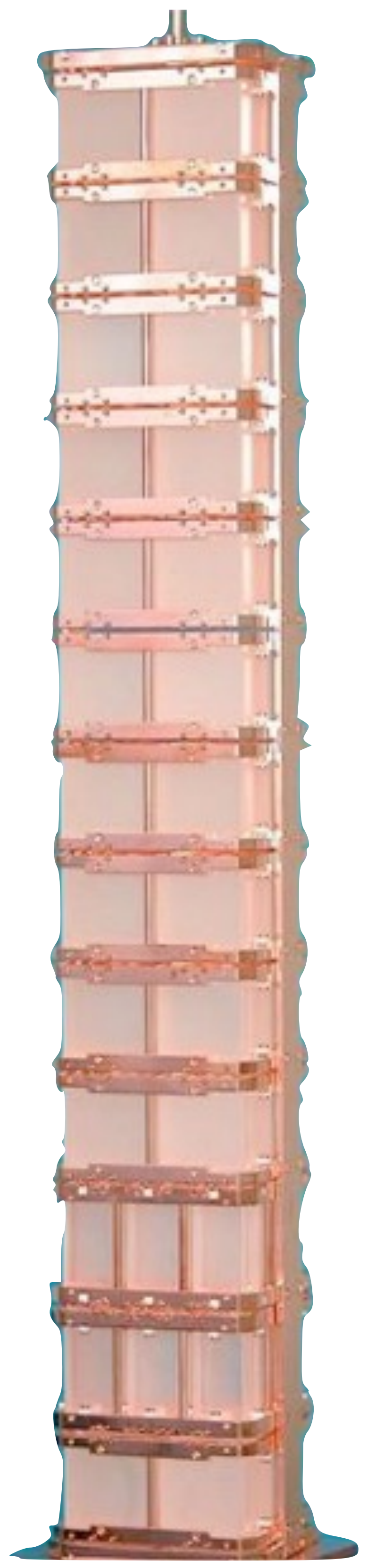
CUORE @ Gran Sasso





- ~3800 m.w.e. deep
- µs: ~3×10^{-8}/(s cm^2)
- γs: ~0.73/(s cm^2)
- neutrons: 4×10^{-6} n/(s cm^2)

The CUORE program

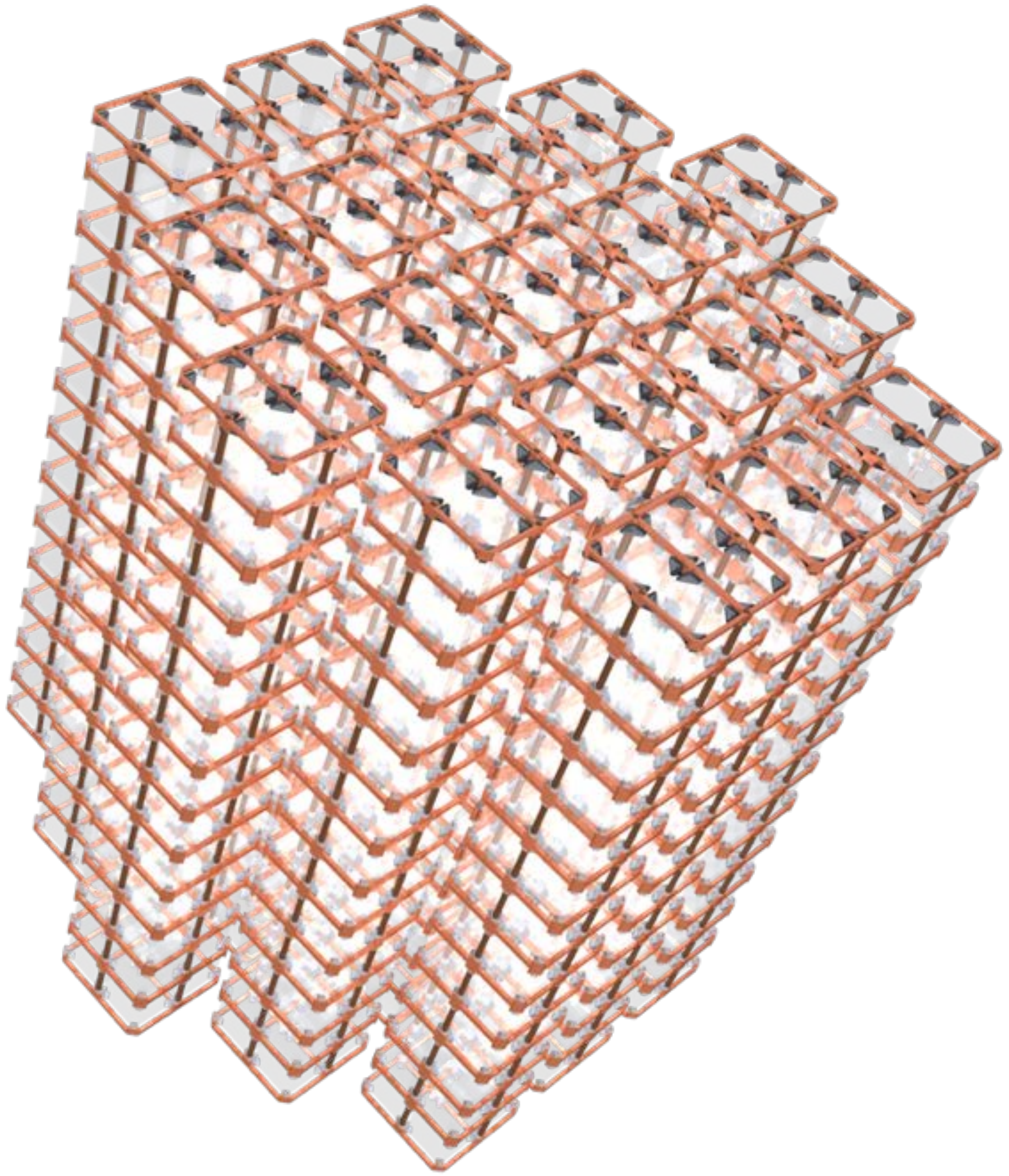


CUORICINO
(2003-2008)

COMPLETED

CUORE-0
(2012- 2015)

COMPLETED

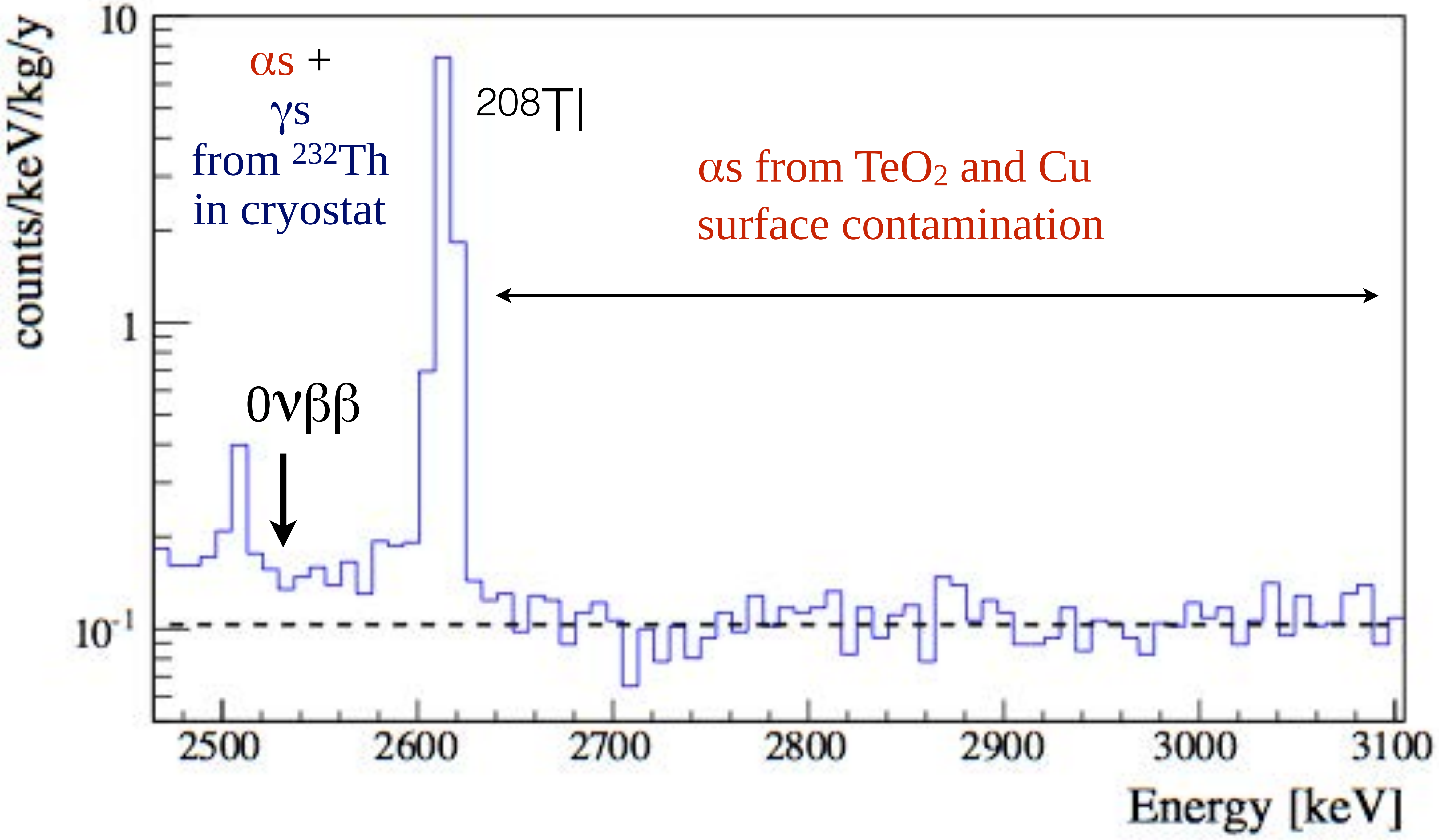


CUORE
2016

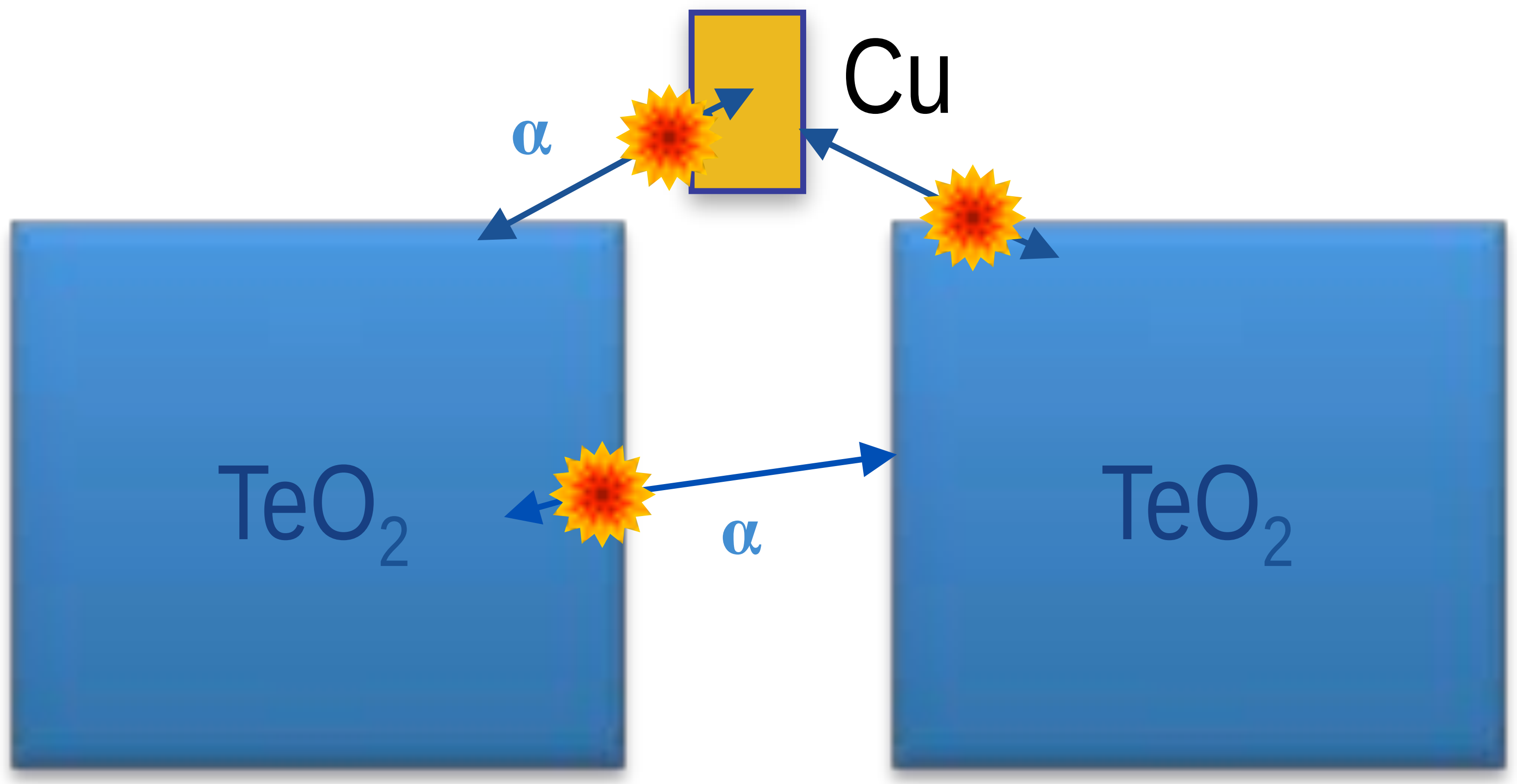
Ready for detector installation

Cuoricino background

Cuoricino final energy spectrum



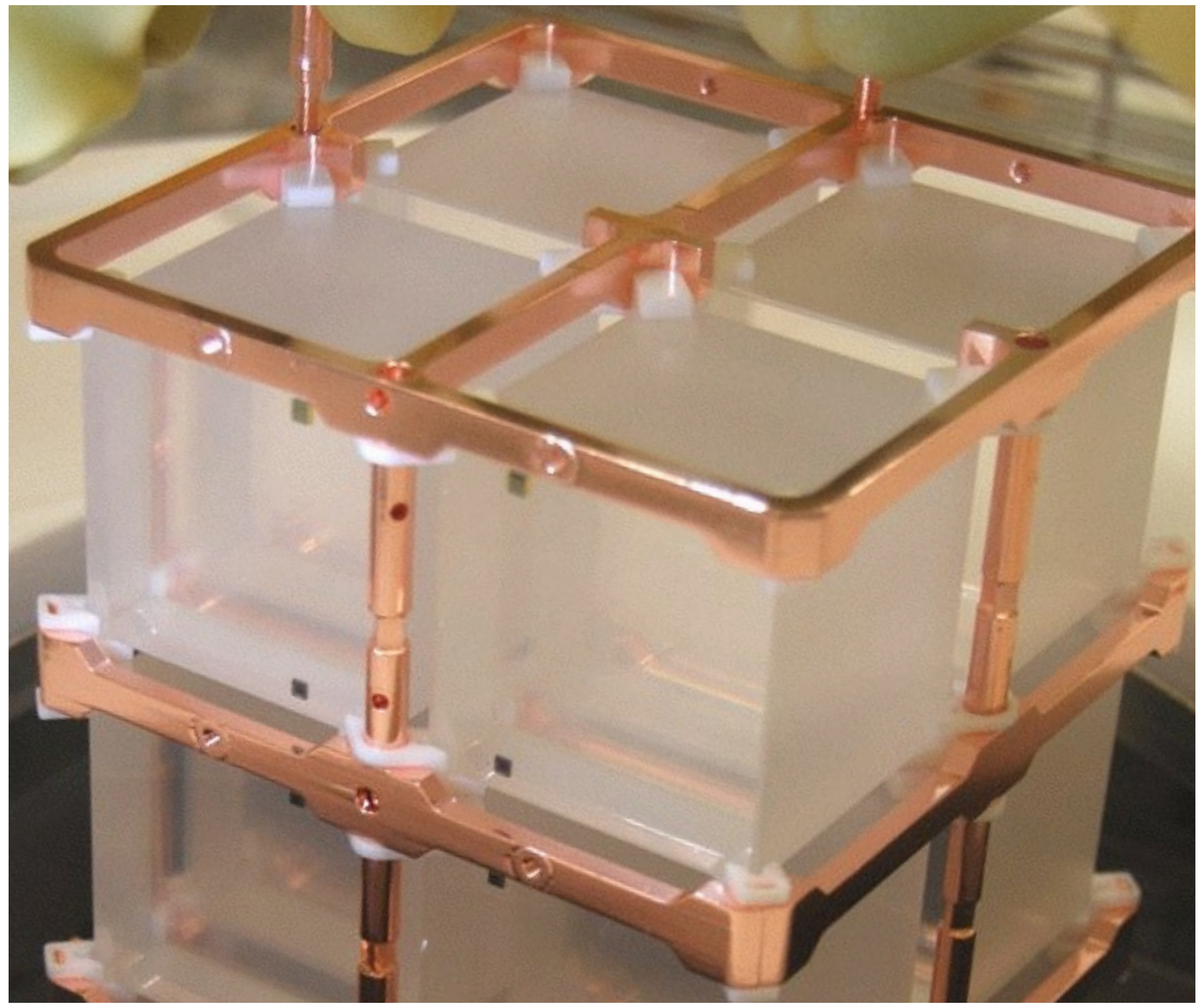
Background @ 0vDBD Q-value:
0.161 c keV^{-1} kg^{-1} y^{-1}

