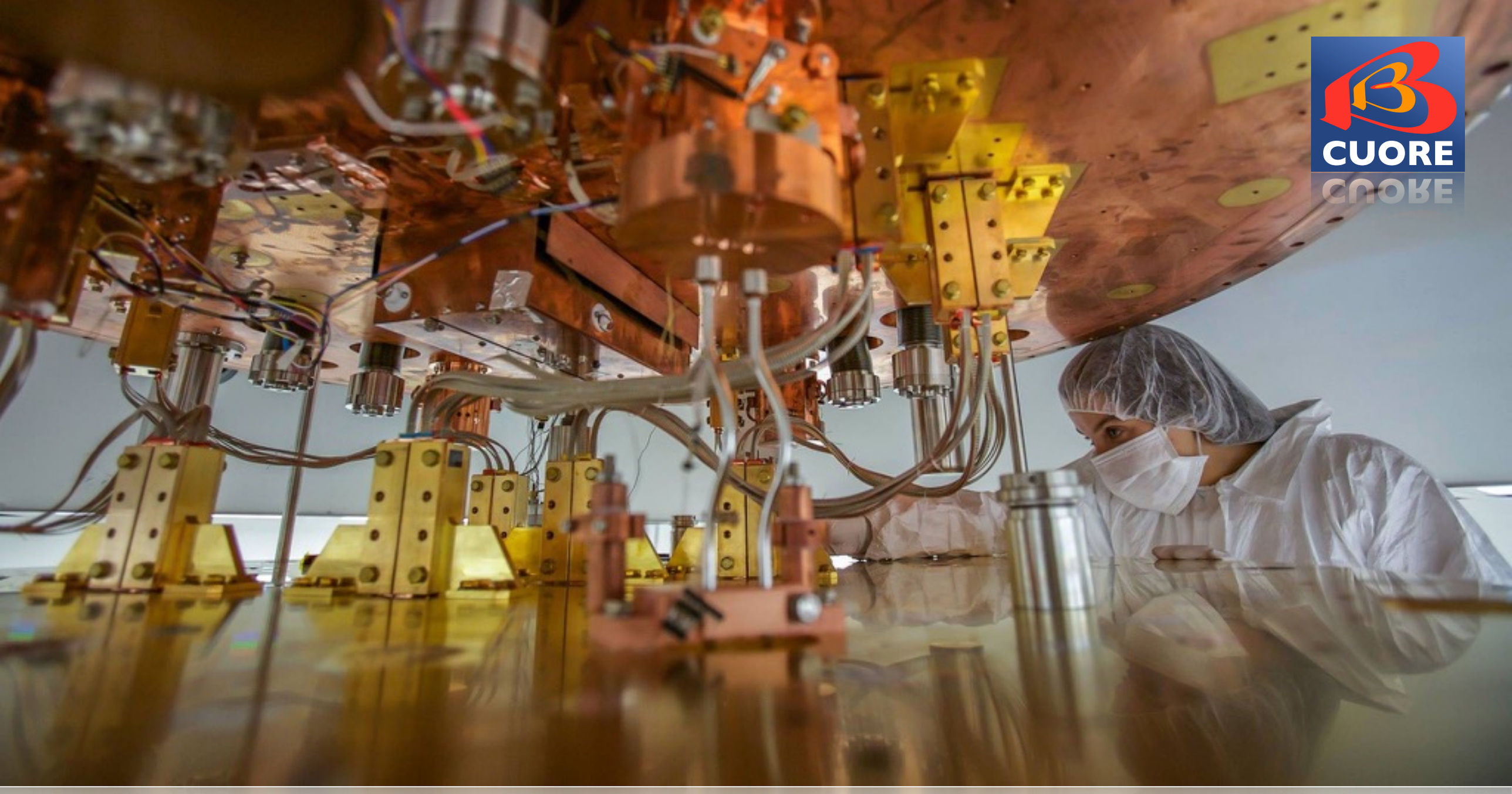
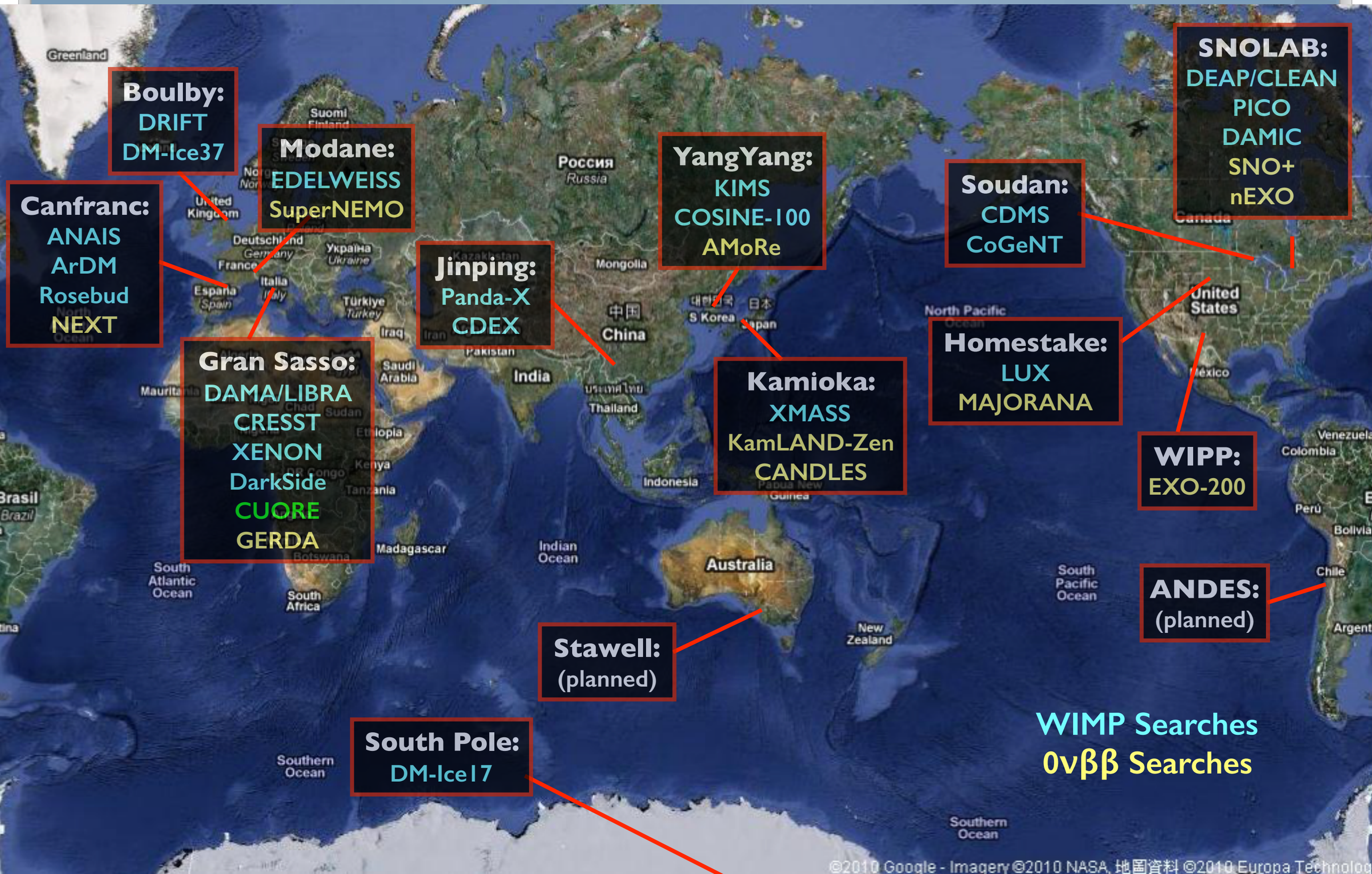


Results of CUORE-0 and Prospects of the CUORE Experiment

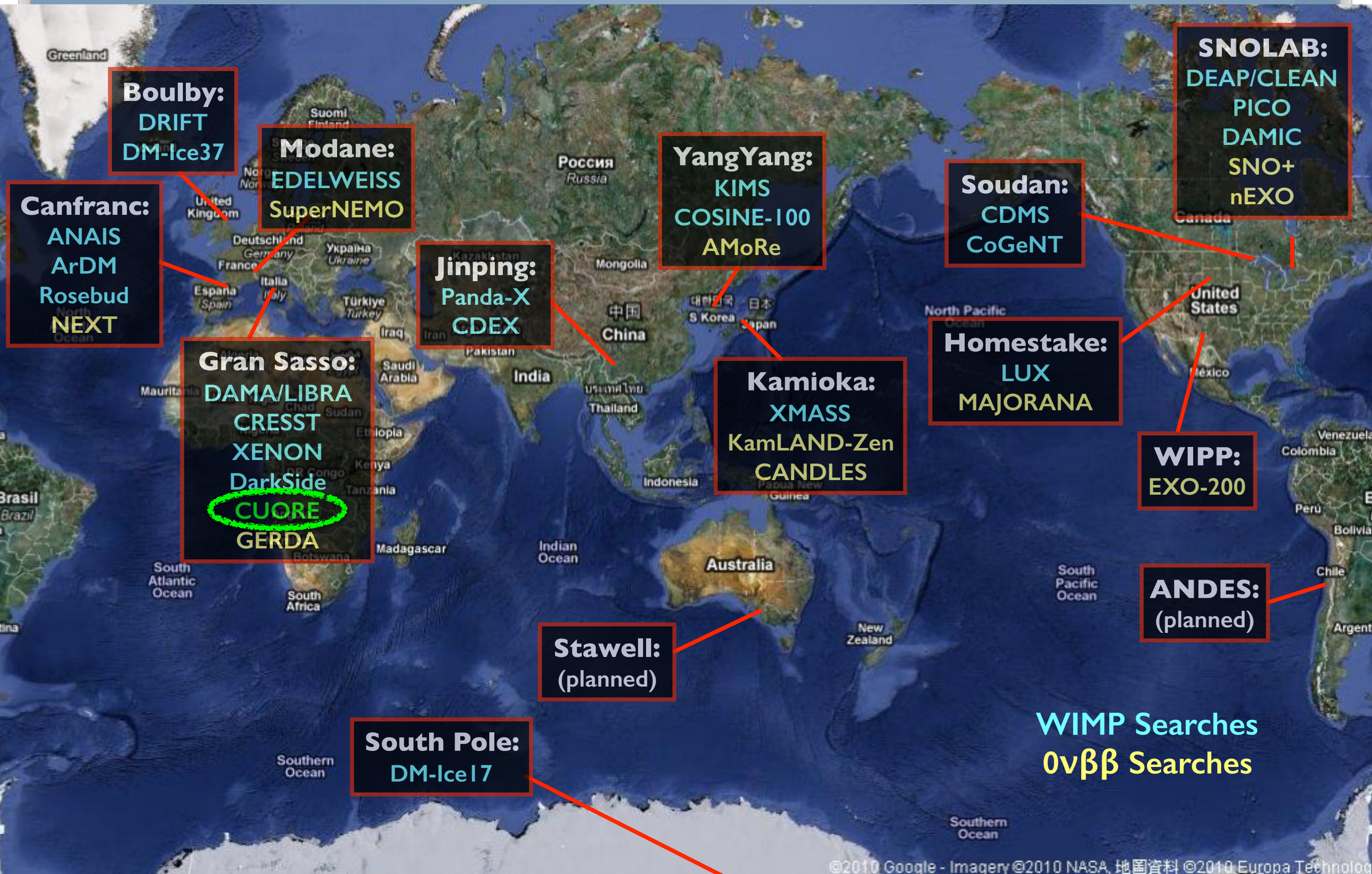
Kyungeun E. Lim on behalf of the CUORE collaboration