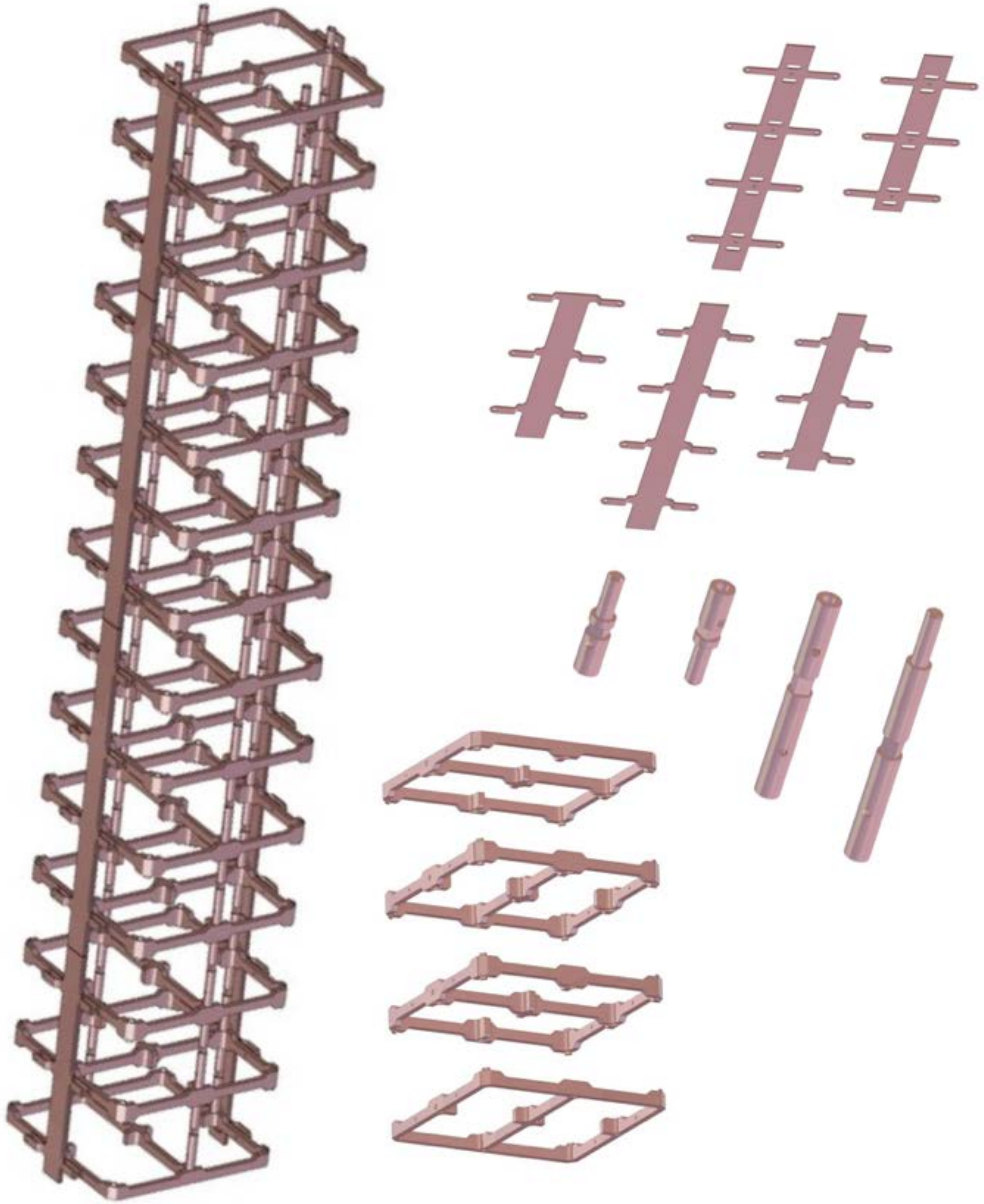


Source	^{208}Tl	$\beta\beta(0\nu)$ region	3-4 MeV region
TeO_2 ^{238}U and ^{232}Th surface contamination	-	10± 5%	20± 10%
Cu ^{238}U and ^{232}Th surface contamination	~15%	50± 20%	80± 10%
^{232}Th contamination of cryostat Cu shields	~85%	30± 10%	-

From CUORICINO to CUORE

- Strict material selection
- New lighter detector design structure
- Reduced overall copper surfaces by a factor ~2
- New surface cleaning technique
- Strict production protocols for TeO_2 surface contamination
- Minimization of Rn exposure (N_2 glove box assembly)





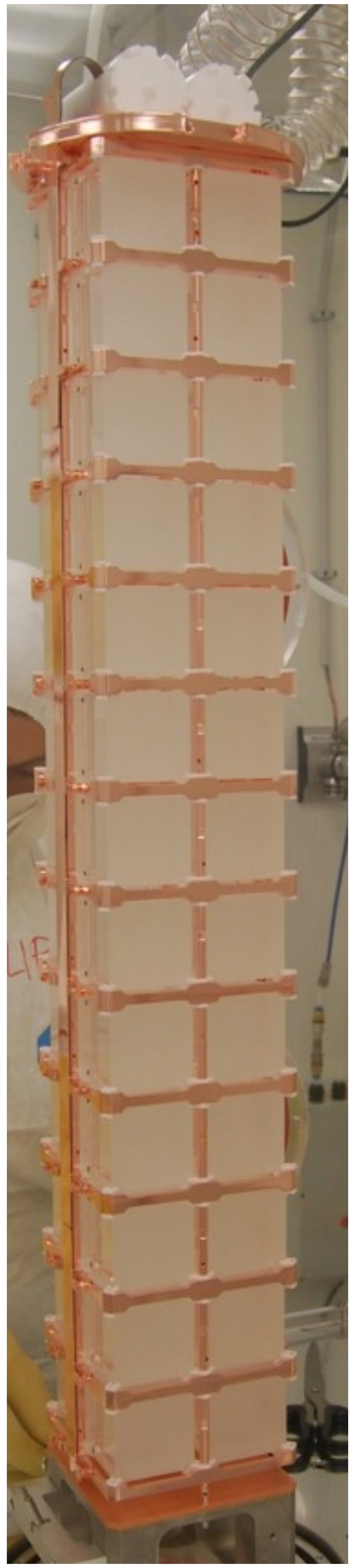
CUORE-0

CUORE-0 was the first tower produced out of the CUORE assembly line.

- 52 TeO_2 5x5x5 cm^3 crystals (~750 g each)
- 13 floors of 4 crystals each
- total detector mass: 39 kg TeO_2 (10.9 kg of ^{130}Te)

CUORE-0 took data from March 2013 to September 2015 in the 25 years old Cuoricino cryostat.

- Proof of concept of CUORE detector in all stages
- Test and debug of the CUORE tower assembly line
- Test of the CUORE DAQ and analysis framework
- Check of the radioactive background reduction
- Sensitive 0vDBD experiment



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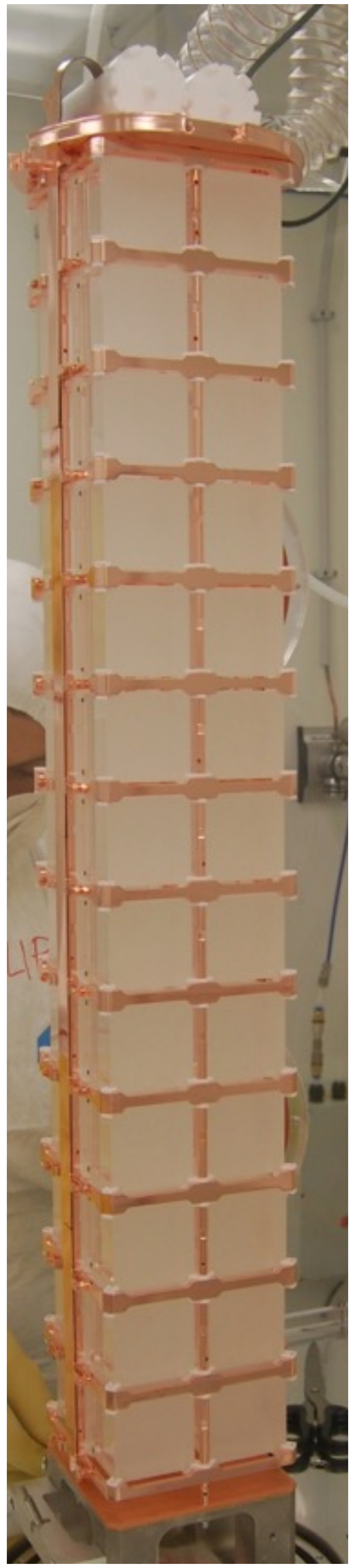
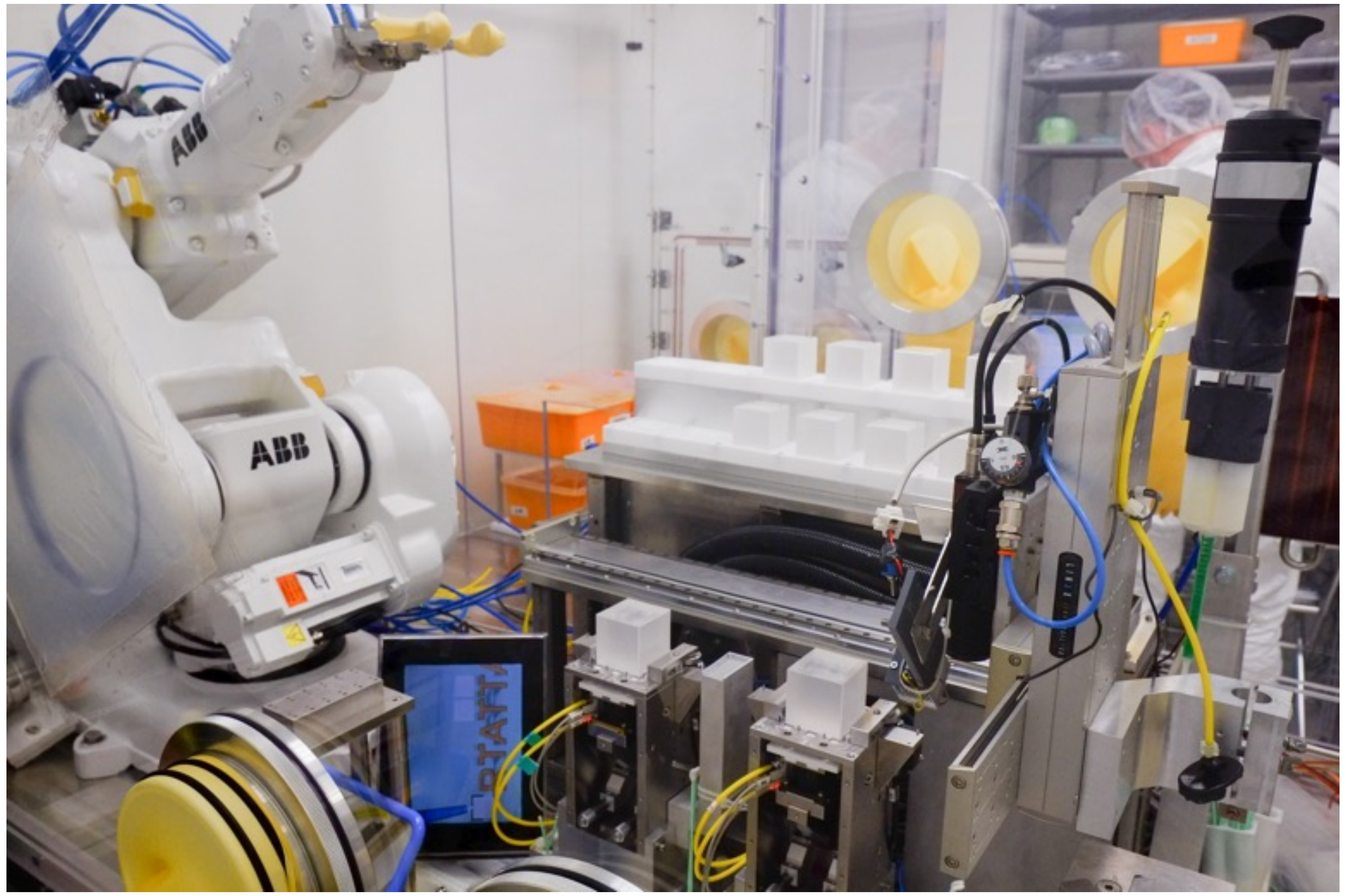
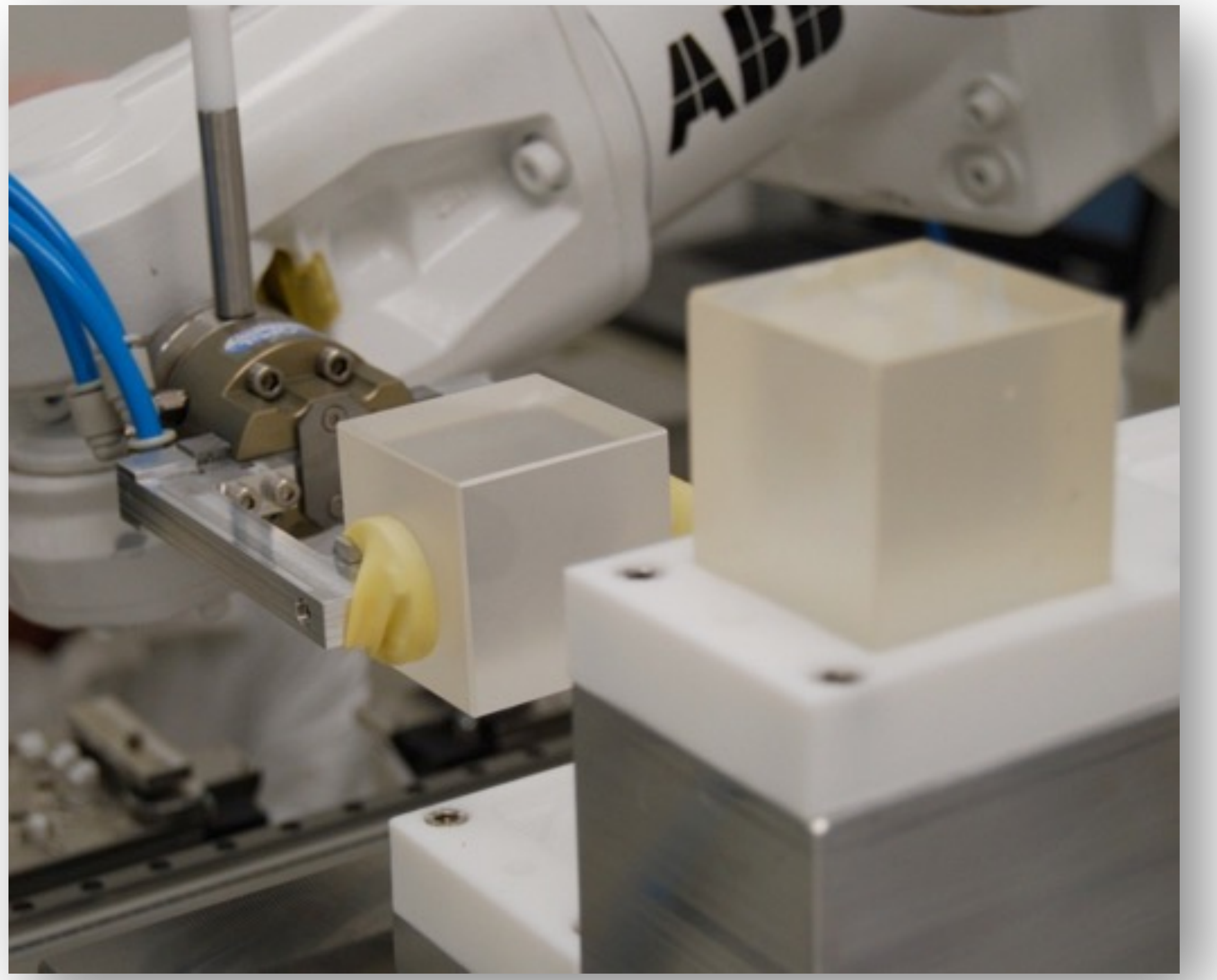