Aug. 5, 2016, 38th International Conference on High Energy Physics, Chicago, IL

Going Deep to Search for 0νββ and WIMPs



Placing CUORE in the Map



The CUORE Experiment

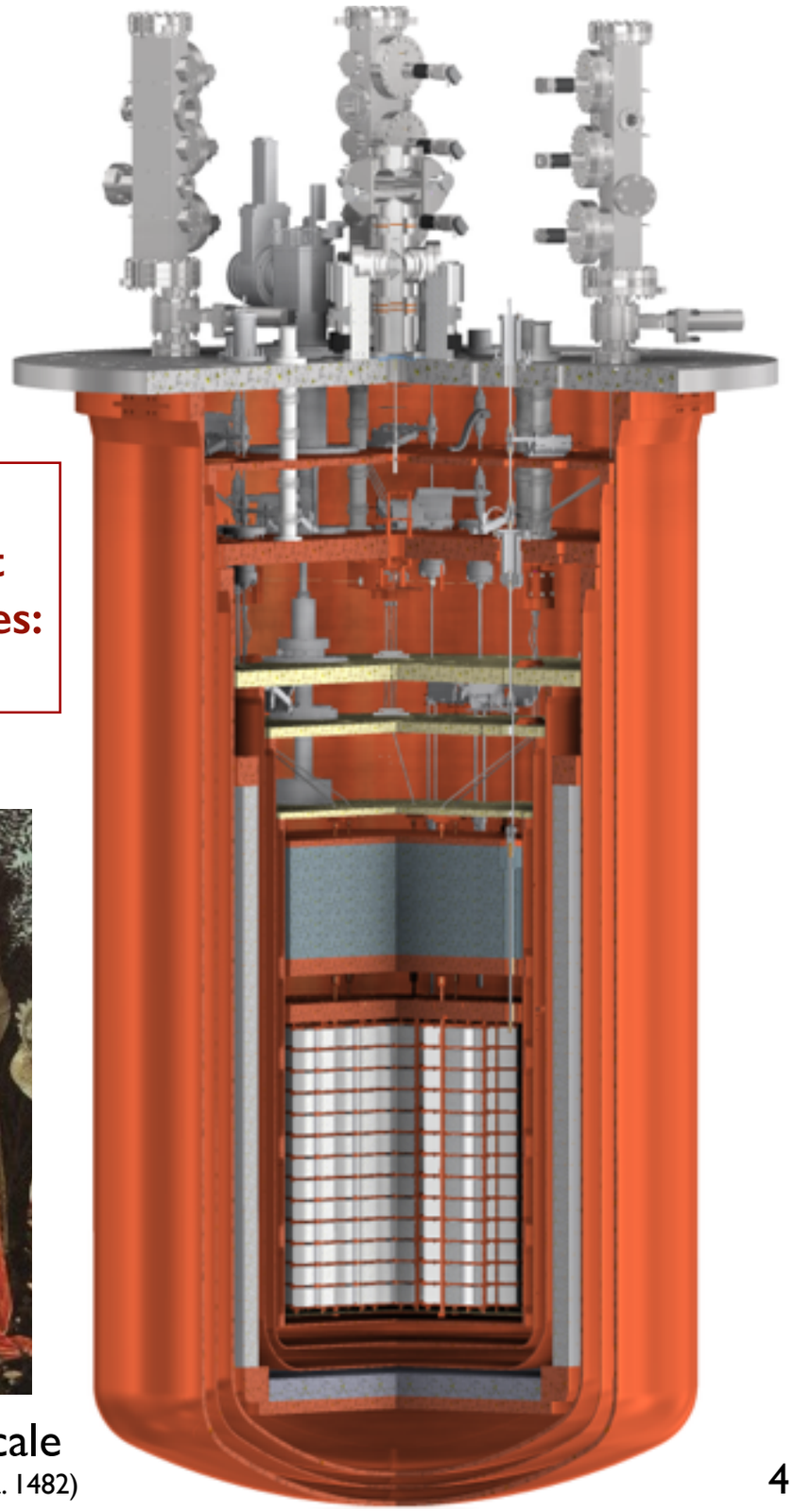
- CUORE is a cryogenic detector consisting of 988 $^{nat}TeO_2$ bolometers arranged in 19 towers, operated at ~ 10 mK
- Primarily search for $0\nu\beta\beta$ decay
- Overburden 3600 m.w.e. (LNGS)
- With 5 keV FWHM at $Q_{\beta\beta}$, 0.01 counts/(kg · keV · yr) at ROI, and 5 years of data accumulation,

$$T_{1/2}^{0\nu\beta\beta}(^{130}\mathrm{Te}) > 9.5 \times 10^{25}\ \mathrm{y\ (90\%\ C.L.)}$$

$m_{\beta\beta} < 50–130$ meV

- Also suitable for other rare event searches such as dark matter

Detector: ~ 1t
Pb shields: ~ 10t
Cu shields/flanges: ~ 8t



Person for scale
(Primavera, Botticelli ca. 1482)

The CUORE Experiment

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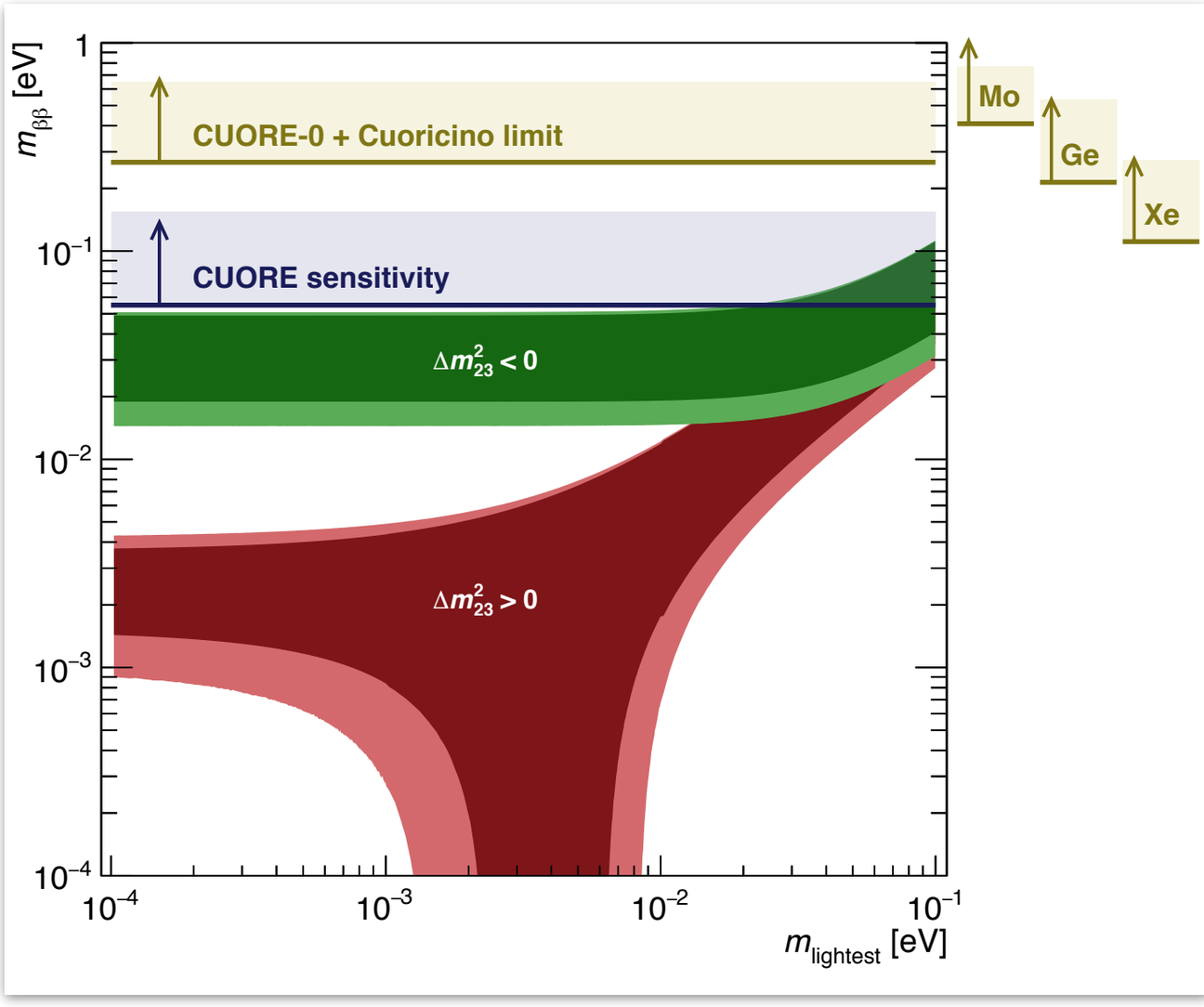
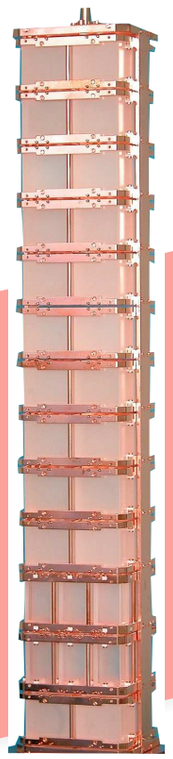


The CUORE Program

CUORE: Cryogenic Underground Observatory for Rare Events

Cuoricino (2003–2008)



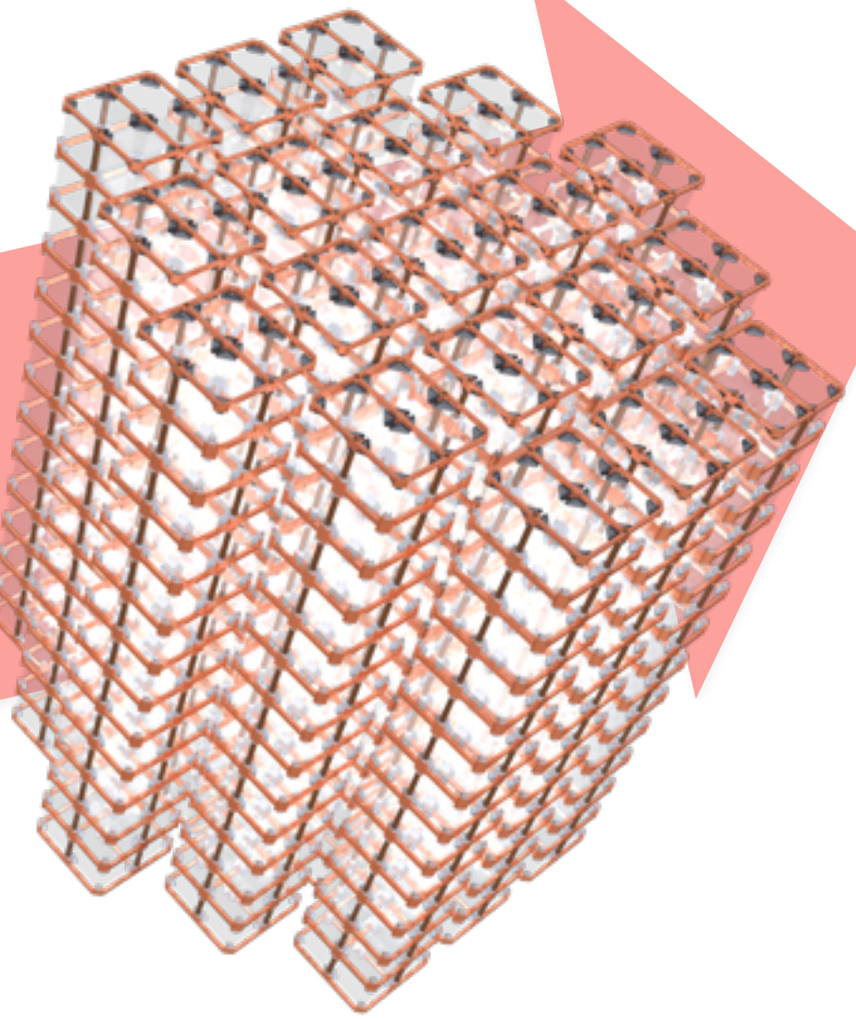
Completed (2008)

$T_{1/2}^{0\nu} > 4.0\times10^{24}$ yr (90% C.L.)