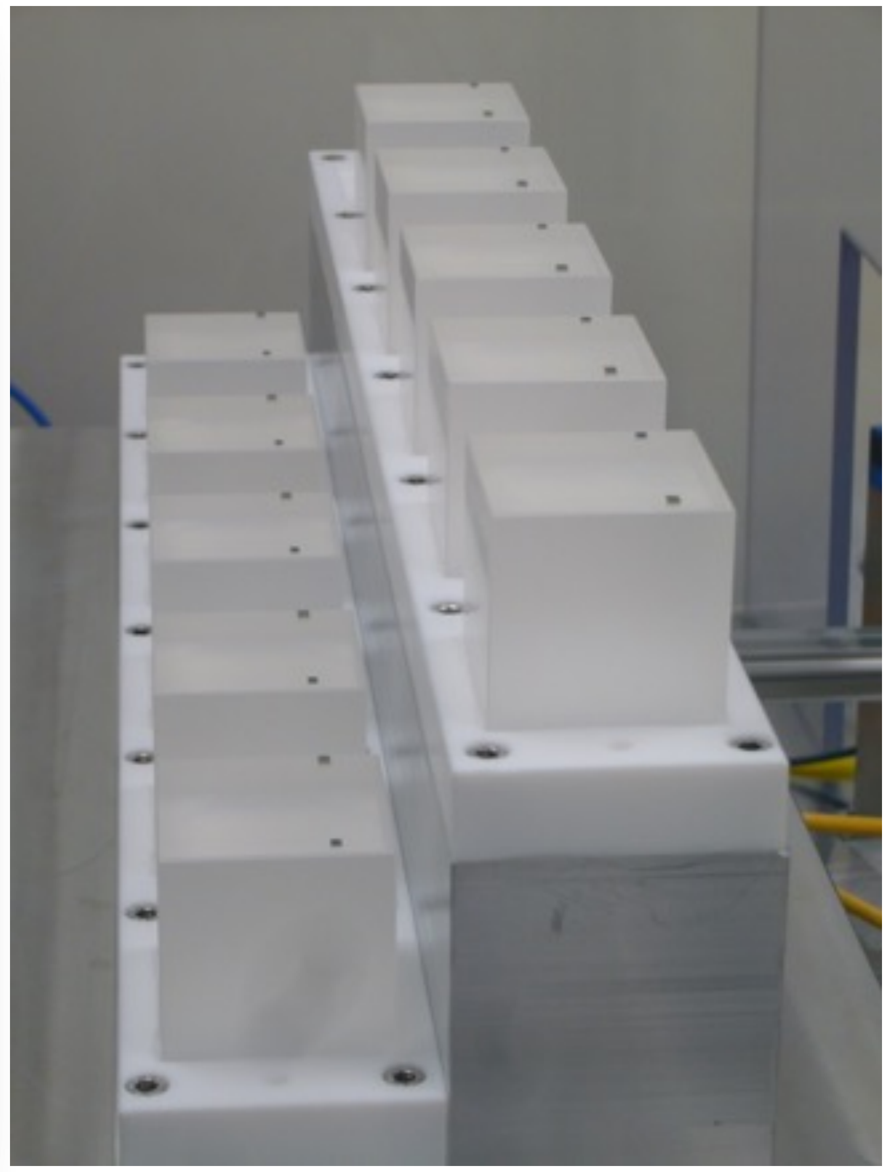
Thermistors & Heaters coupling

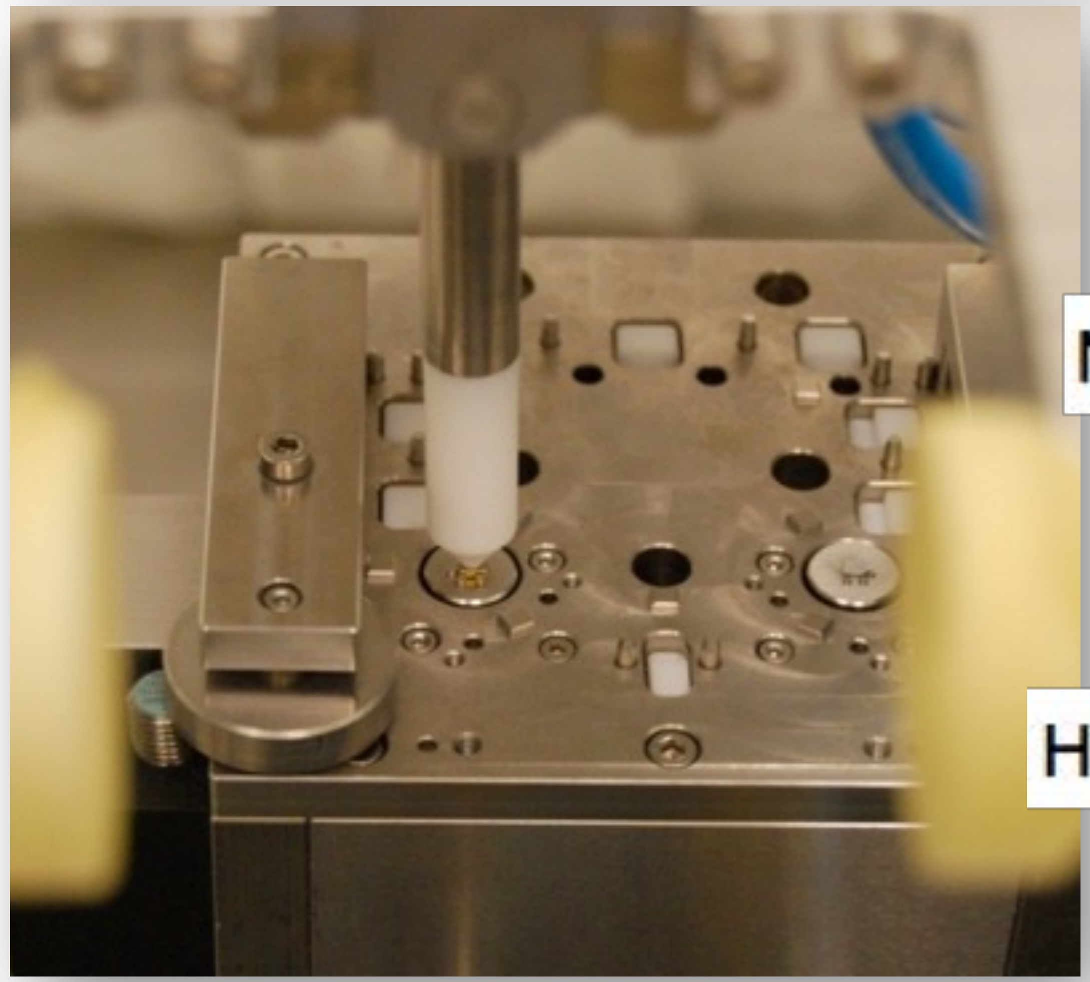


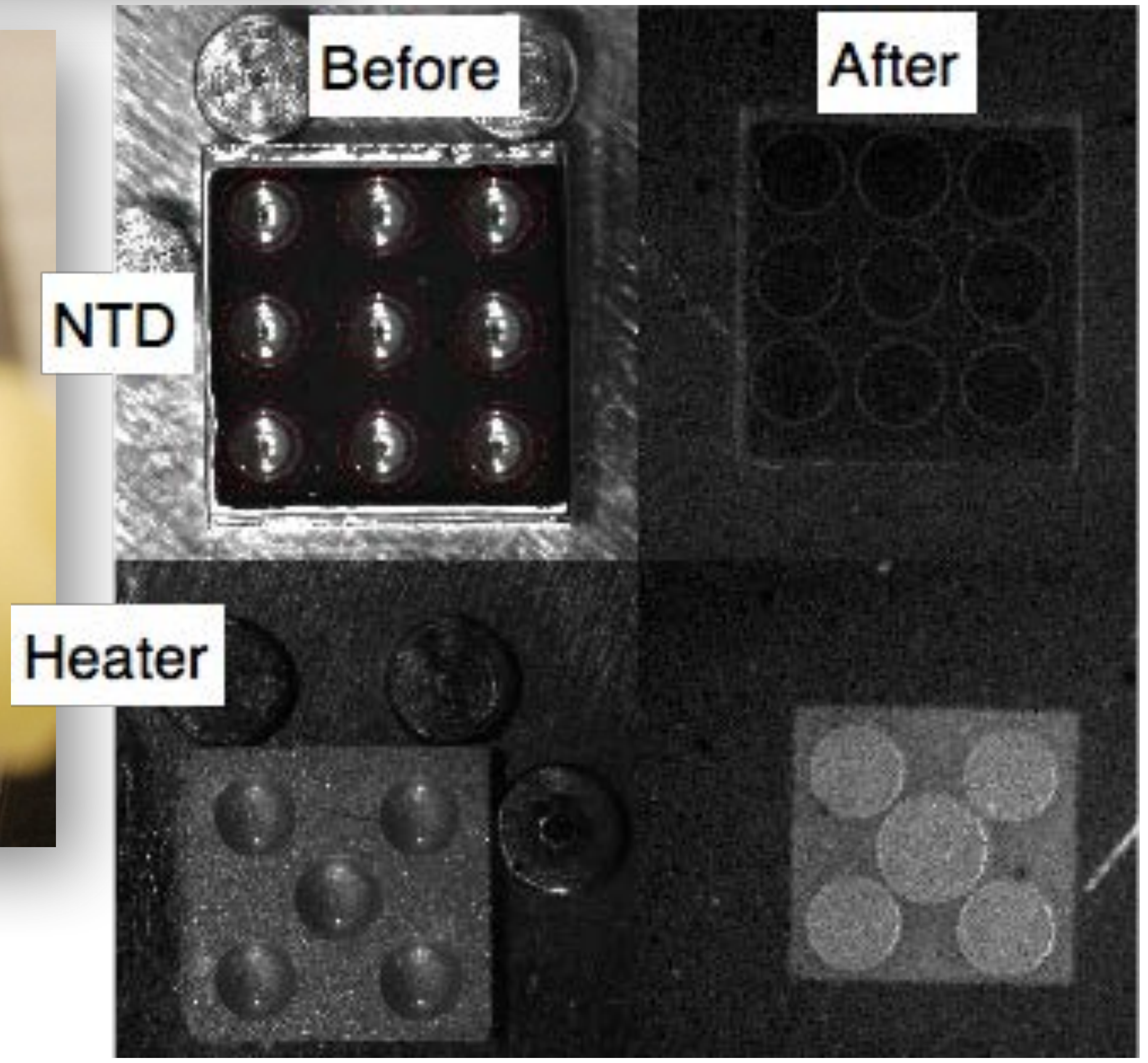
Features:

- new semi-automatic system
- highly-reproducible
- fully performed under N_2 atmosphere to minimize radioactive recontamination.