CUORE-0 (2013–2015)

Completed (2015)

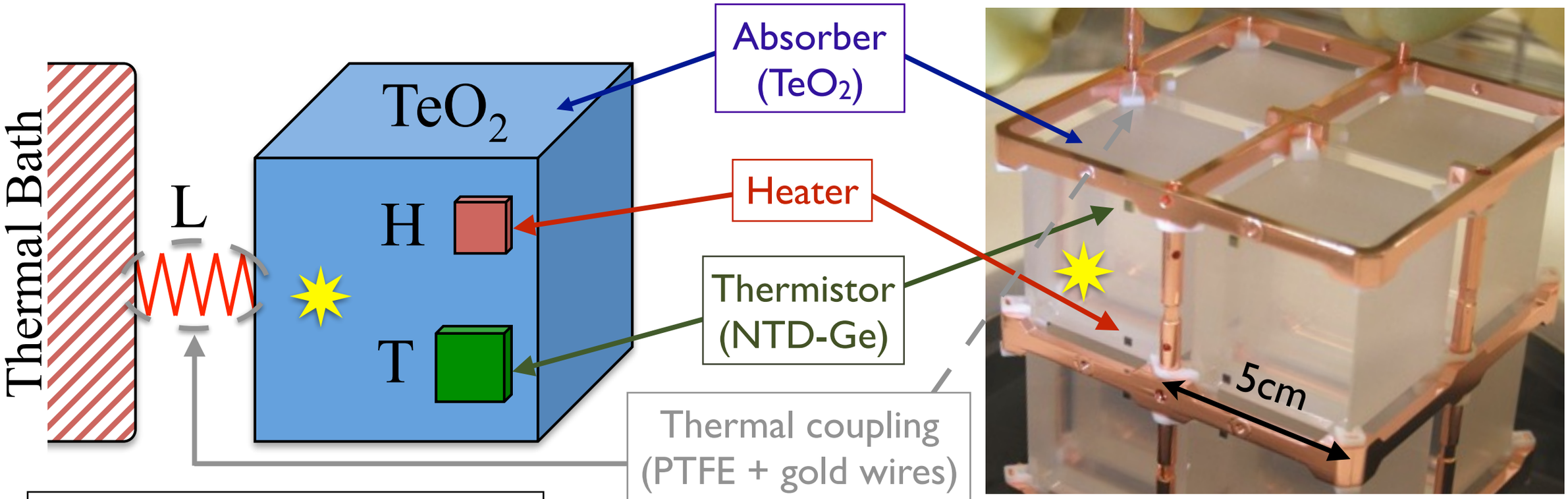
CUORE (2016–2020)



Projected (2020)

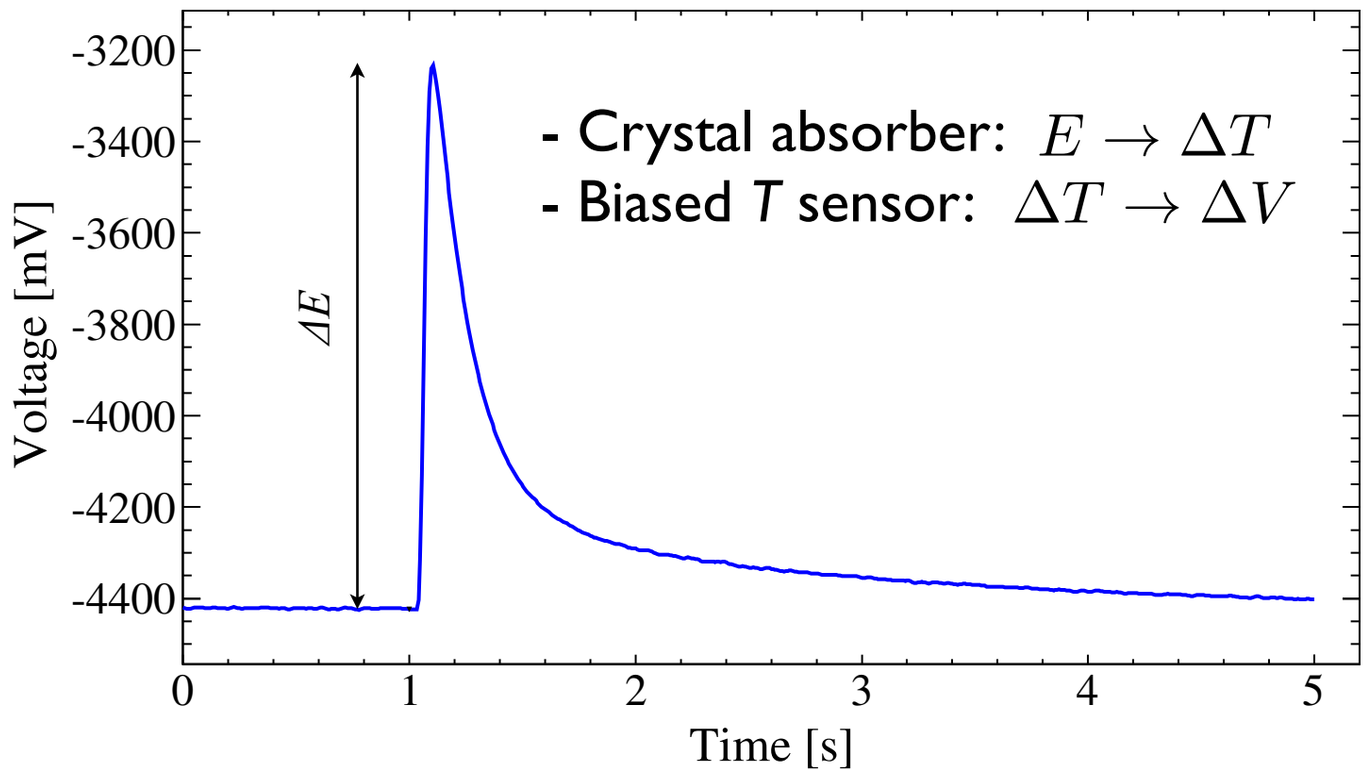
$T_{1/2}^{0\nu} > 9.5\times10^{25}$ yr (90% C.L.)

CUORE Detector: TeO_2 Bolometers

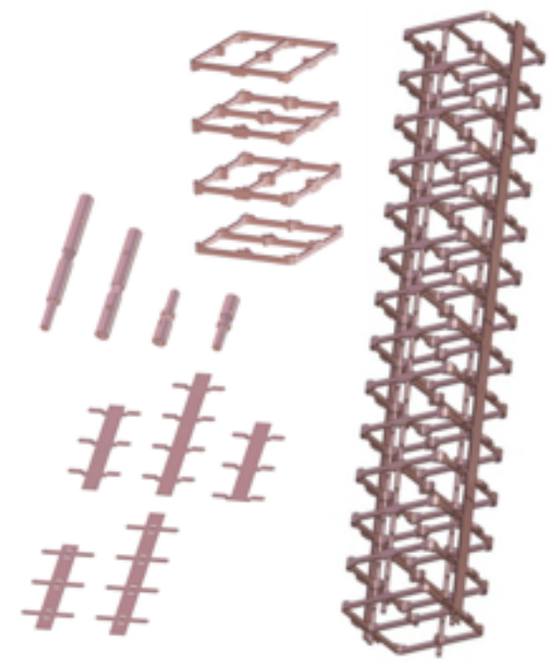


Eur. Phys. J. C 74, 2956 (2014)

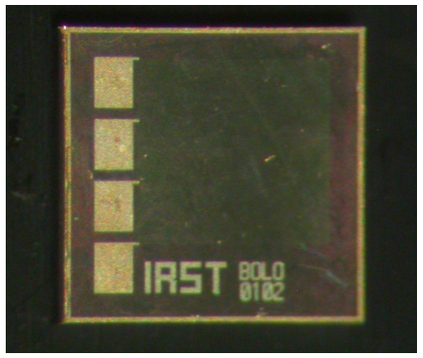
- Measure energy deposition through temperature rise
- Provides excellent energy resolution