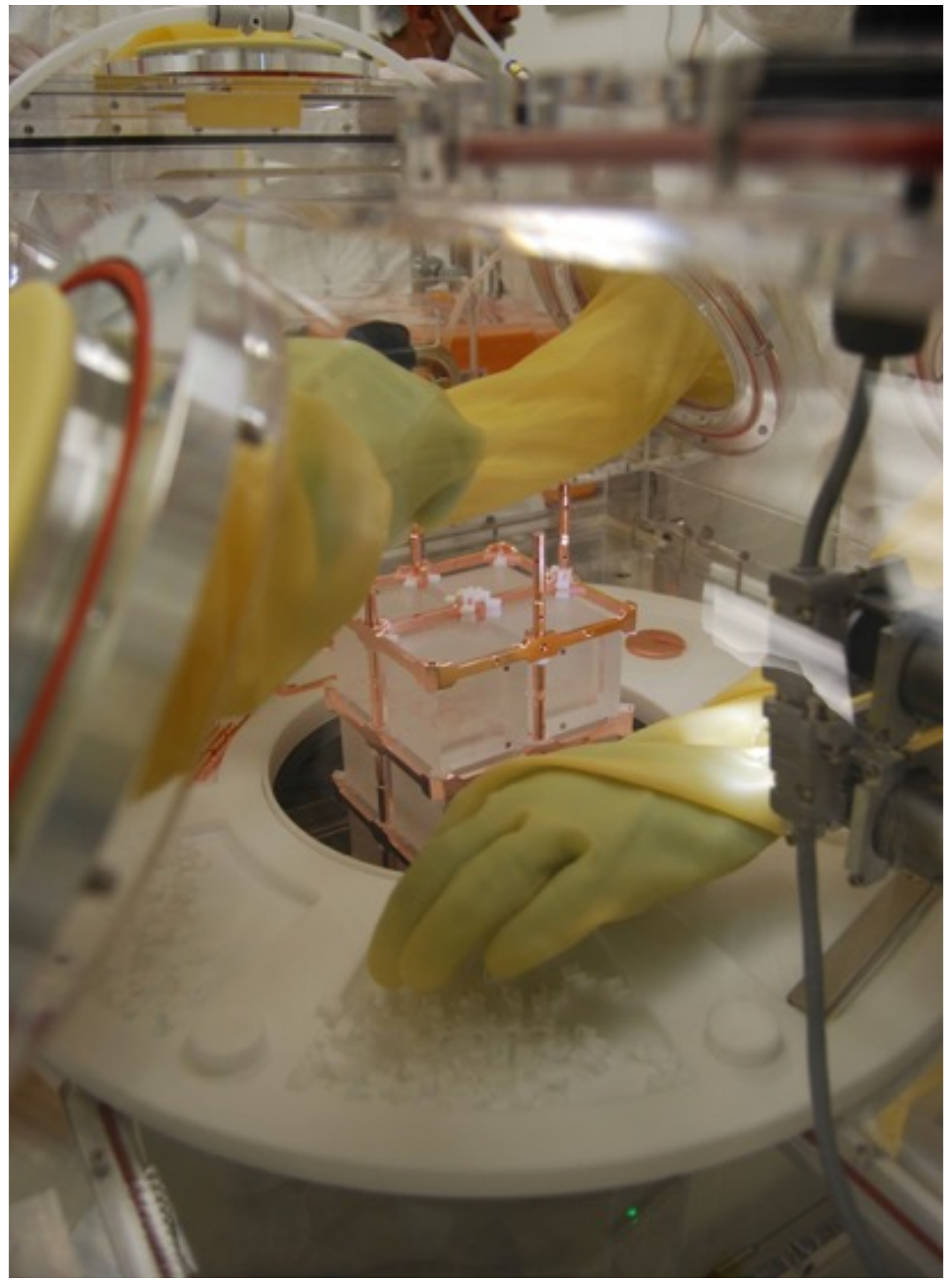


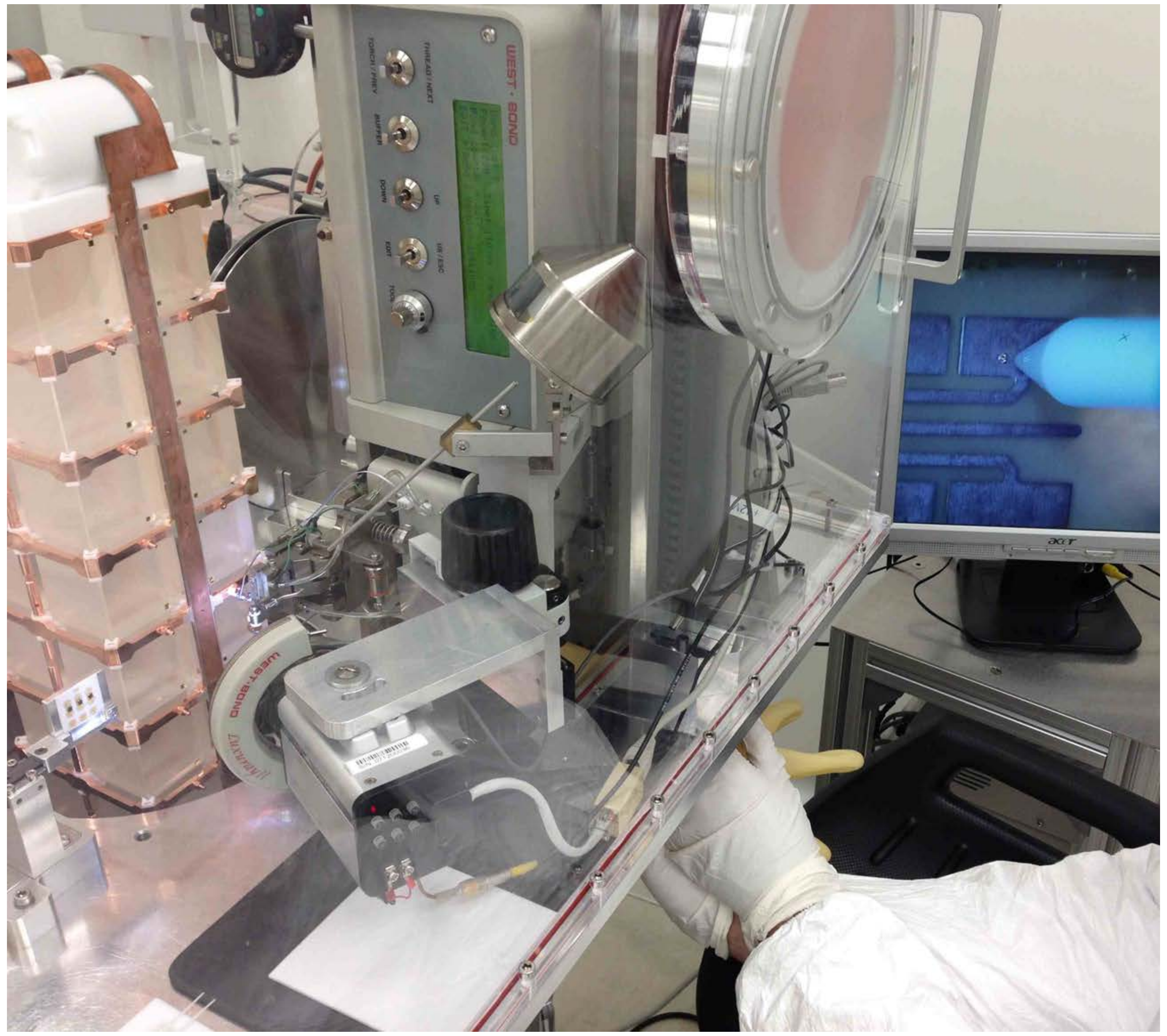






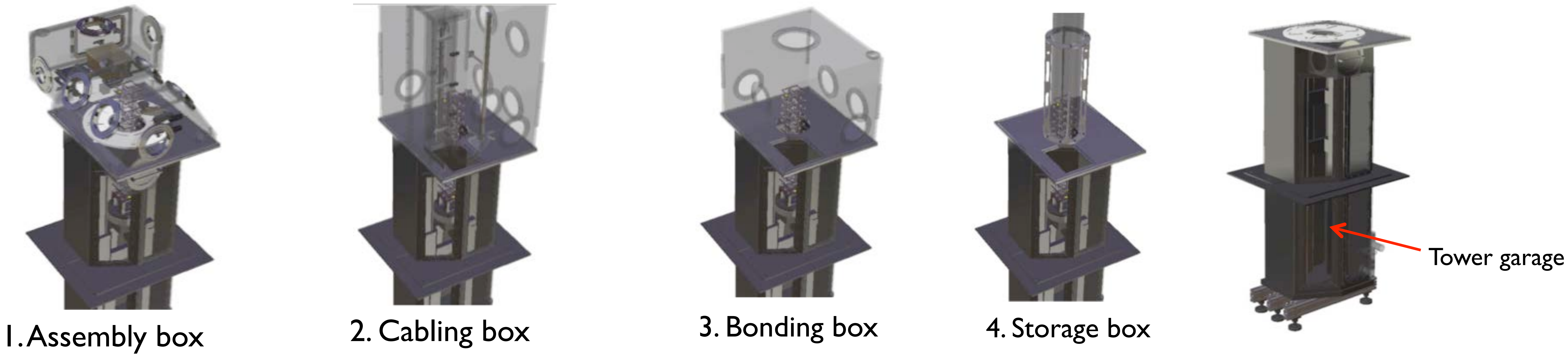
CUORE-0 Assembly & Bonding

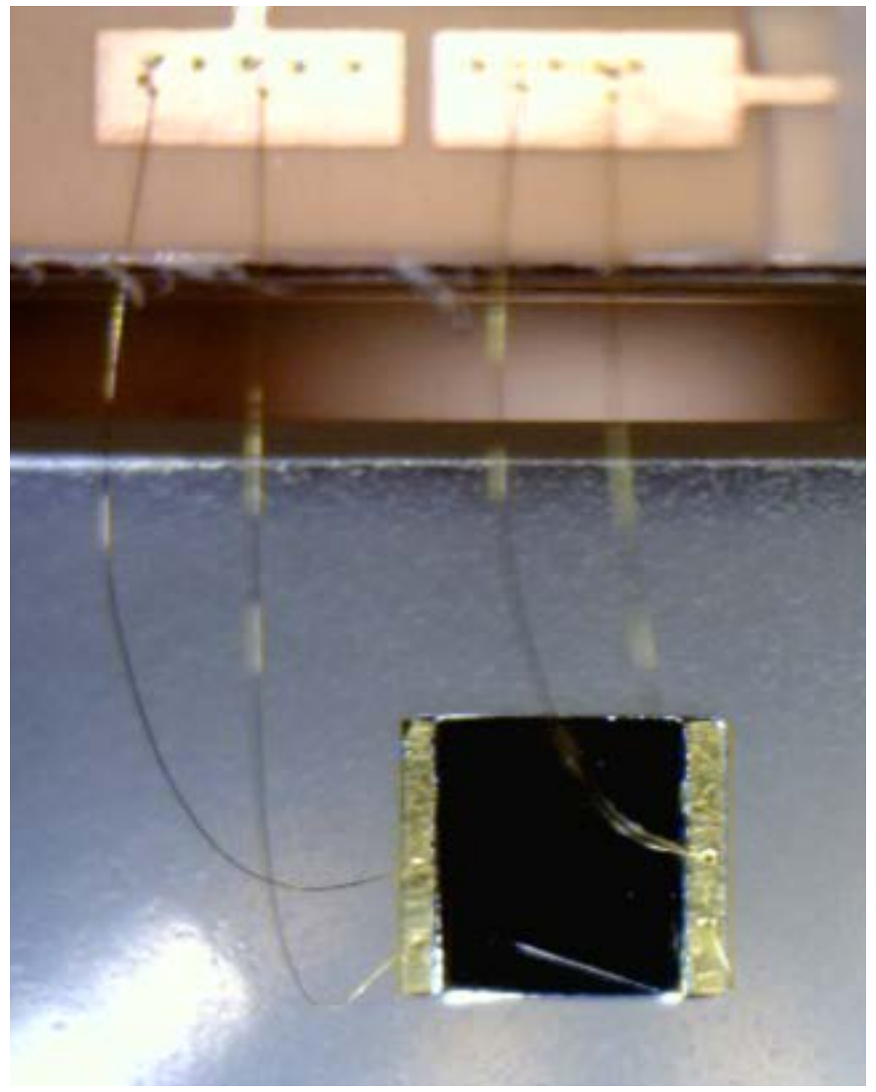




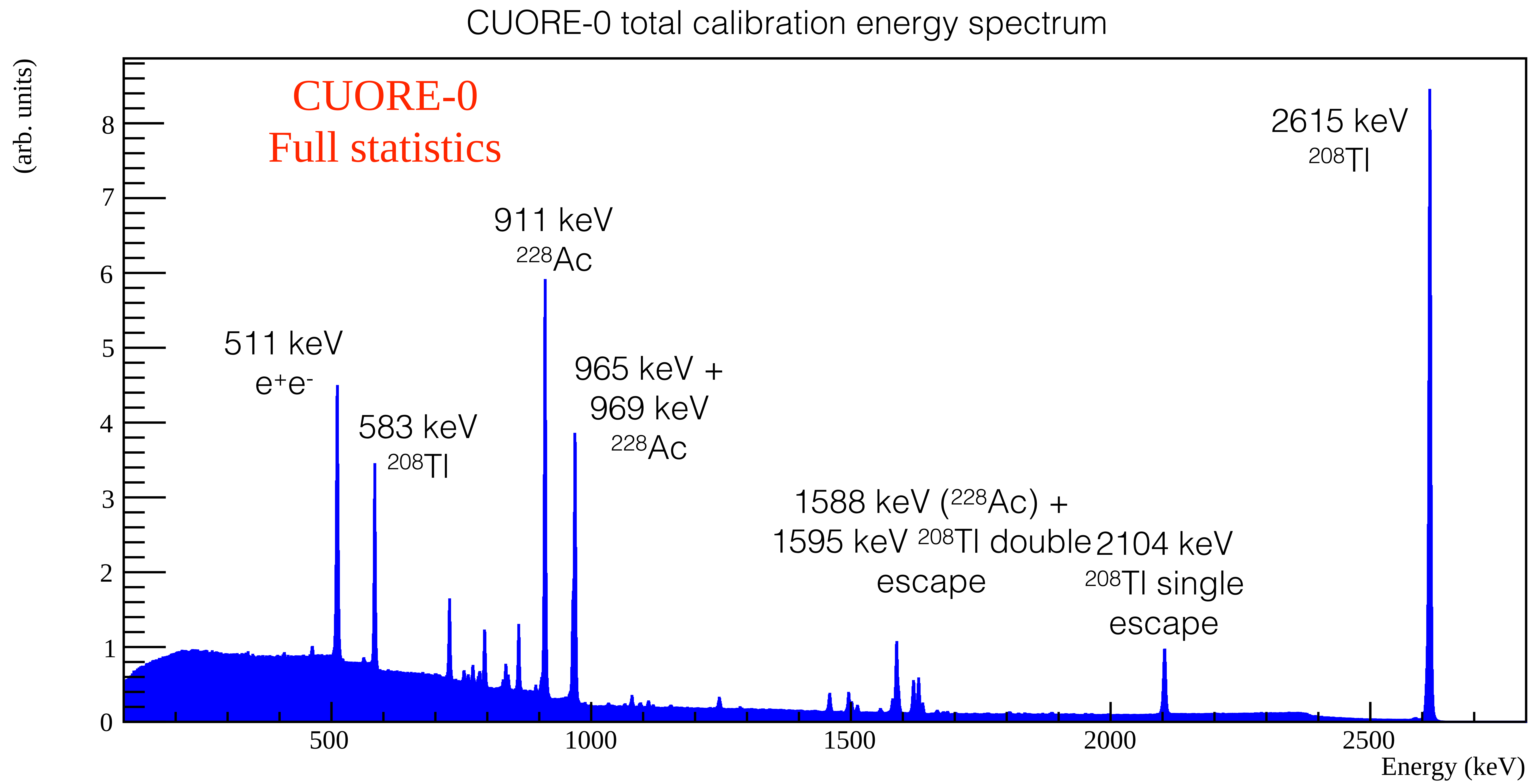
Contact less approach:

- All the operations carried out in N2 atmosphere



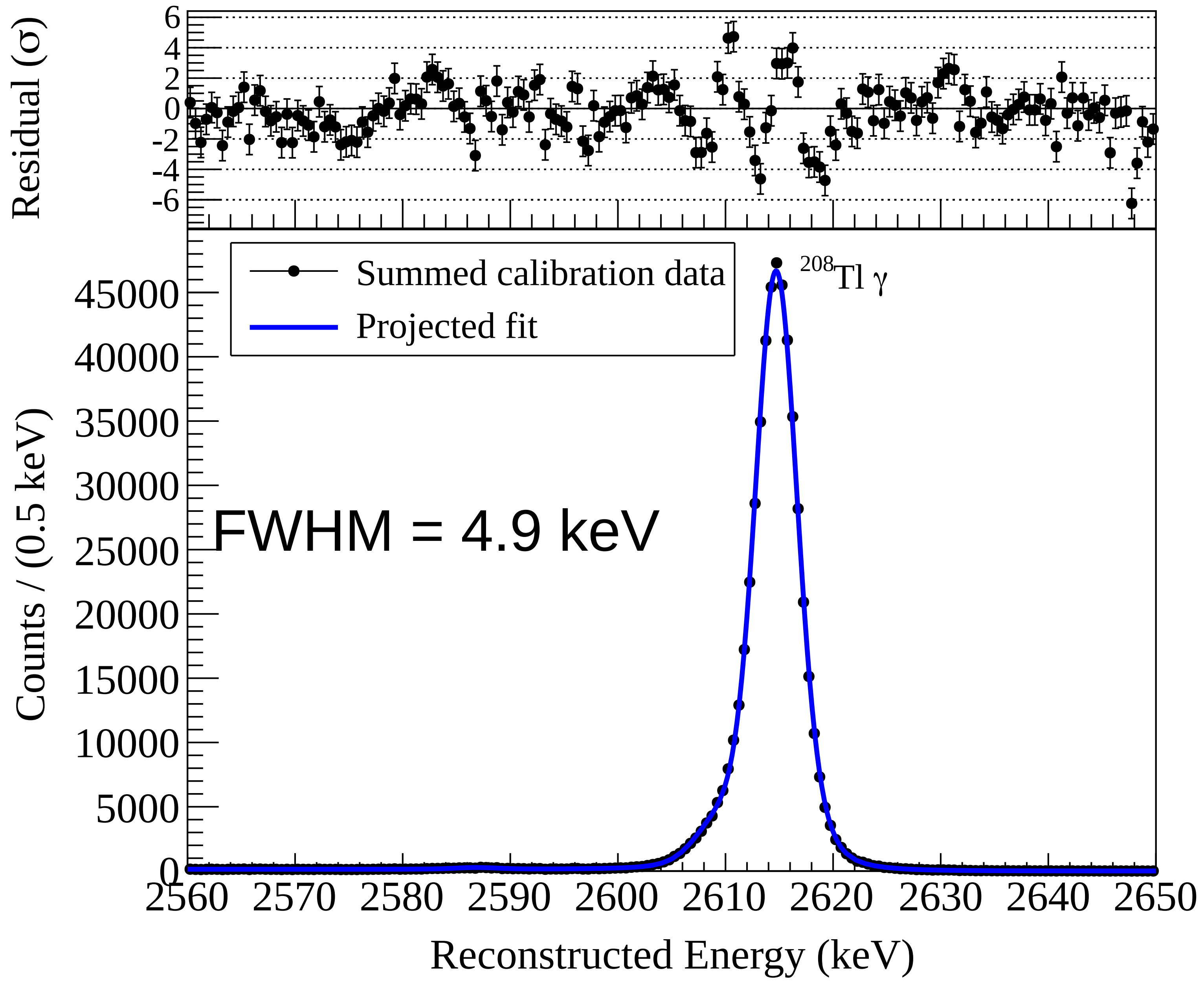


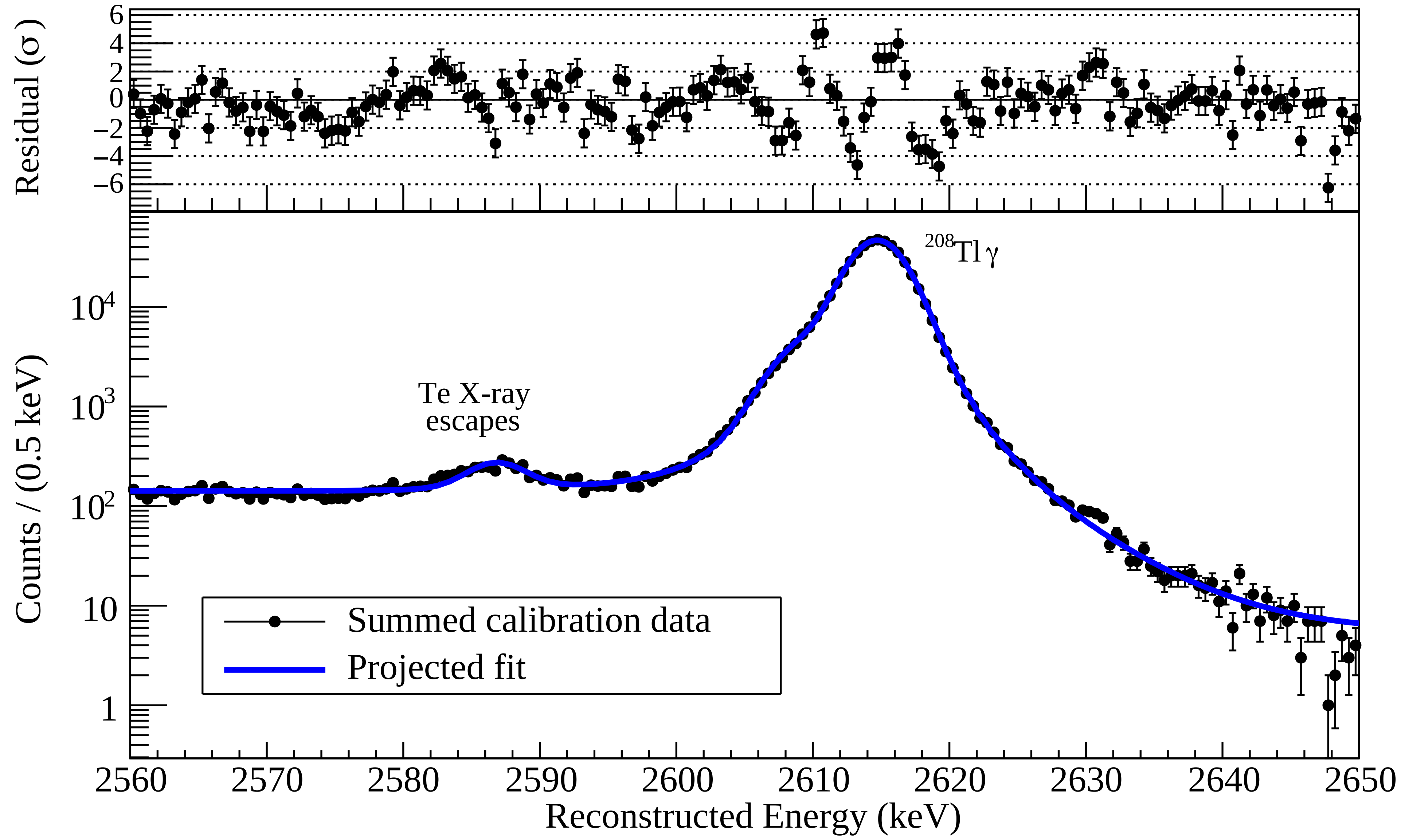
CUORE-0 ^{232}Th calibration



CUORE-0 calibration resolution

Total fit on the 2615 keV line



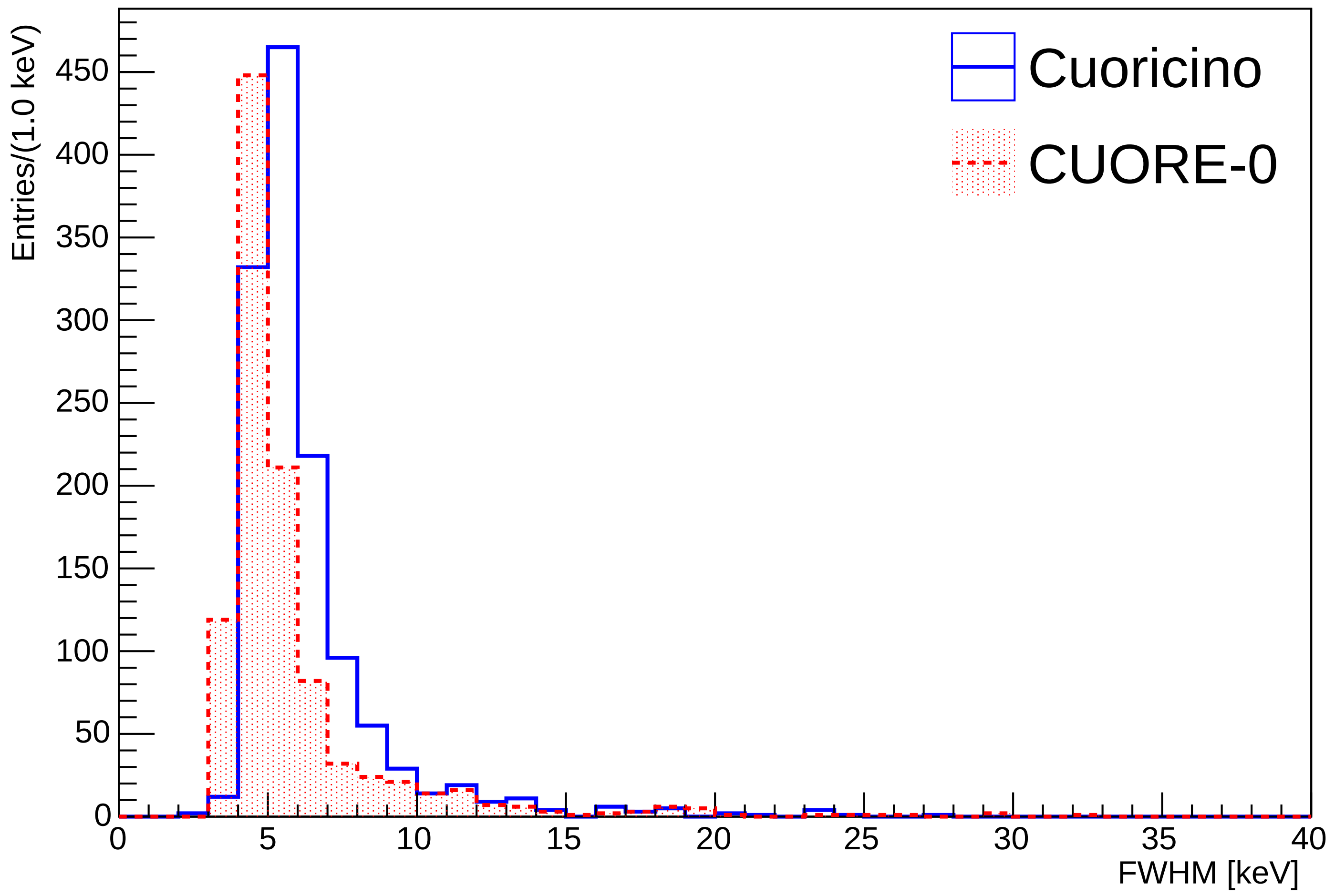


The 5 keV CUORE goal has been reached

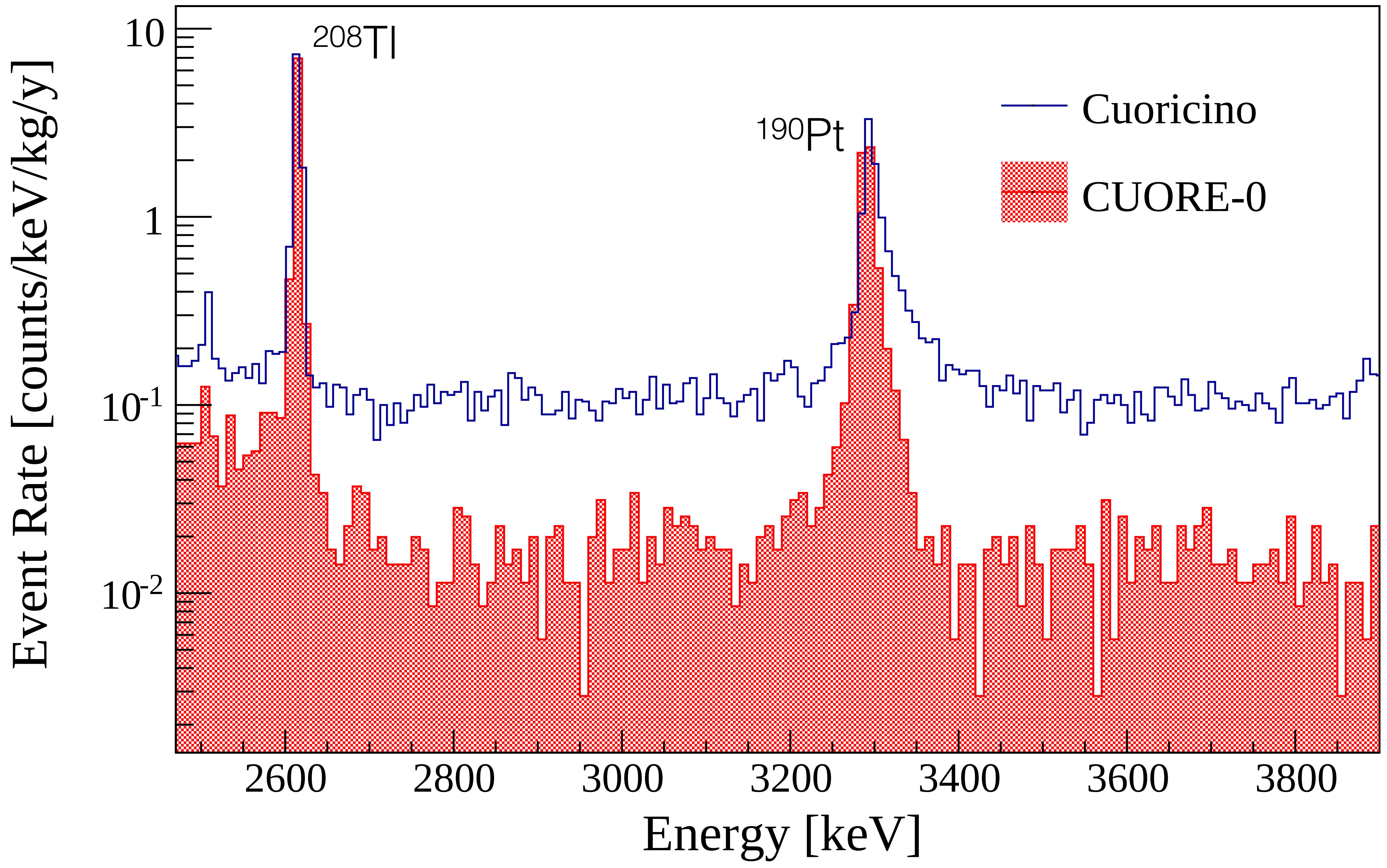
Physics-exposure-weighted harmonic mean

@ 2615 keV	Average FWHM [keV]	RMS of FWHM [keV]
Cuoricino	5.8	2.1
CUORE-0	4.9	2.9

Distribution of energy resolution @ 2615 keV



CUORE-0 background



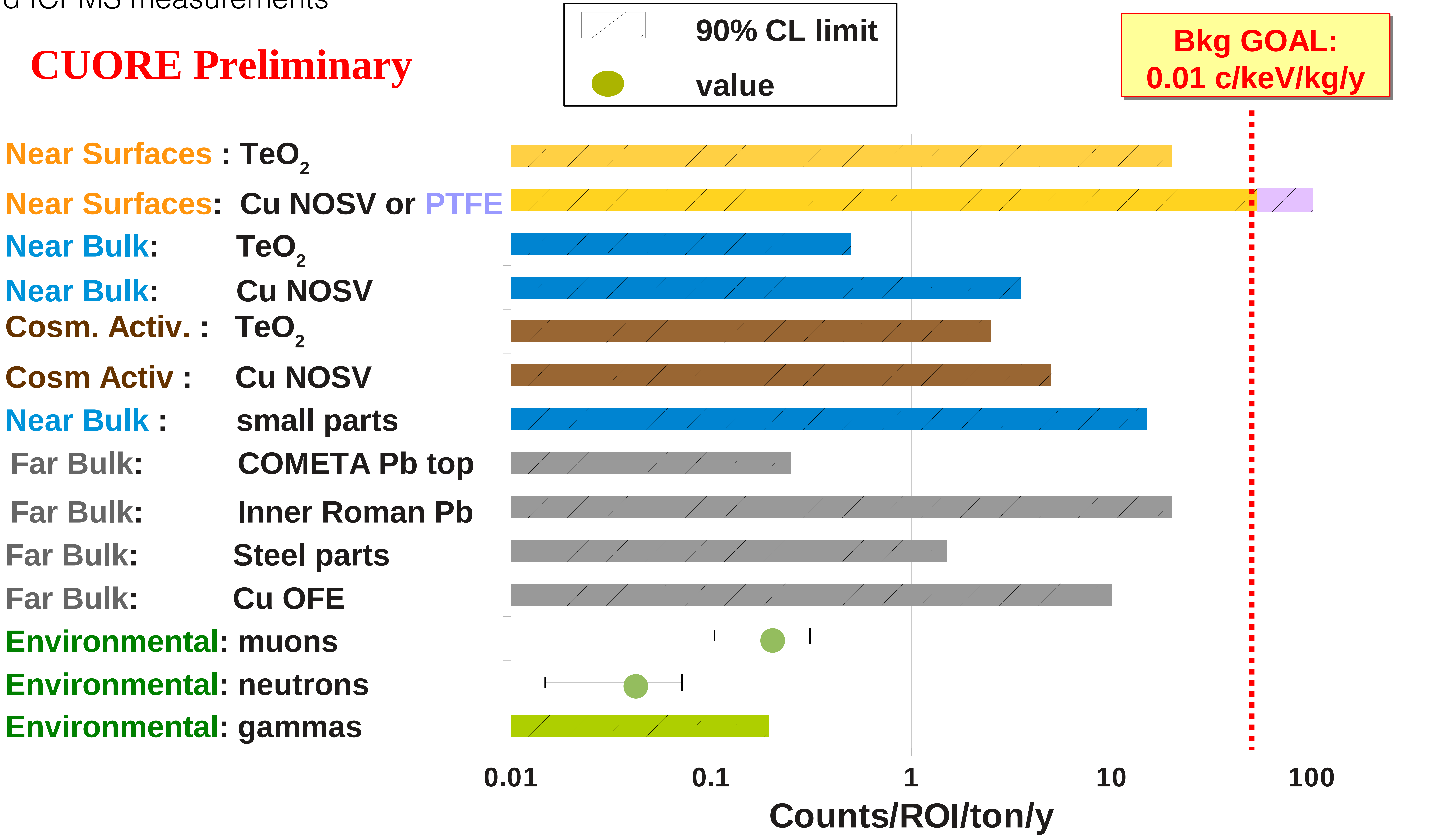
	2.7-3.9 MeV [counts/keV/kg/y]	ROI [counts/keV/kg/y]
CUORE-0	0.016 ± 0.001	0.058 ± 0.004
Cuoricino	0.110 ± 0.001	0.169 ± 0.006

~ factor 7 reduction in the alpha continuum region

CUORE background budget

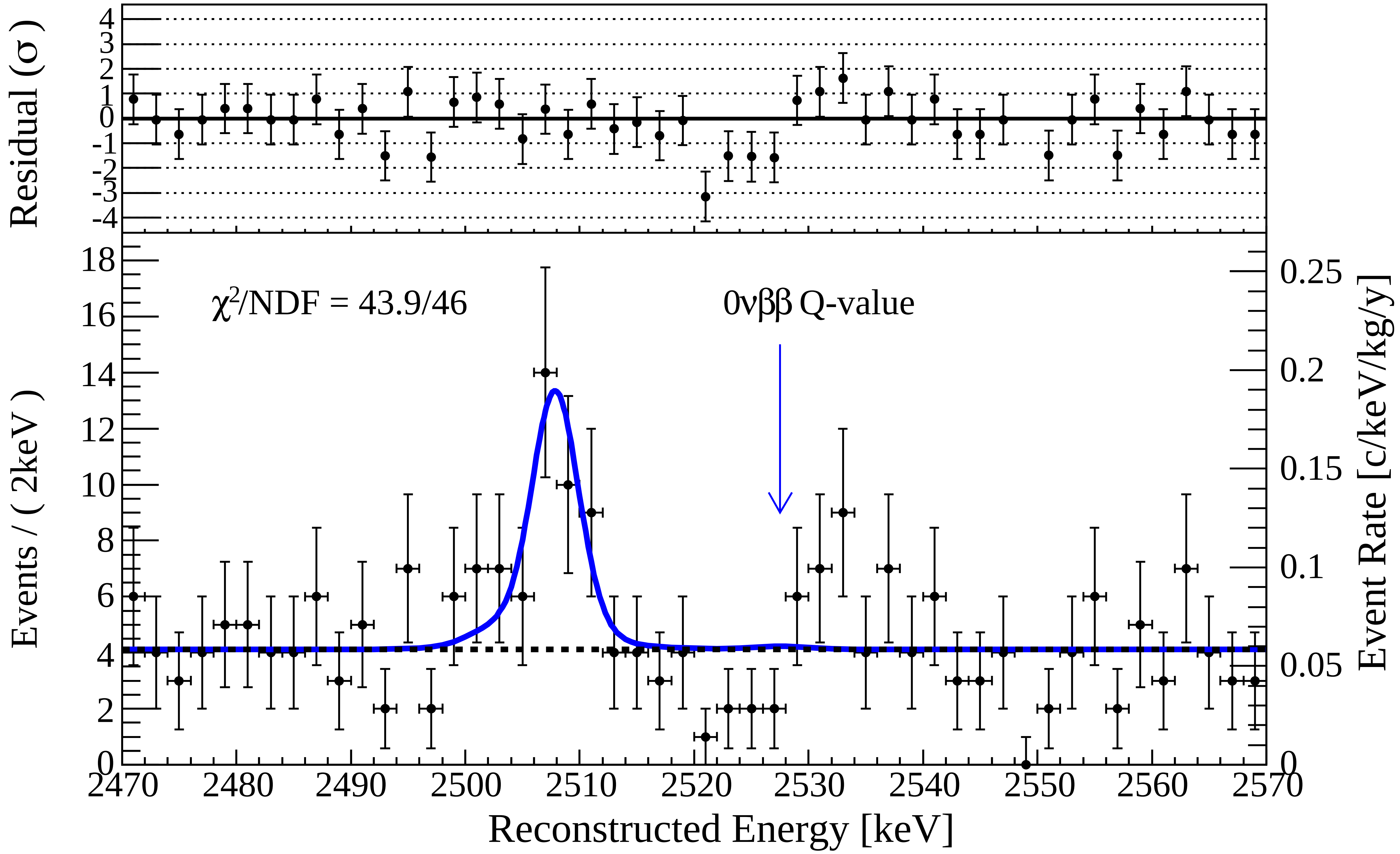
Based on

- Cuoricino & CUORE-0 data
- HPGe, NAA and ICPMS measurements
- Montecarlo



C. Alduino et al., in preparation

CUORE-0 results



Exposure: 9.8 kg·yr ^{130}Te

- Fit function in the energy region 2470-2570 keV, composed of 3 elements:
    1. Peak with calibration-derived line- shape at the Q-value of ^{130}Te
    2. Peak at 2507 keV attributed to the summed γ peak of ^{60}Co
    3. Flat continuum background attributed to multi scatter Compton events from ^{208}Tl and surface α events

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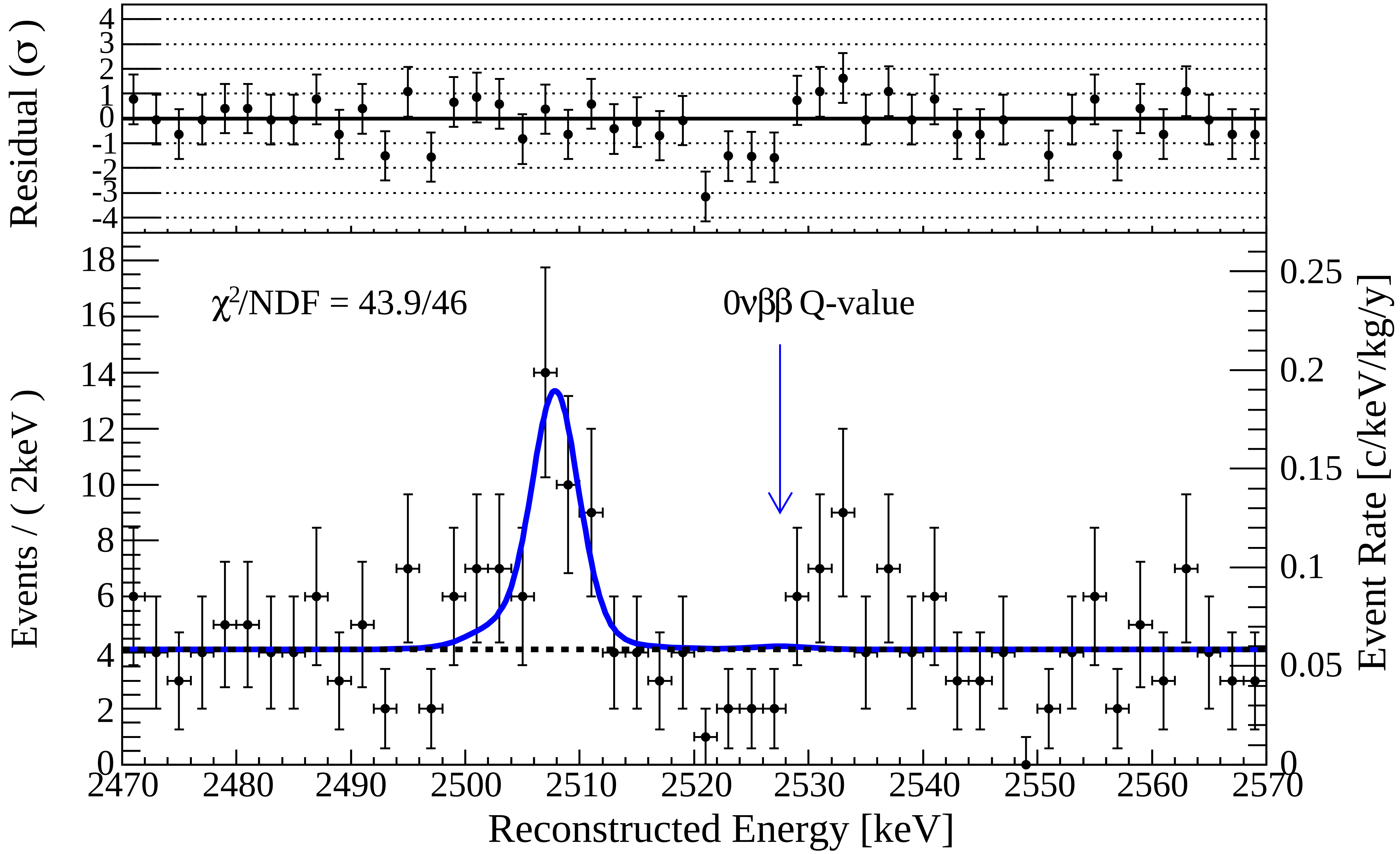