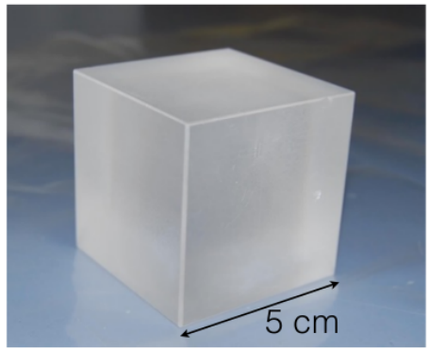
CUORE Module: Tower



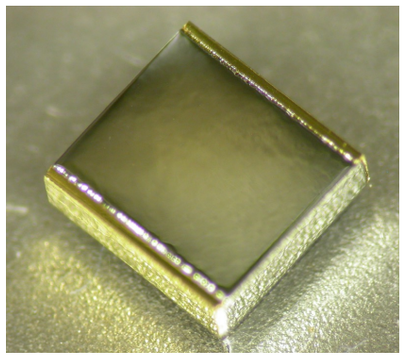
~2000 Cu-ETP1 components



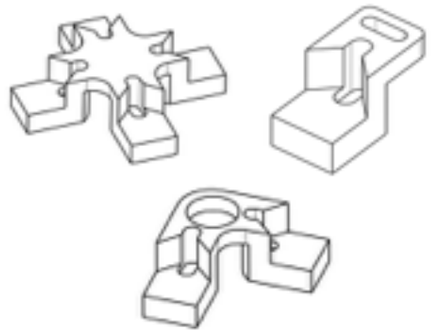
52 Si heaters



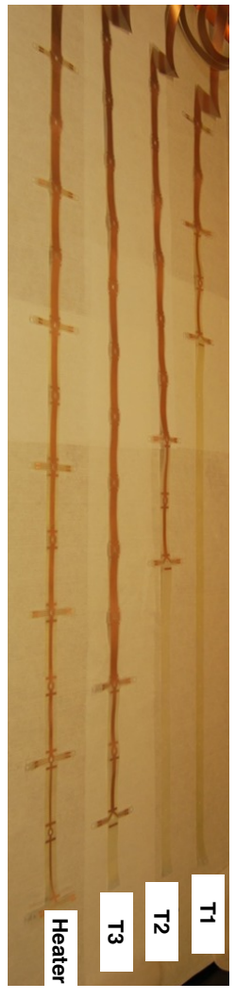
52 TeO_2 crystals



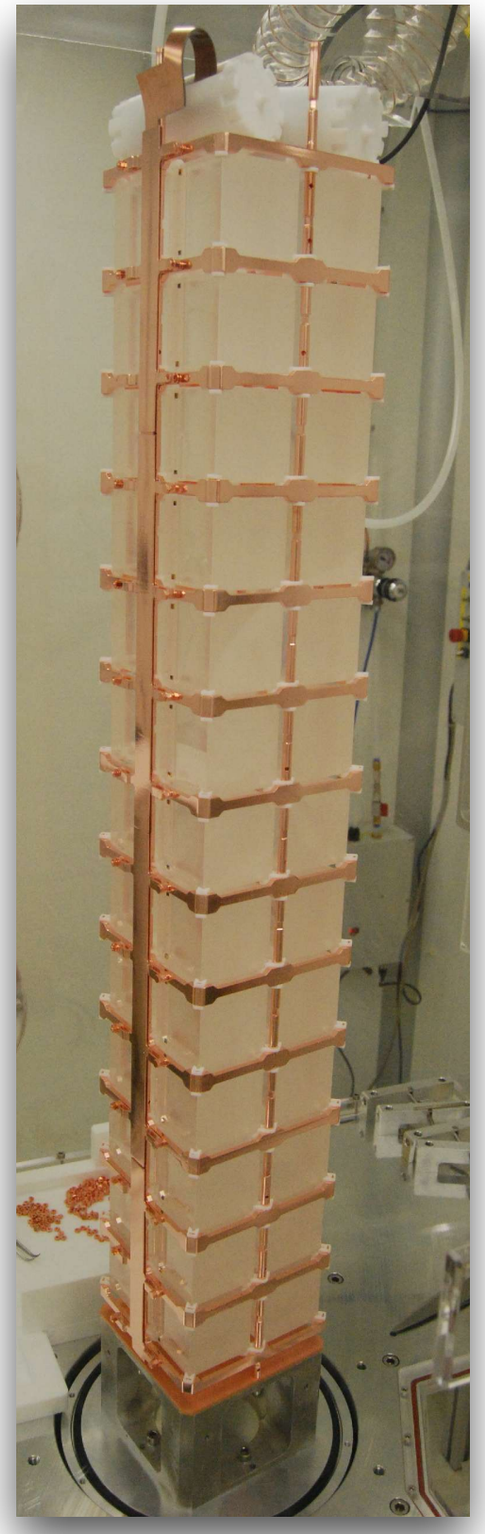
52 thermistors



234 PTFE holders



8 Cu-PEN cables

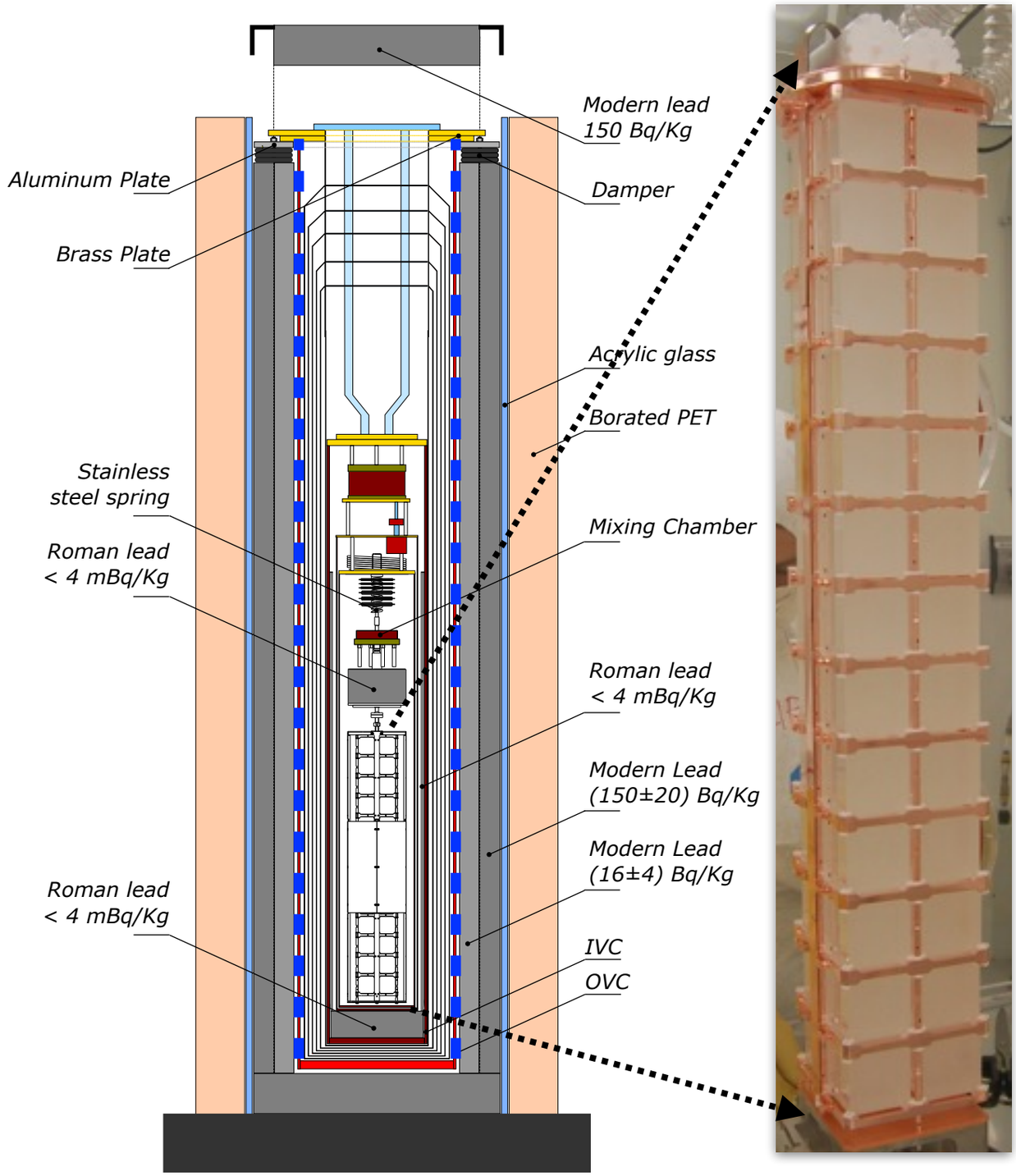


- Reduced materials near the detector with new design
- Strict material selection/surface treatment
- Minimization of Rn exposure (assembled in a N_2-flushed glove box)

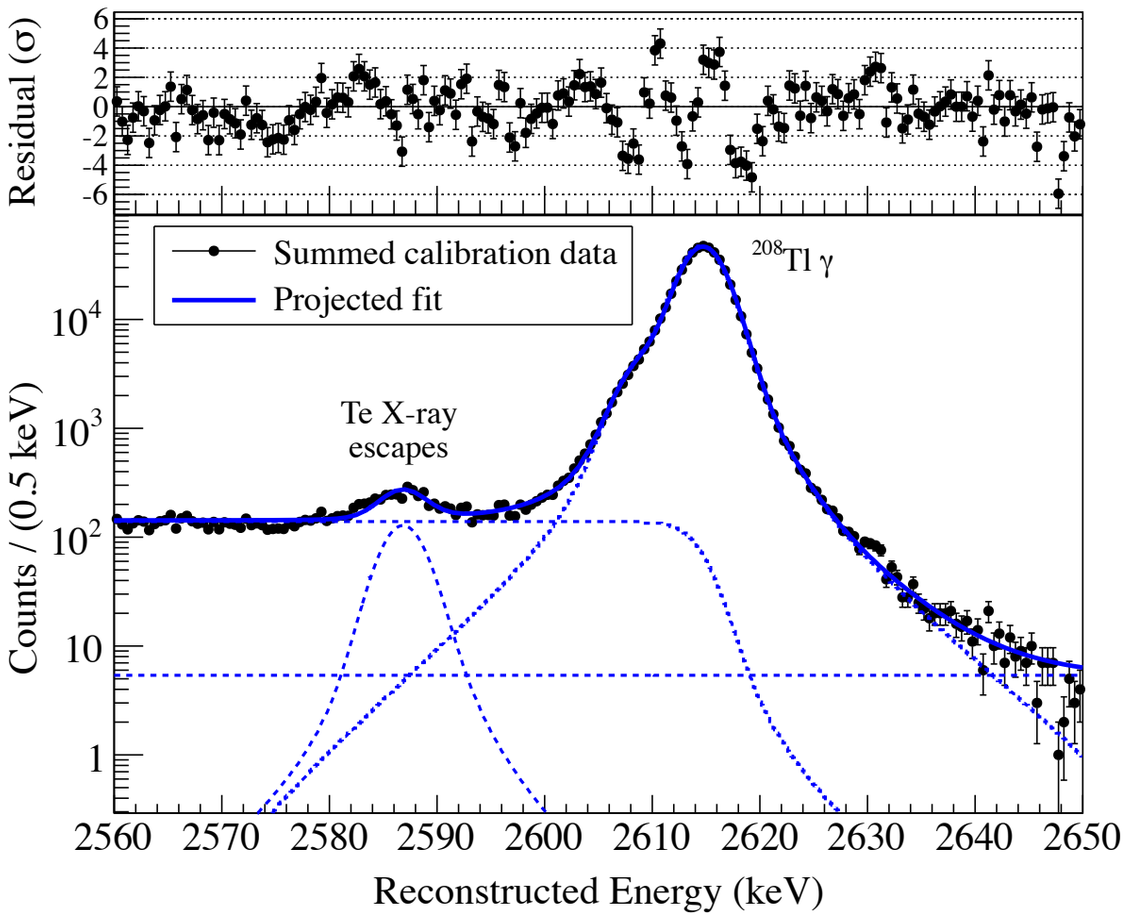
JINST 11 P07009 (2016)