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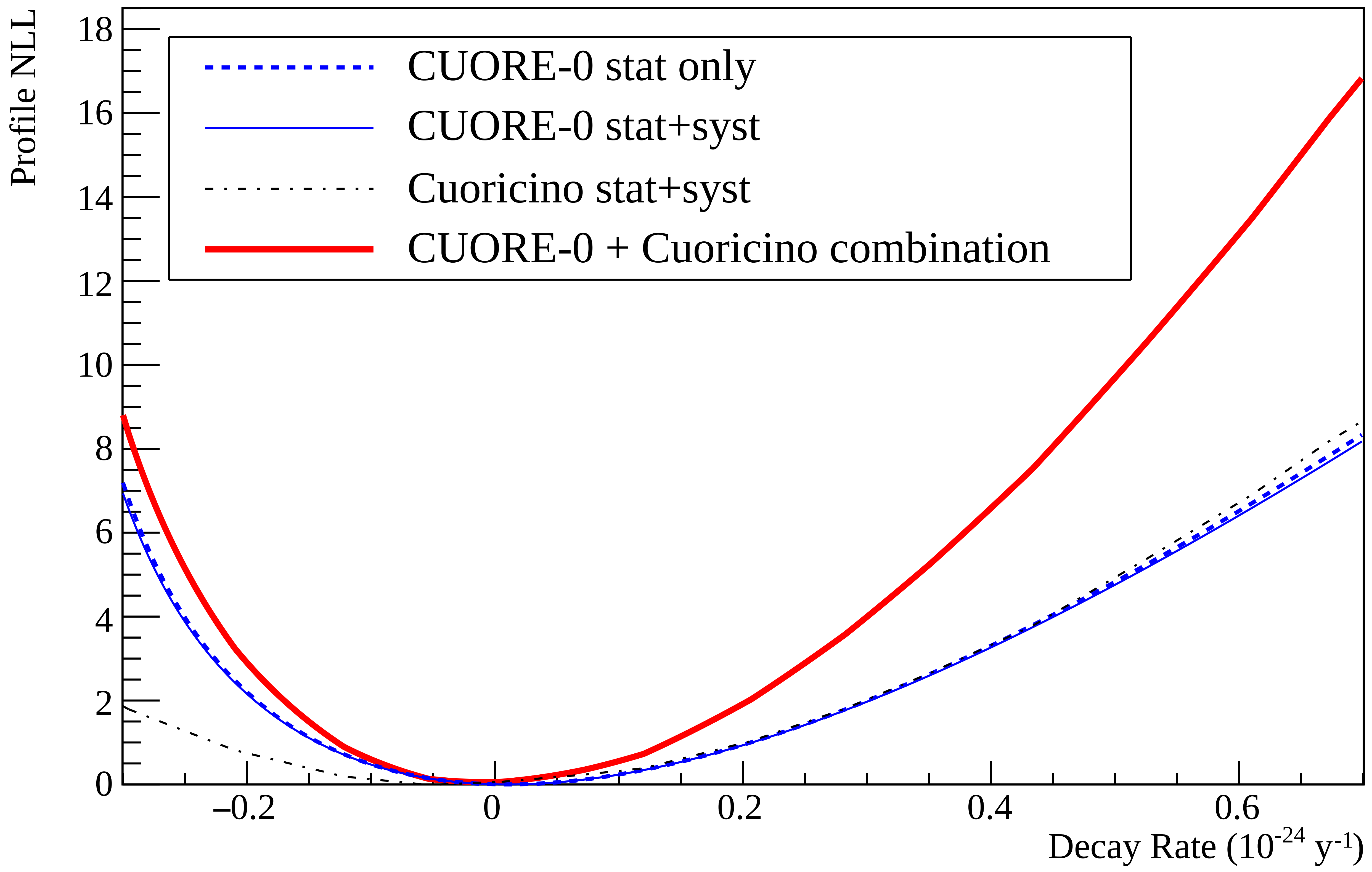
Best Fit Background index: 0.058 ± 0.004 (stat.) ± 0.002 (syst.) c keV^{-1} kg^{-1} yr^{-1}

Best Fit Decay Rate: $\Gamma^{0\nu\beta\beta}$ (130Te) = 0.01 ± 0.12 (stat.) ± 0.01 (syst.) × 10^{-24} yr^{-1}

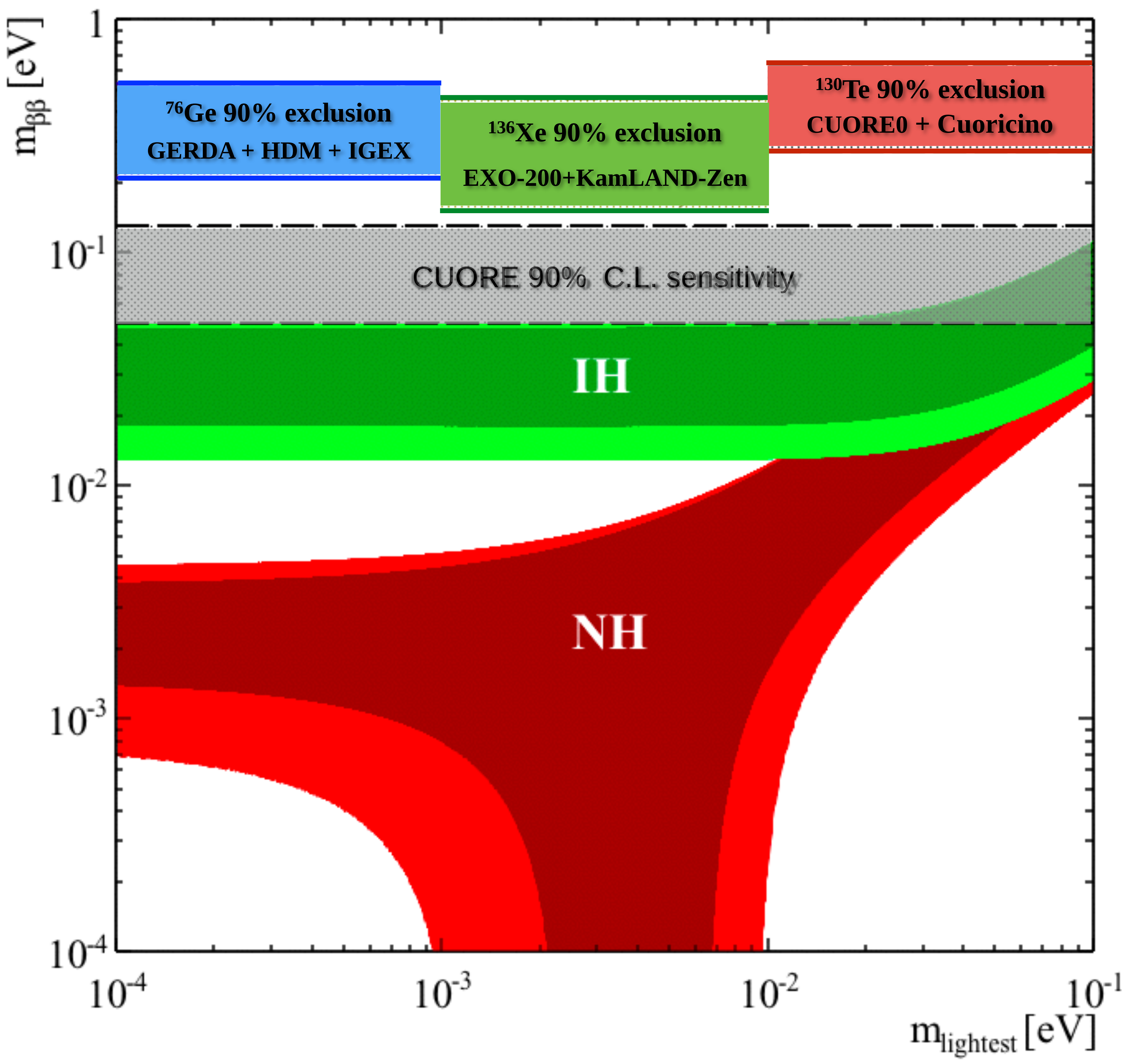
Combining CUORE-0 and Cuoricino

- Combination of the CUORE-0 result with the existing 19.75 kg · yr of ^{130}Te exposure from Cuoricino
- The combined 90% C.L. limit is $T_{1/2} > 4.0 \times 10^{24}$ yr.



Phys. Rev. Lett. 115, 102502

Limit on the effective Majorana mass



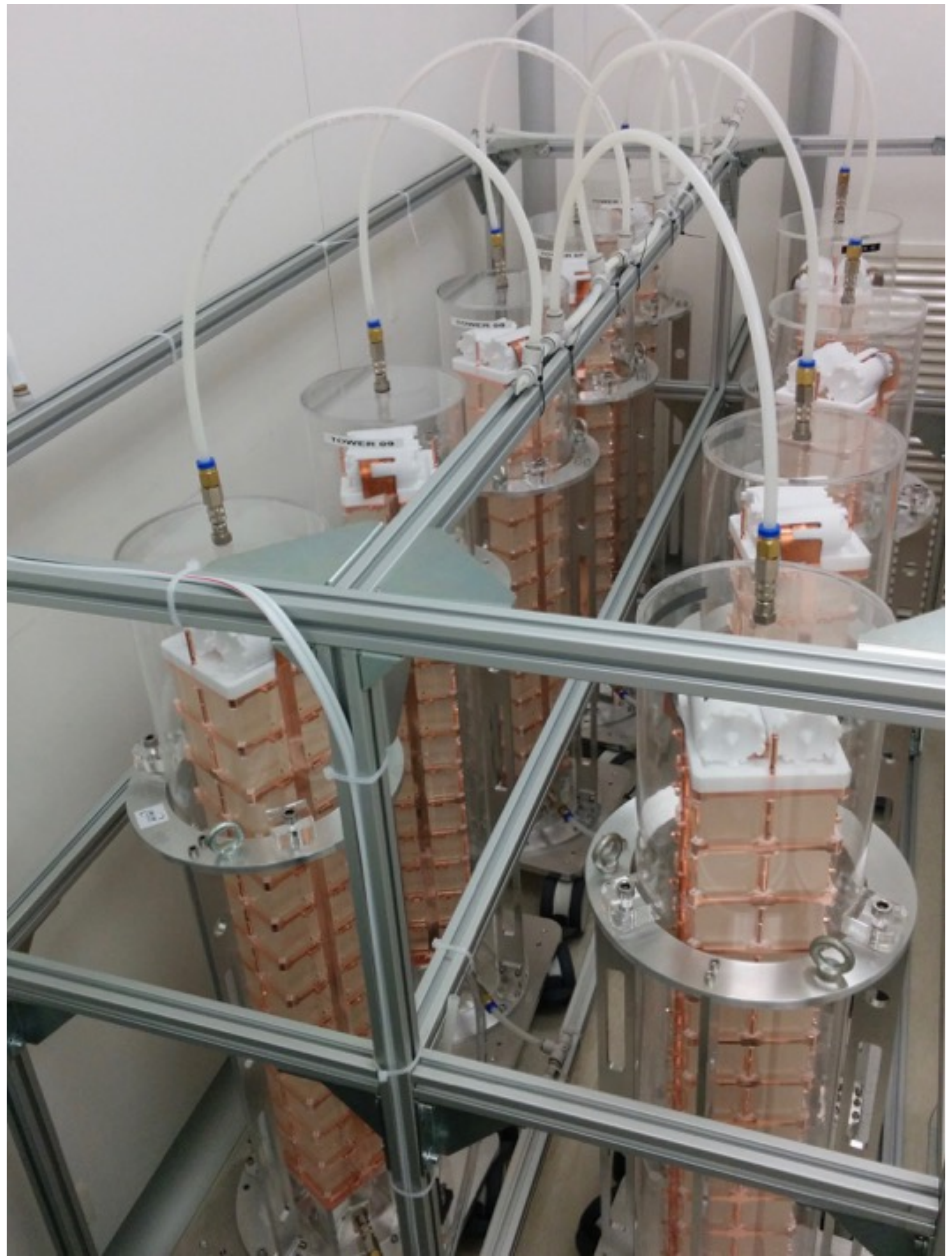
The combined result gives a limit on the effective Majorana neutrino mass:

$\langle m_{\beta\beta} \rangle <$ (270-650) meV

IBM-2 Phys. Rev. C 91, 034304 (2015)
QRPA-TU Phys. Rev. C 87, 045501 (2013)
pnQRPA Phys. Rev. C 91, 024613 (2015)
ISM Nucl. Phys. A 818, 139 (2009)
EDF Phys. Rev. Lett. 105, 252503 (2010)

CUORE Towers Assembly

- Assembly of all the 19 CUORE towers completed in 2014



Assembly line improved after CUORE-0

CUORE-0

51/52 NTD connected

51/52 heaters connected

CUORE

988/988 NTD connected

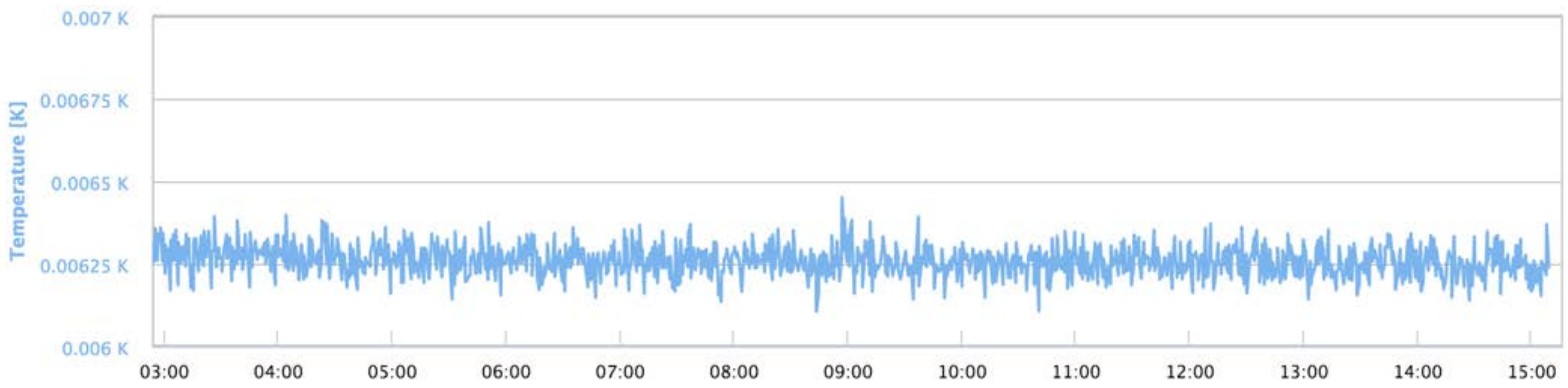
988/988 heaters connected

- Also a mockup tower for the Detector installation phase and a minitower to be used during the cryostat commissioning runs were produced