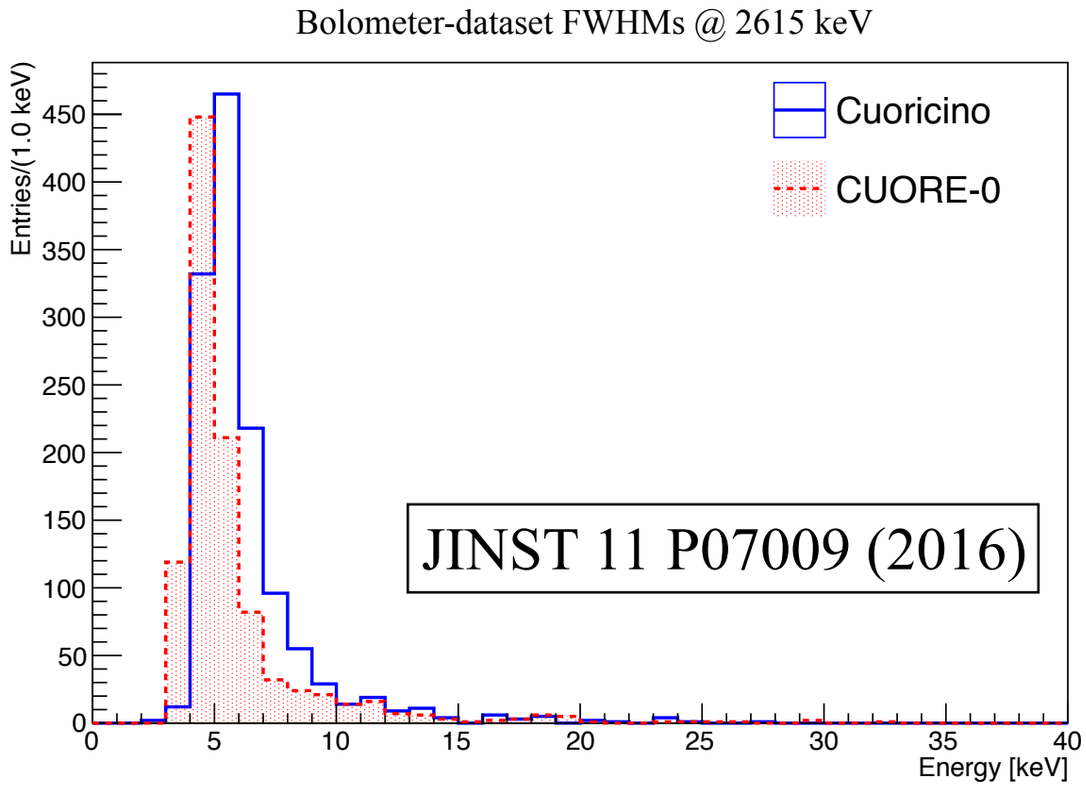
The CUORE-0 Experiment

- First tower produced by CUORE assembly procedure with new cleaning
- 52 (13 x 4) crystals, 39 kg of TeO_2 (*11 kg of* ^{130}Te), 4 kg of copper structure
- Tested DAQ & Analysis framework for CUORE
- Reported the limit on the half-life of $0\nu\beta\beta$ with 9.8 kg · yr of ^{130}Te exposure
- Measured the half-life of $2\nu\beta\beta$ of ^{130}Te with the highest precision (results to be reported soon)
- WIMP dark matter annual modulation analysis is on-going



CUORE-0: Detector Performance



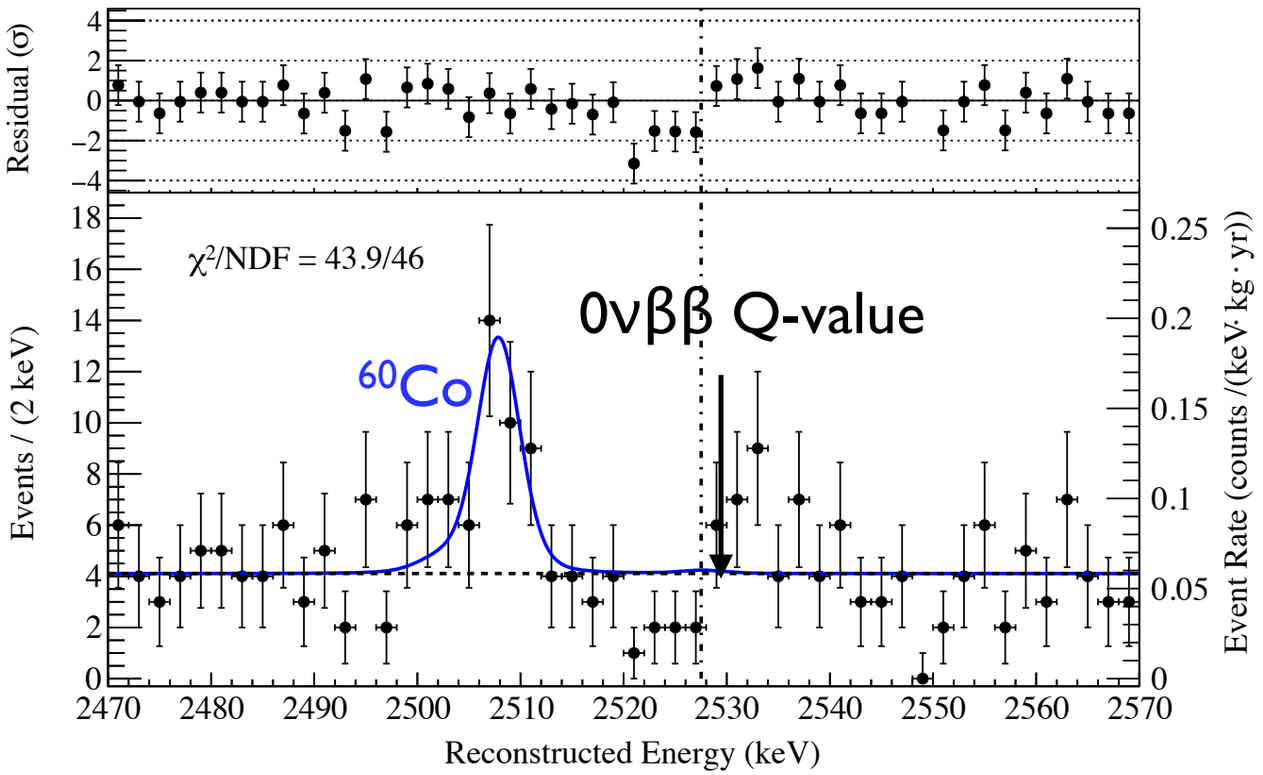


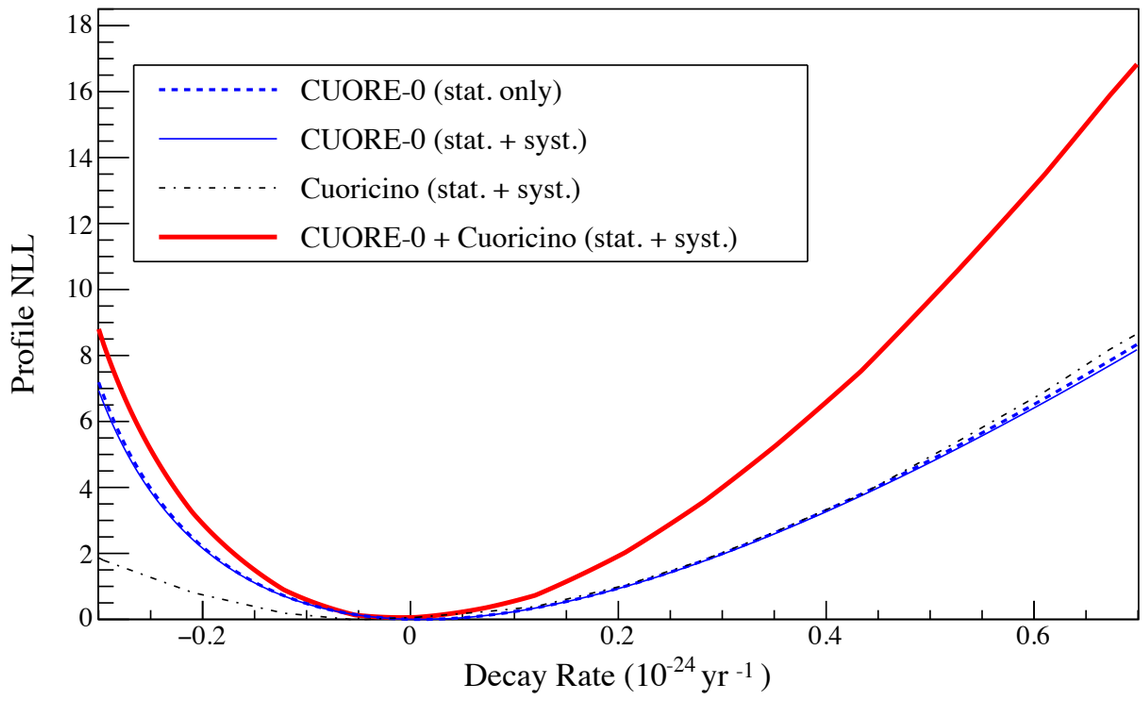
Weight FWHMs by corresponding exposure

	FWHM harmonic mean [keV]	FWHM dist RMS [keV]
Cuoricino	5.8	2.1
CUORE-0	4.9	2.9

- Energy resolution is evaluated for each bolometer and dataset by fitting the 2615 keV peak from ^{208}Tl in the calibration data
- The obtained resolution is < 5 keV, which is the CUORE goal

CUORE-0: 0νββ Results





Background rate at ROI:

0.058 ± 0.004 (stat.) $\pm$ 0.002 (sys.) cts/(keV·kg·yr)

CUORE-0 results on half-life:

$\Gamma^{0\nu\beta\beta}(^{130}\mathrm{Te}) < 0.25 \times 10^{-24}\ \mathrm{yr}^{-1}$ (90% C.L.)

$T_{1/2}^{0\nu\beta\beta}(^{130}\mathrm{Te}) > 2.7 \times 10^{24}$ yr (90% C.L.)

Combining the CUORE-0 result with the Cuoricino result from 19.75 kg · yr of ^{130}Te exposure yields the Bayesian lower limit:

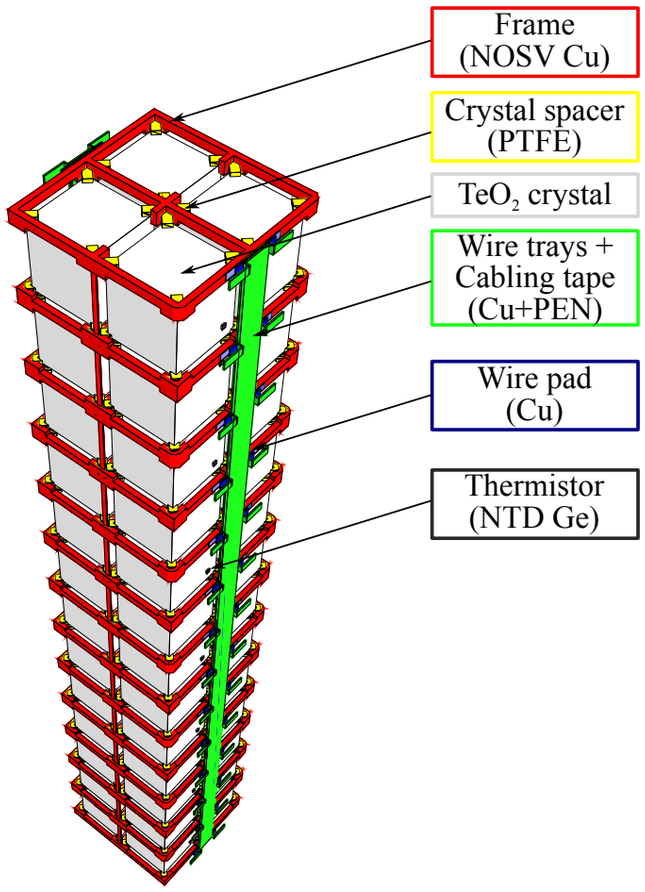
$T_{1/2}^{0\nu\beta\beta}(^{130}\mathrm{Te}) > 4.0 \times 10^{24}$ yr
(90% C.L., stat.+sys.)

Phys. Rev. Lett. 115, 102502 (2015)

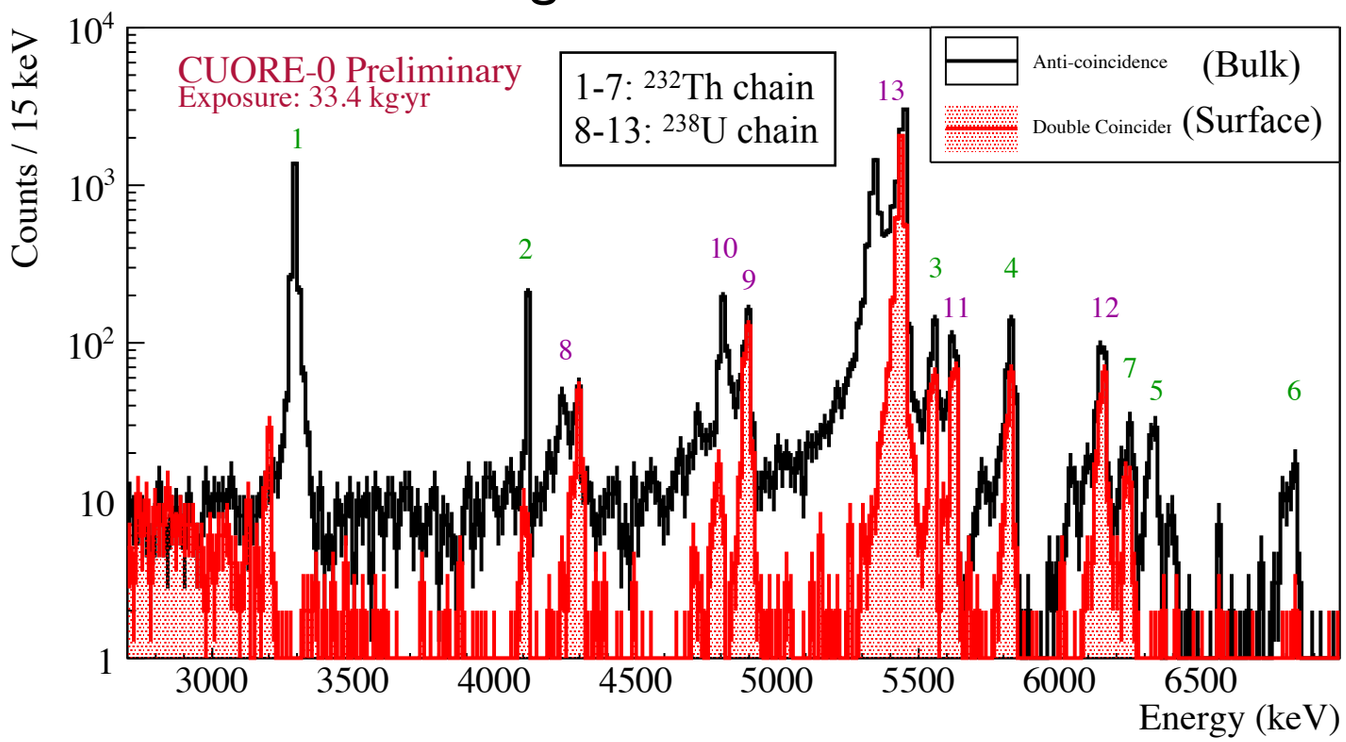
Phys. Rev. C 93, 045503 (2016)

CUORE-0: Background Model

- Identify background sources using
  - Radio-assay measurements
  - Cosmogenic activation analysis
  - CUORE-0 data analysis
- Use this info as prior for Bayesian fit

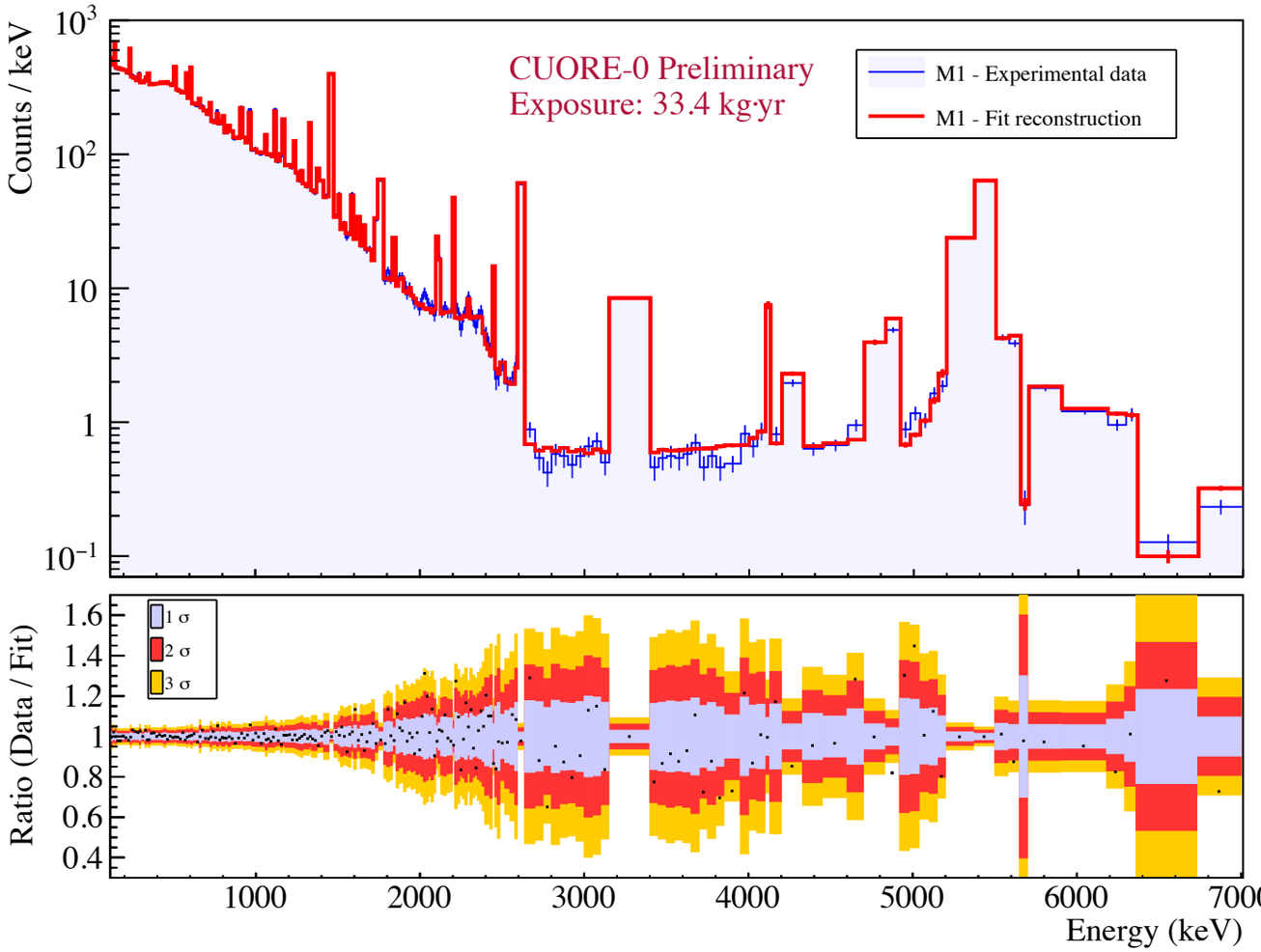


α Background of CUORE-0

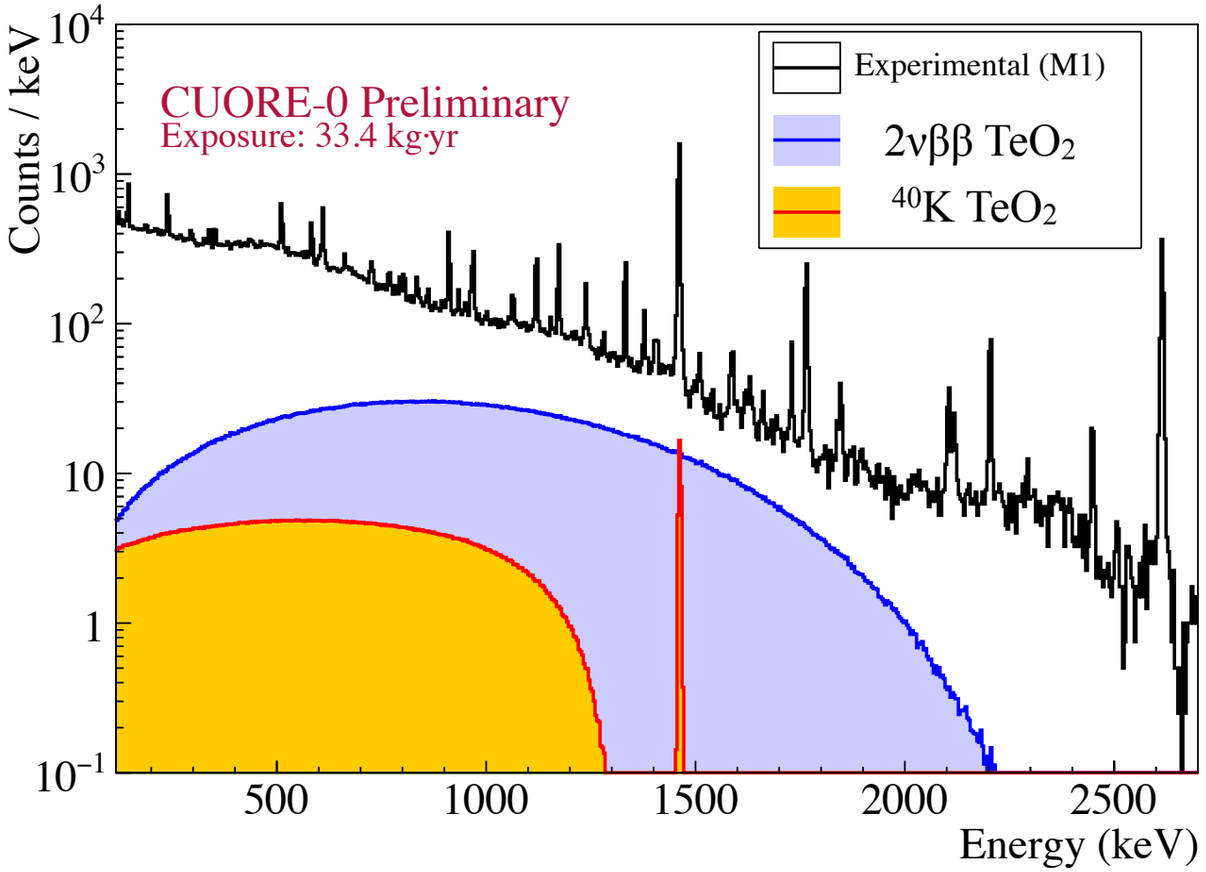


- GEANT4-based Monte Carlo simulation with the detailed detector geometry and response (resolution, coincidence window, thresholds, etc)
- Monte Carlo simulation was verified by comparing it with calibration data
- Background spectrum was reconstructed as a linear combination of 57 sources