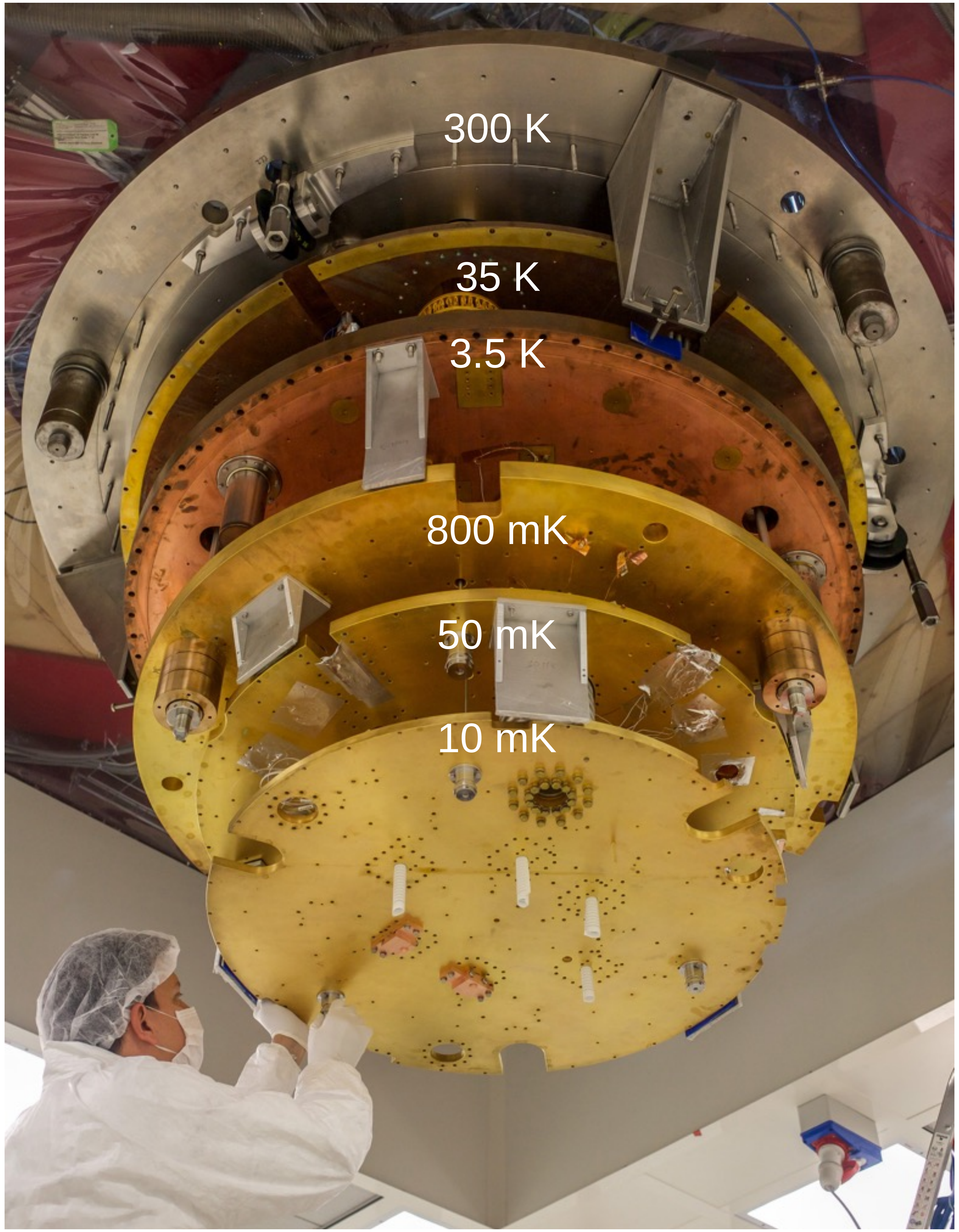
Cryogenic system commissioning

Goal was to develop a cryogenic system capable to deliver stable base T (~10 mK) together with reduced vibrations (baseline RMS at few keV) and a radio clean environment (selected material, cold Pb shields).

- All the cryostat components well thermalized at the different stages (including top Pb @ 50 mK and lateral roman Pb @ 3.5 K). No evident temperature gradient or heat leak.
- Stable base temperature -that allows CUORE bolometers operation- **6.3 mK**. Base T stable for more than 70 days. Proved nominal cooling power: **3 µW @ 10 mK**.

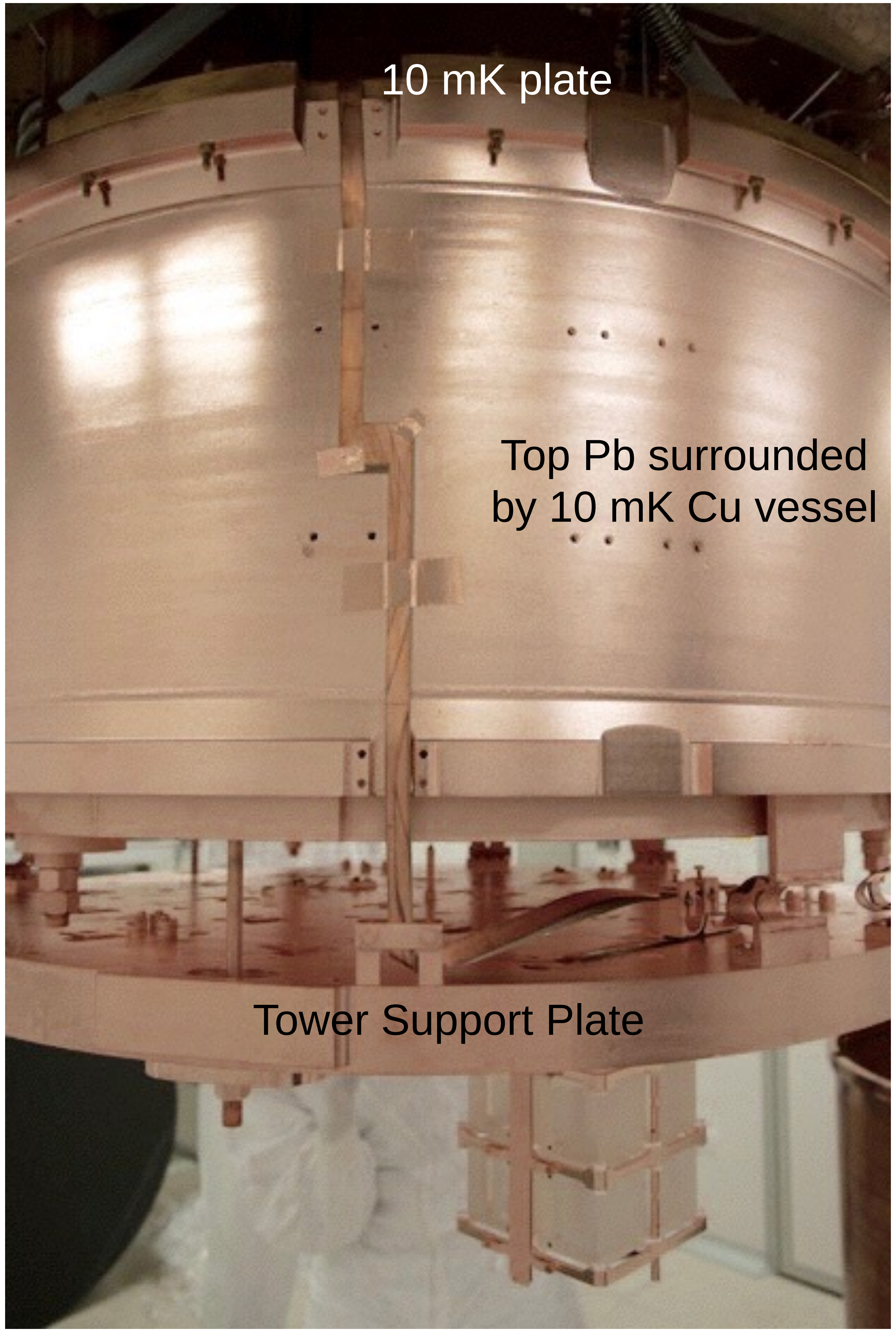


- Base temperature allows to stabilise operating temperature around 10 mK for a stable detector response.



Bolometers and readout commissioning

- Encouraging detector performance (energy resolution) on 8 detectors array (Mini-Tower)
- Commissioned electronics, DAQ, temperature stabilization, and detector calibration systems



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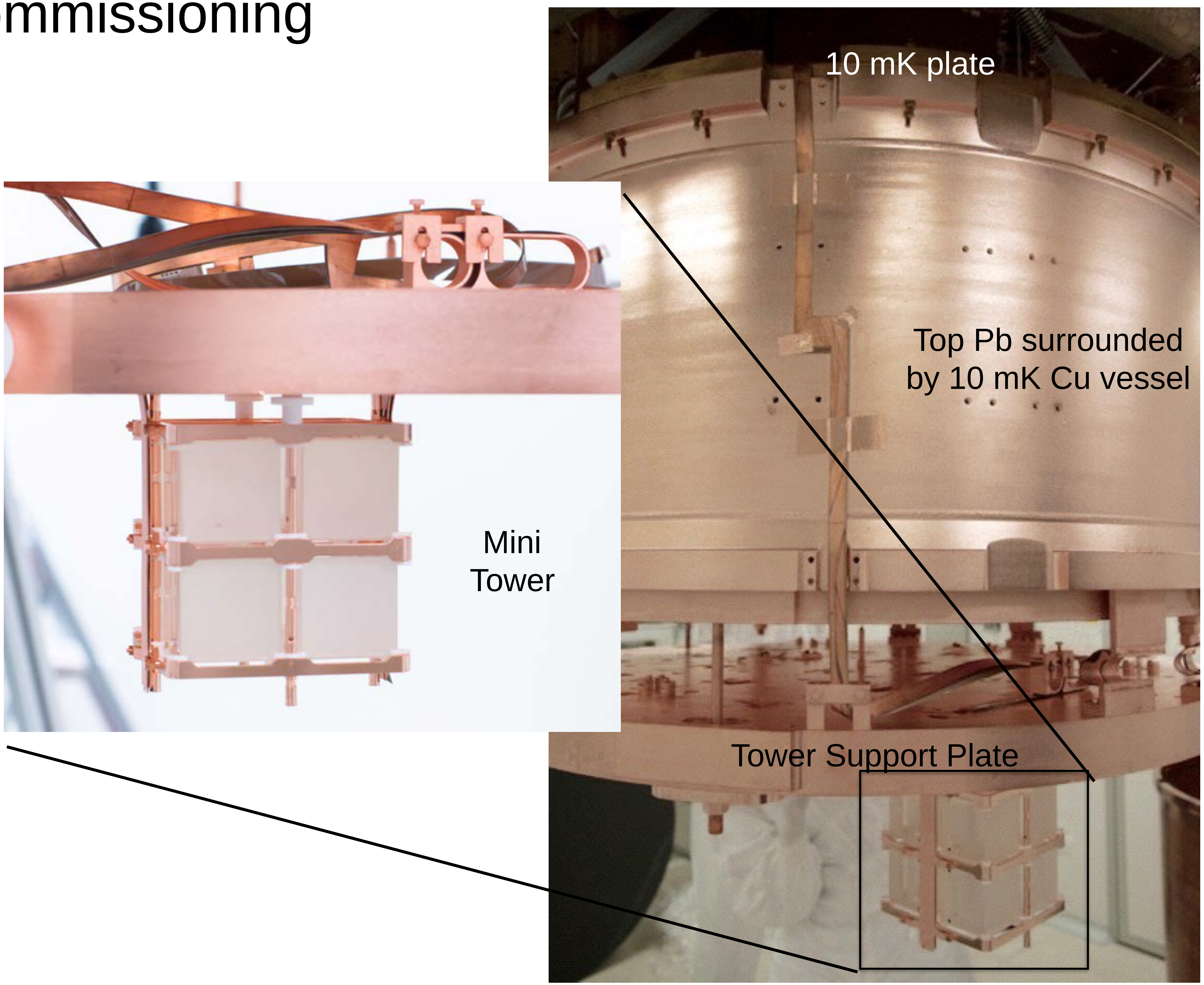

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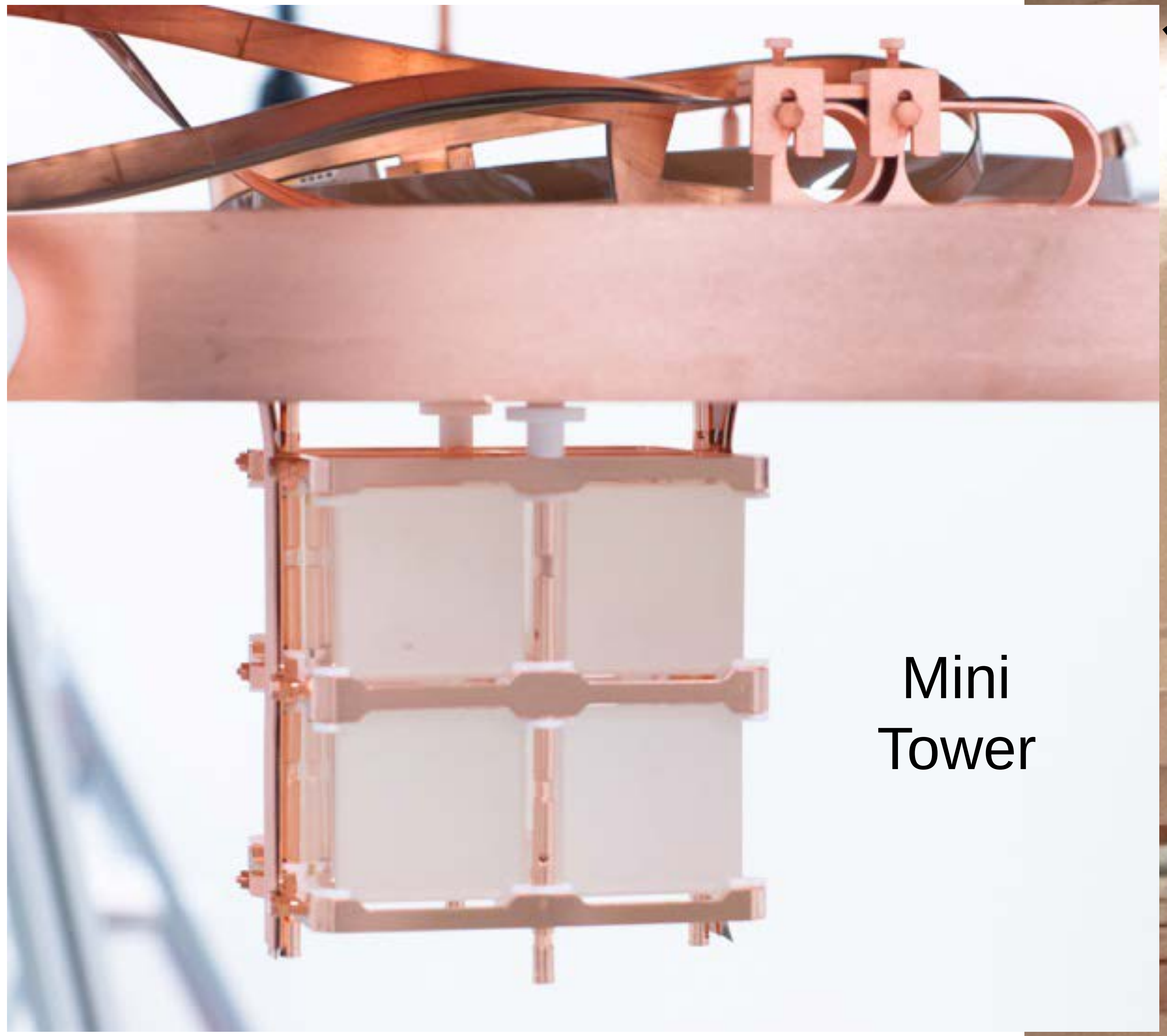
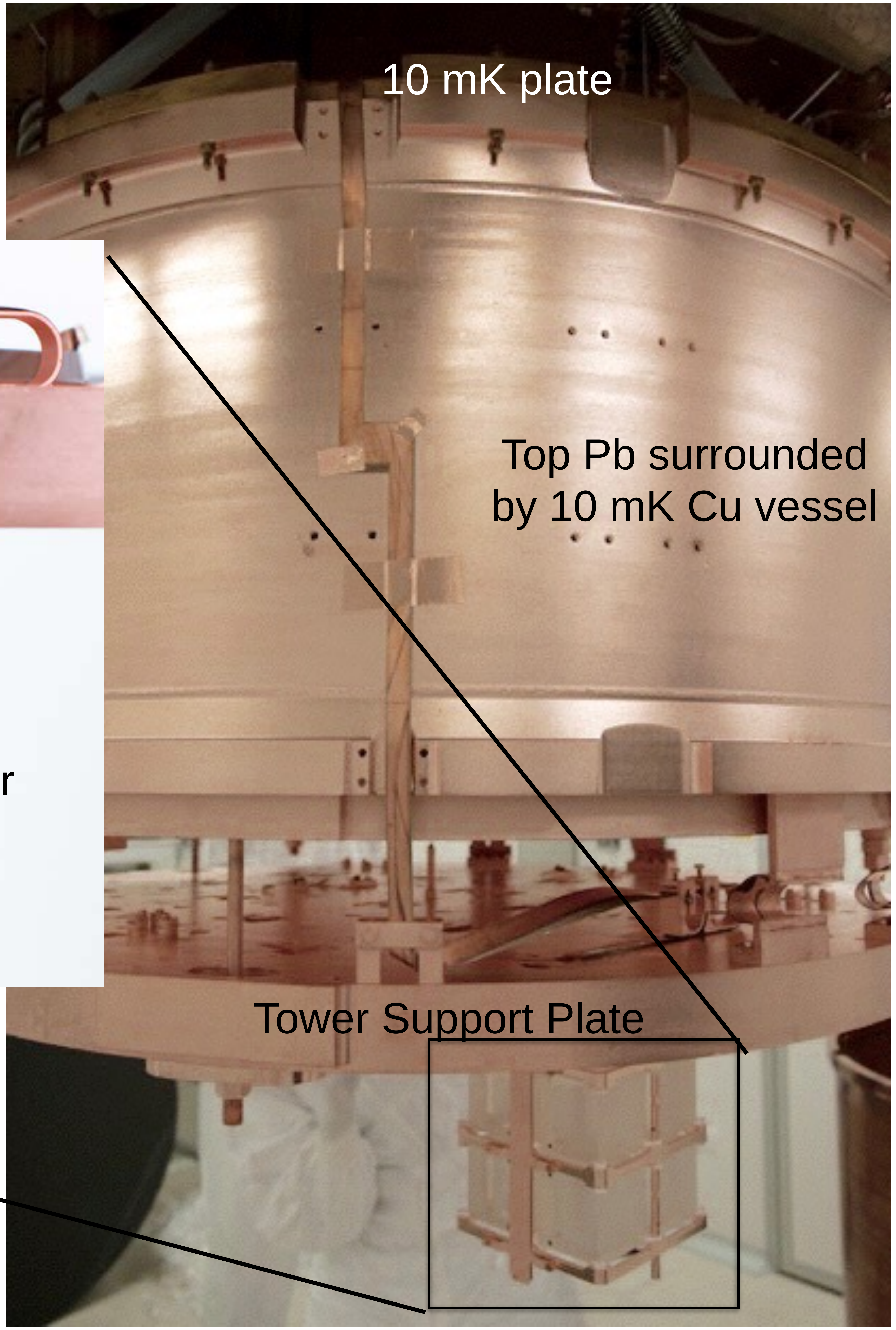




Cryogenic commissioning complete: detector installation in Spring 2016

Conclusions

CUORE-0

- Achieved its energy resolution and background level objectives
- Improved 0vDBD limit for ^{130}Te (no 0vDBD evidence)
- Indicated CUORE sensitivity goal is within reach.