CUORE-0: 2νββ Results



Paper to be submitted soon



$$\text{CUORE-0: } T^{2\nu}_{1/2} = [8.2 \pm 0.2\ (\text{stat.}) \pm 0.6\ (\text{syst.})] \times 10^{20}\ \text{y}$$

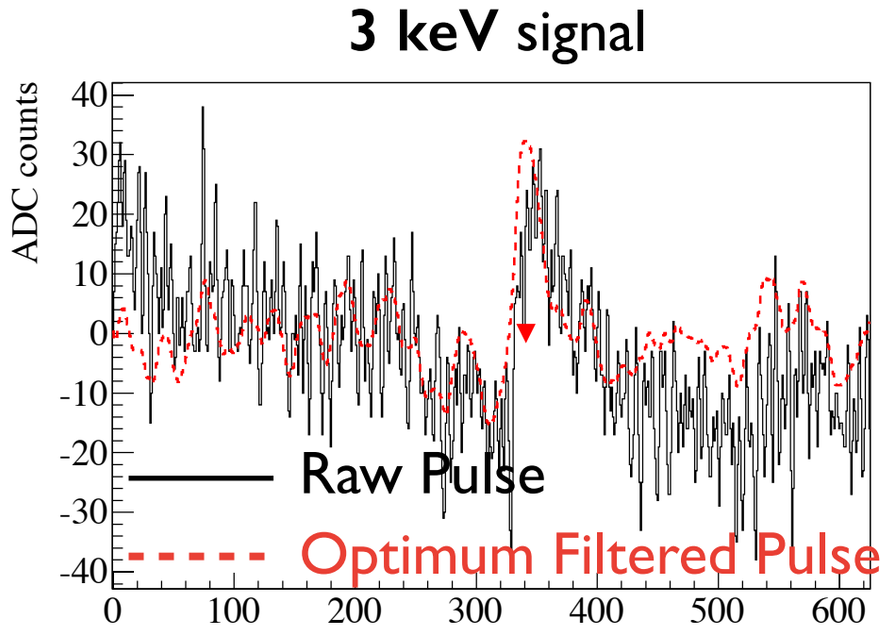
$$\text{NEMO: } T^{2\nu}_{1/2} = [7.0 \pm 0.9\ (\text{stat.}) \pm 1.1\ (\text{syst.})] \times 10^{20}\ \text{y}$$

$$\text{MiDBD: } T^{2\nu}_{1/2} = [6.1 \pm 1.4\ (\text{stat.})\ ^{+2.9}_{-3.5}\ (\text{syst.})] \times 10^{20}\ \text{y}$$

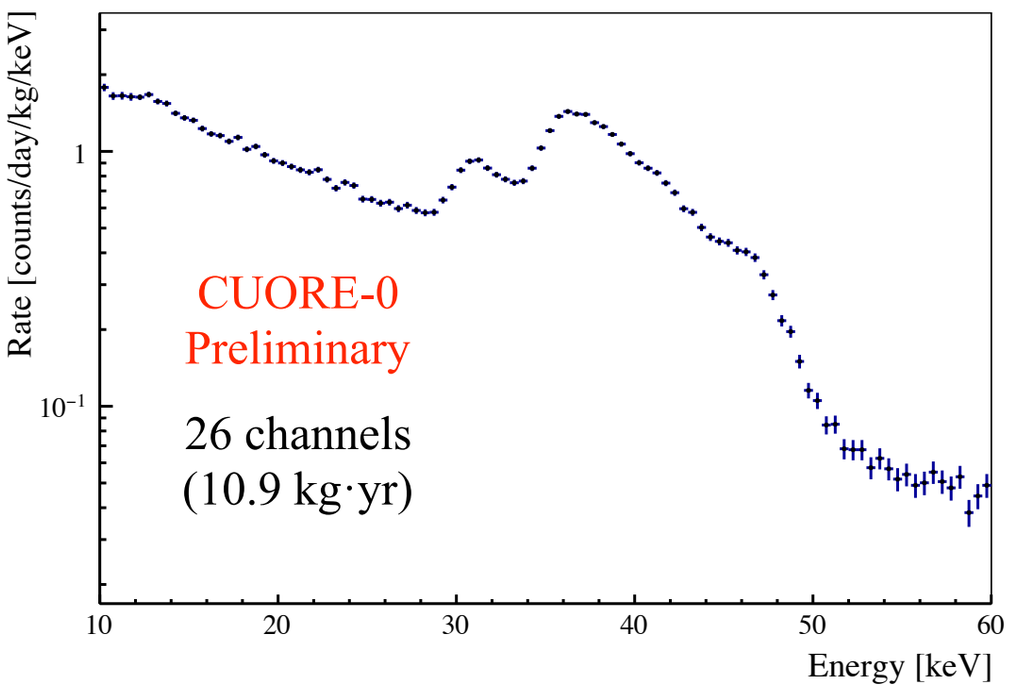
NEMO-3 Collaboration, Phys. Rev. Lett., 107, 062504 (2011)
C. Arnaboldi et al., Phys. Lett. B, 557, 167 (2003)

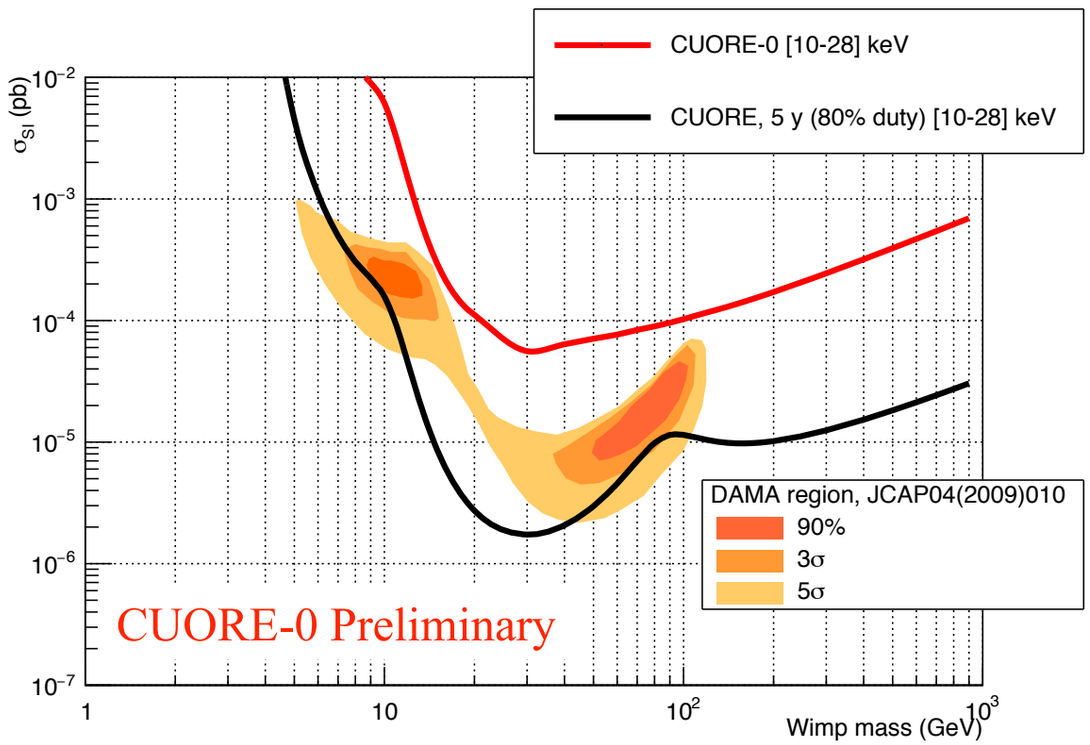
CUORE-0: WIMP Dark Matter Analysis

- Continuous data acquisition provides access to the low energy events
- Optimum filter can identify low energy events
- Nuclear quenching factor (~1) benefits detection of nuclear recoil events
- WIMP annual modulation analysis on-going