CUORE

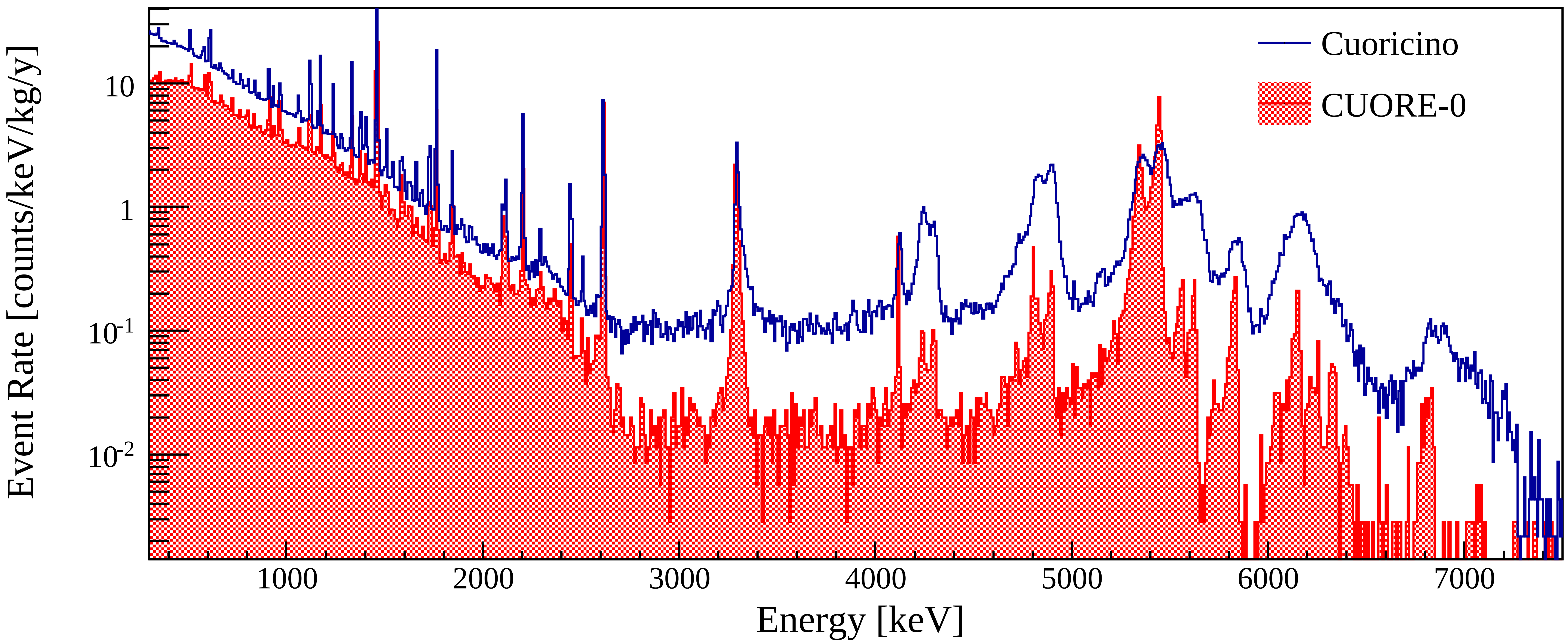
- Assembly of the 19 CUORE towers is complete.
- CUORE cryostat assigning is completed
  - stable base temperature of ~ 6 mK
  - positive indications on noise and performances
- The cryostat is now ready to host the detector
- Detector installation foreseen in spring 2016
- CUORE cool down expected in summer 2016

The CUORE collaboration

Backup

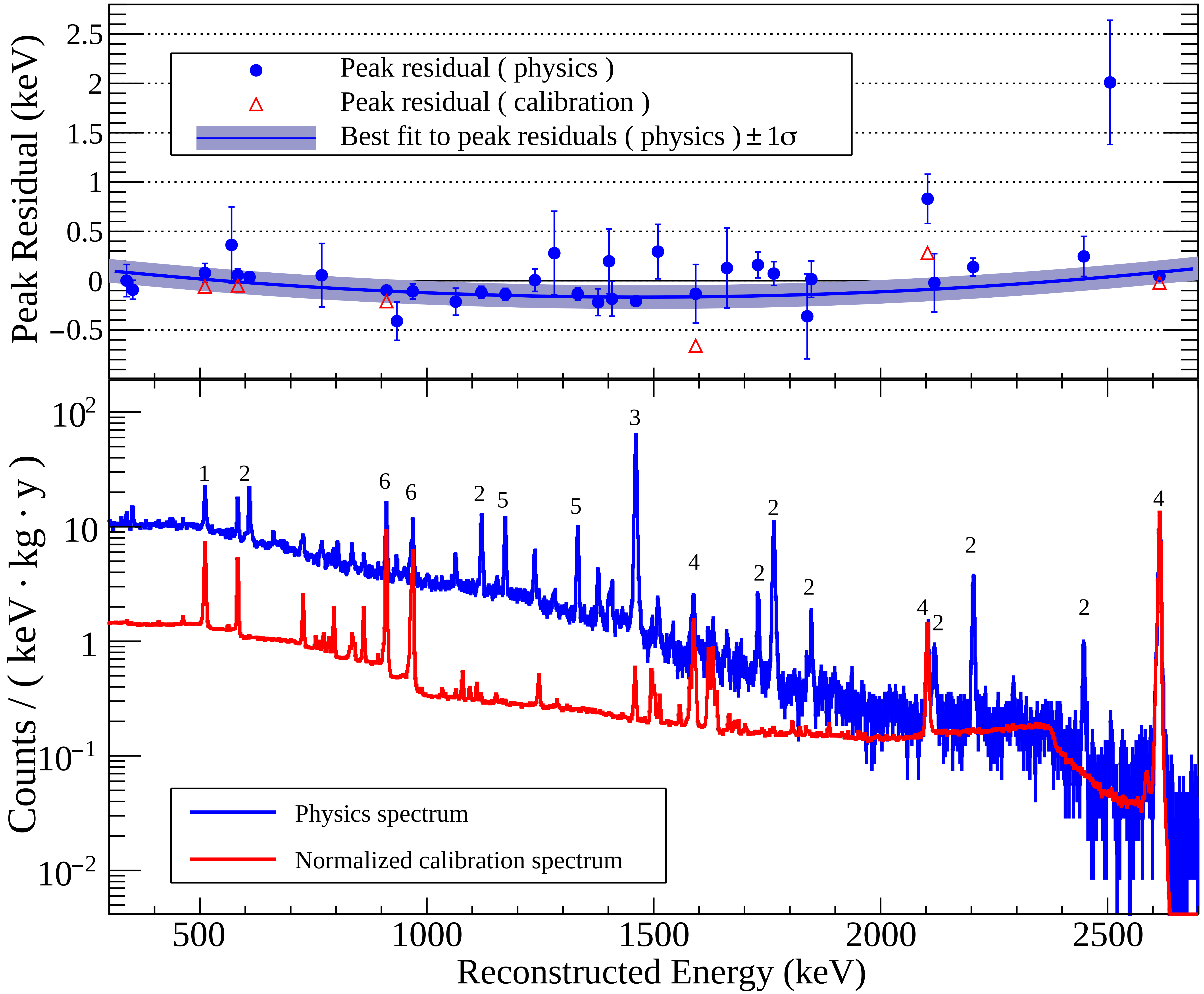
CUORE-0 background

Comparison of the total background spectrum in CUORE-0 and Cuoricino



- ^{238}U and ^{232}Th α lines reduced thanks to the new detector surface treatment
- ^{238}U γ lines reduced by a factor 2 (better radon control)
- ^{232}Th γ lines not reduced (originate from the cryostat)

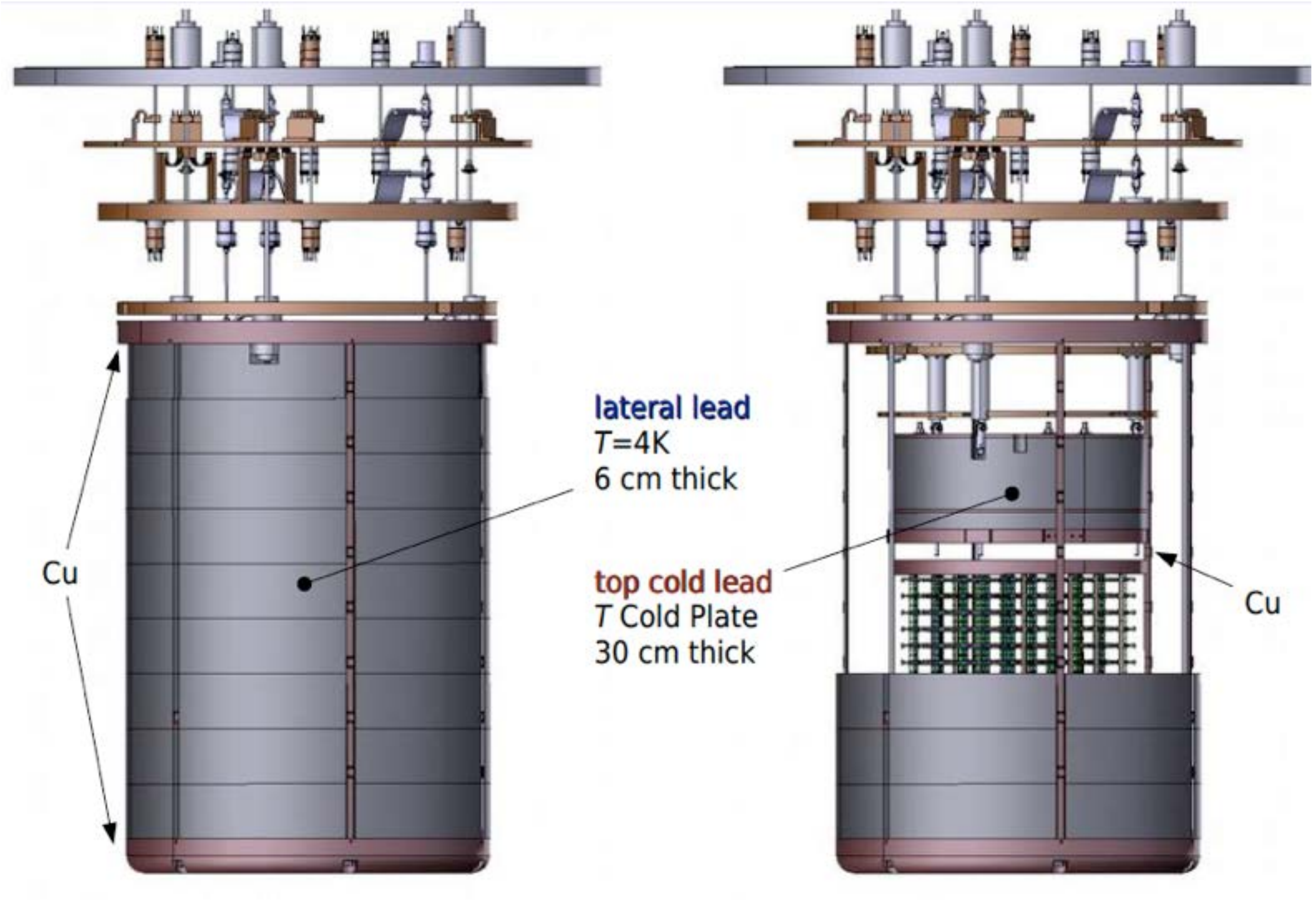
Energy spectrum and calibration residuals



Two outliers:

- ^{60}Co, which reconstruct at 2507±0.6 keV, 2.0±0.6 keV higher than the nominal value
- ^{208}Tl single-escape line, which reconstruct 0.84±0.22 above the nominal value 2103.51 keV.

Cold Pb shields



2 main elements

- side & bottom: roman Pb, 6 cm thick
- top: 5 discs (6 cm thickness each) of modern lead

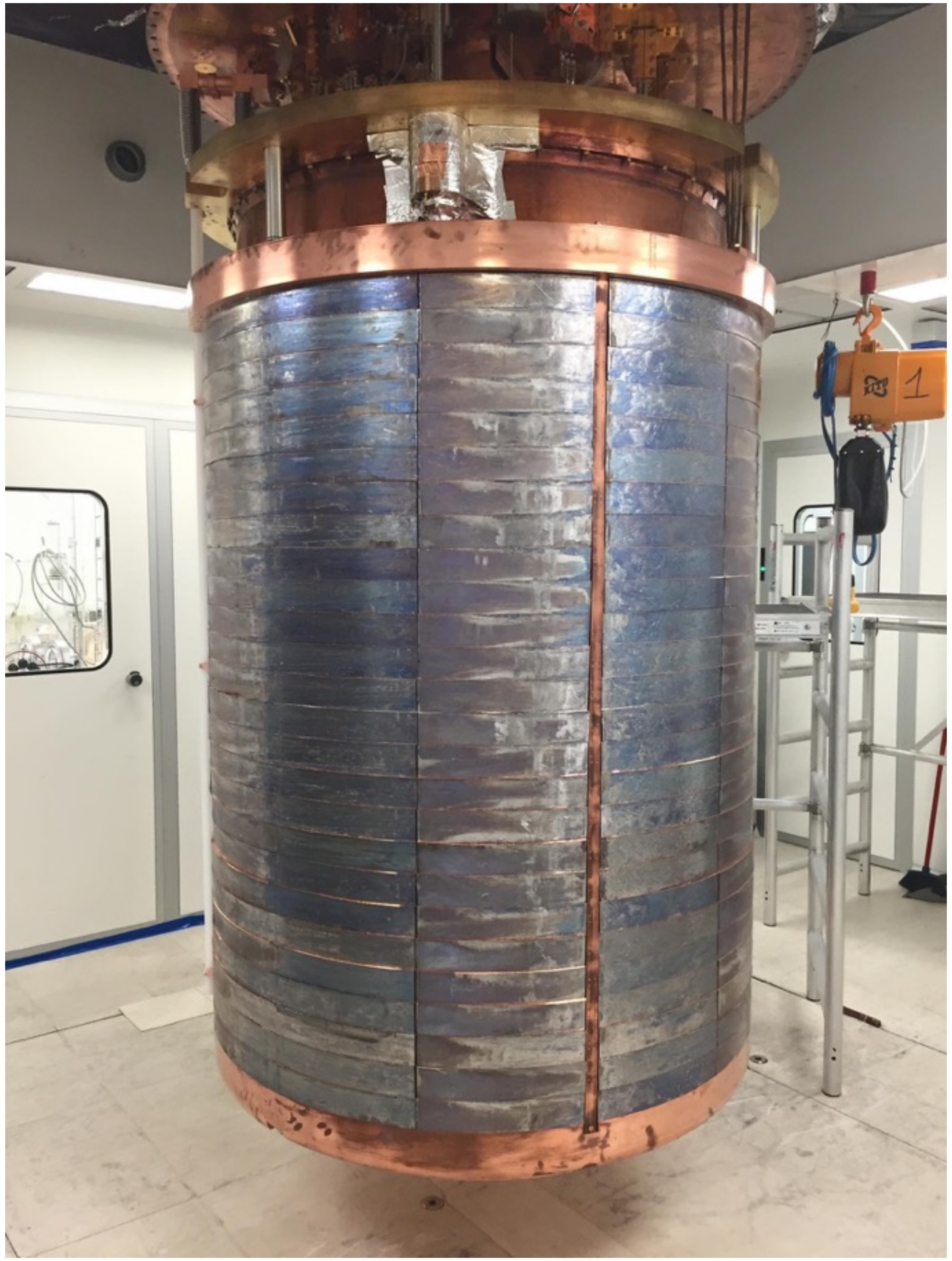
Roman Pb

We have to preserve the inscription

needs to strictly follow the agreement

horizontal cut of the top part

230 ingots were cut



Detector Installation