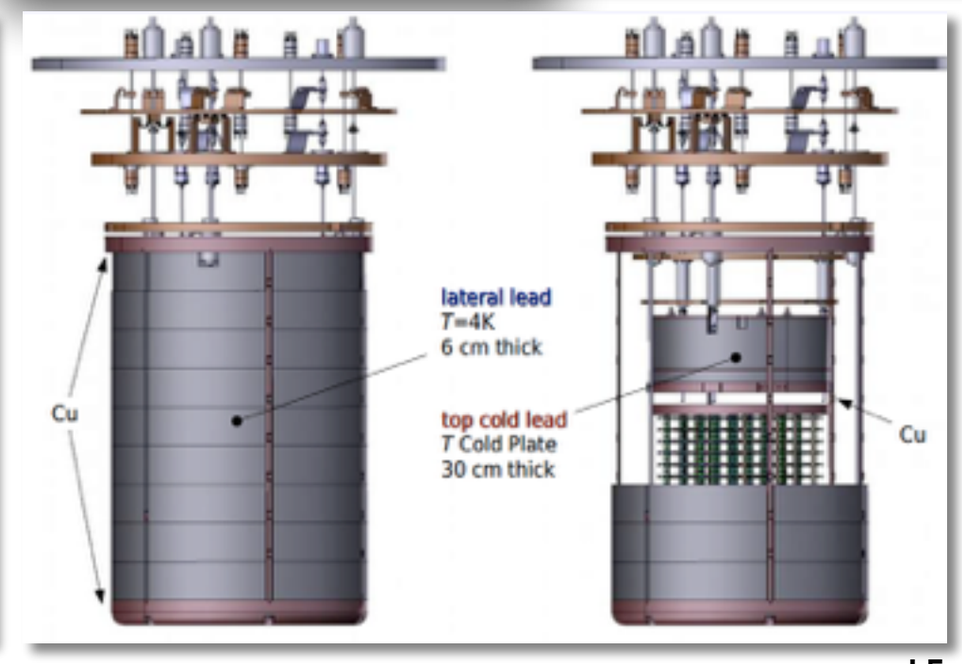
JINST 6 (2011) P02007



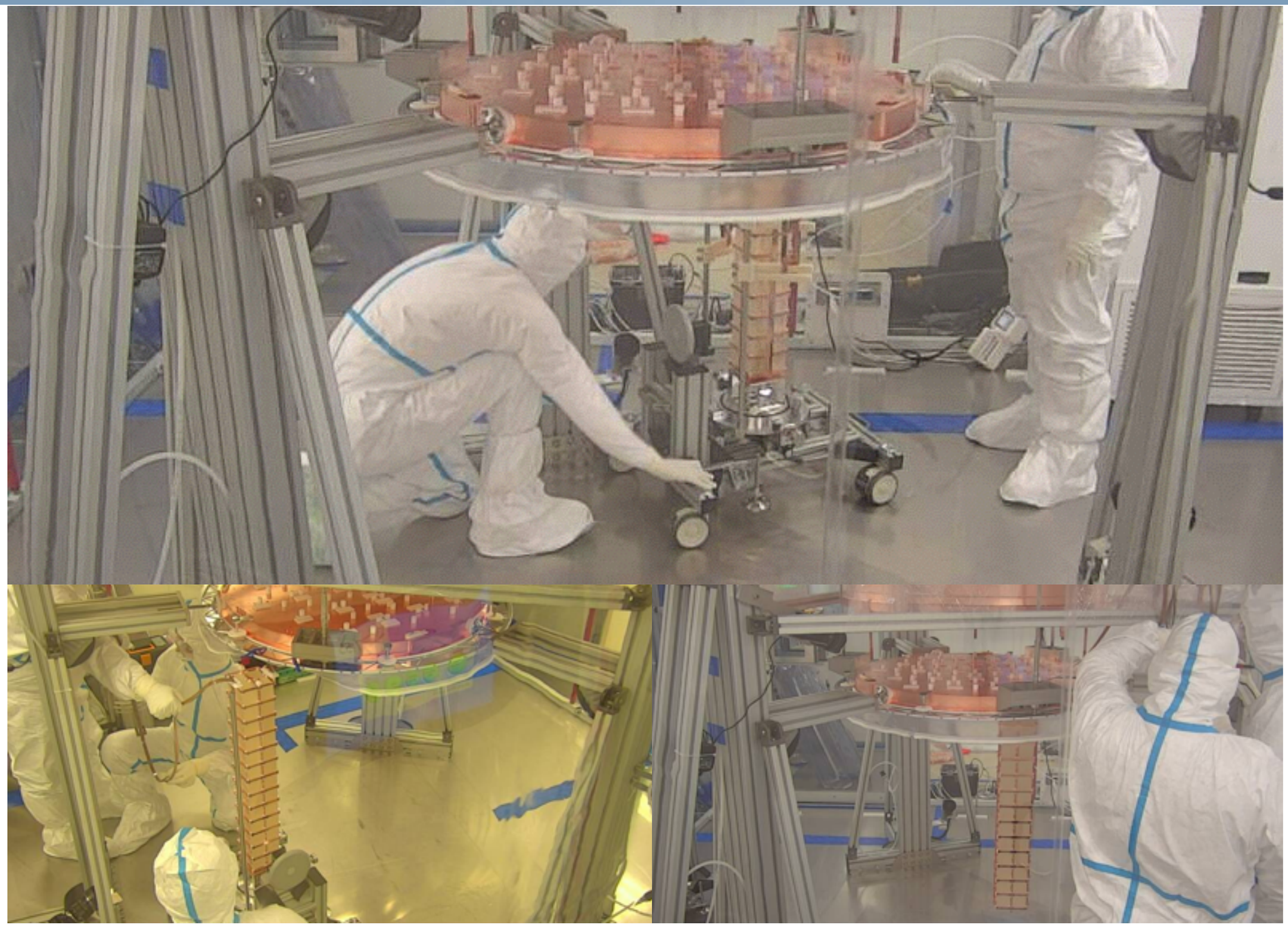


Status of CUORE

- Detectors assembled and stored underground
- Cryostat commissioning completed successfully
  - Stable base temperature at 6.3 mK over 70 days
  - Cooling power 3μW at 10 mK
- ^{232}Th calibration source has been deployed and the system has been tested at 10 mK
- Electronics inside Faraday cage checked

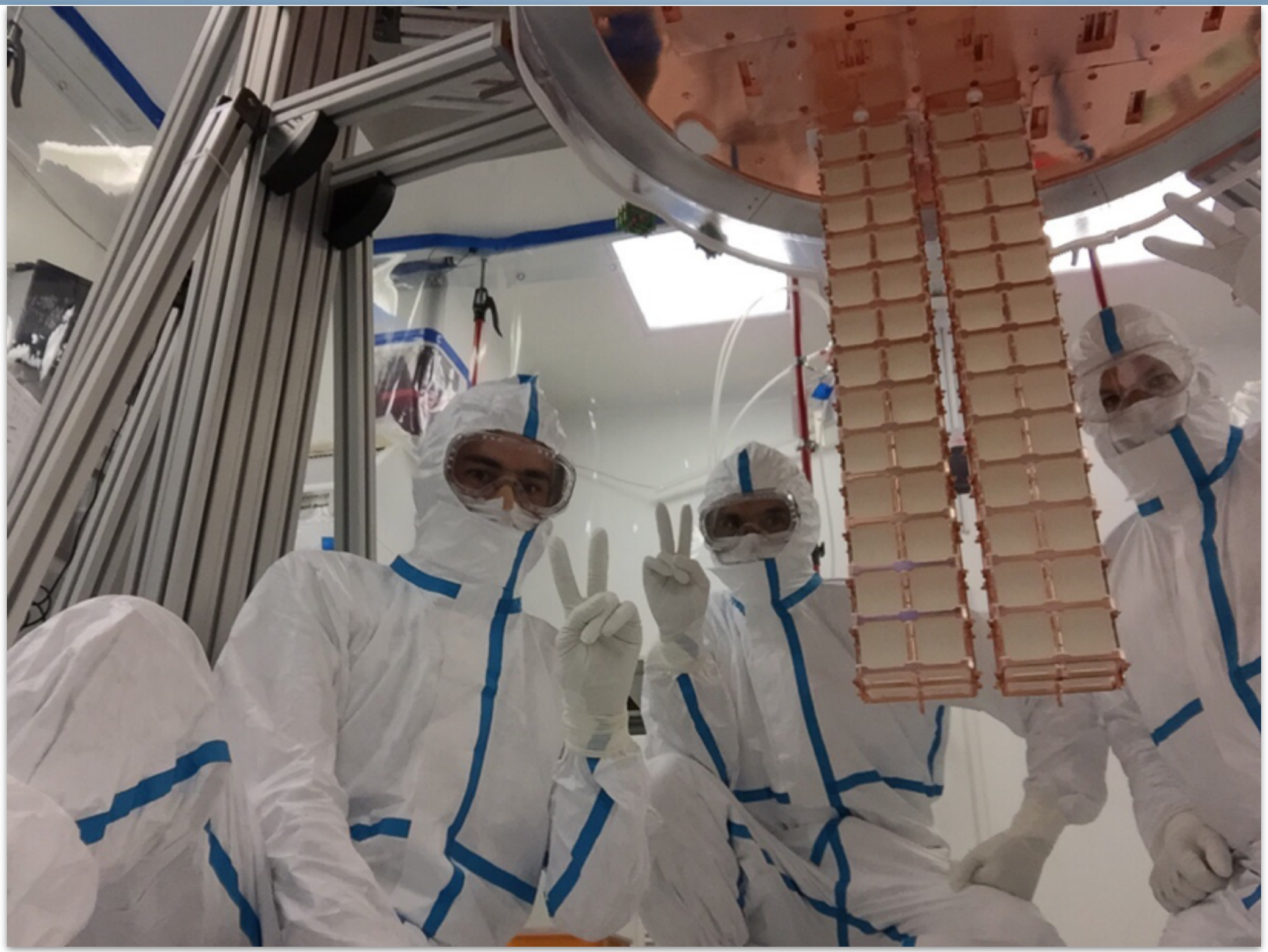


First CUORE Tower Installation

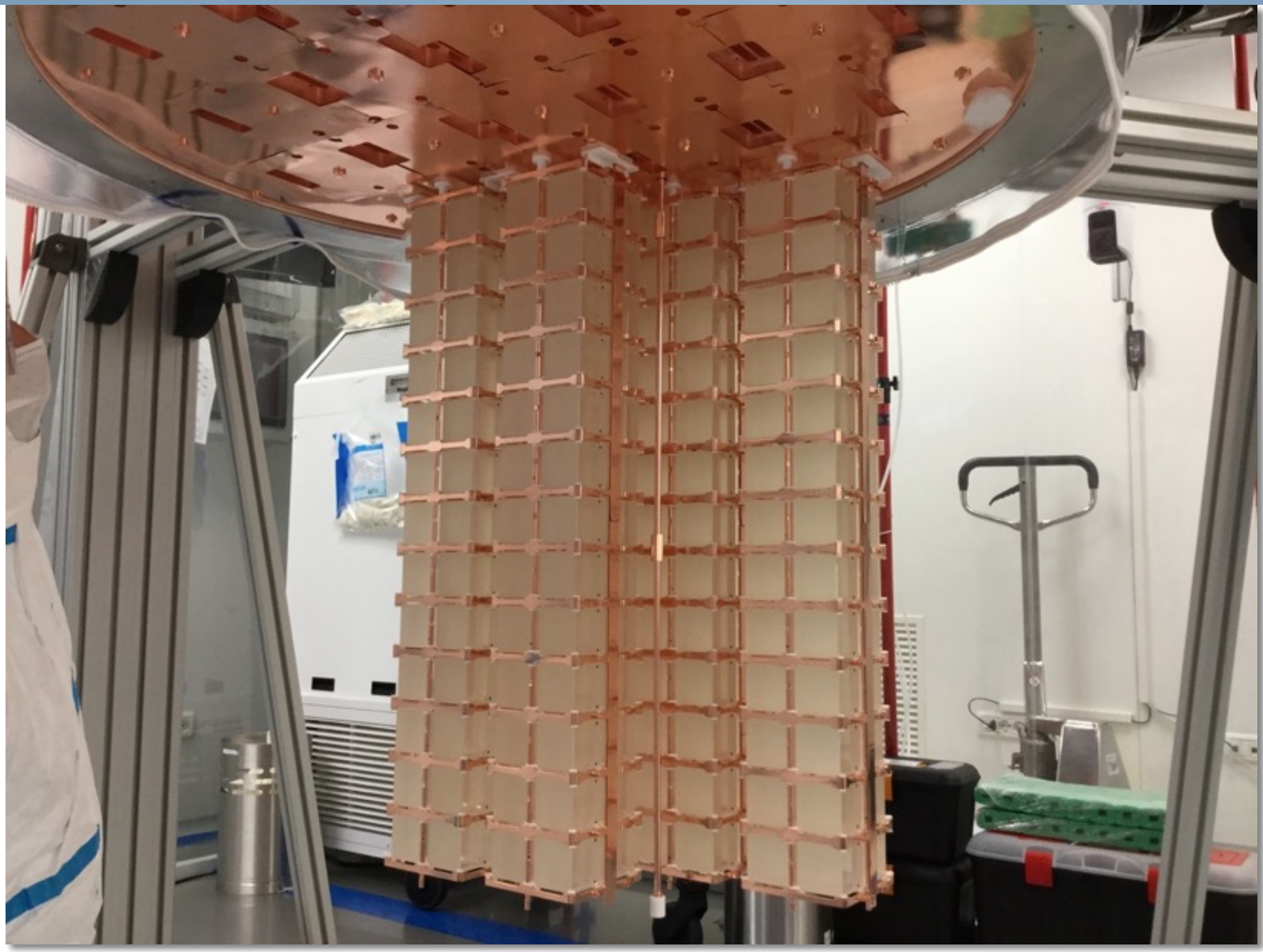


First CUORE Tower Installation

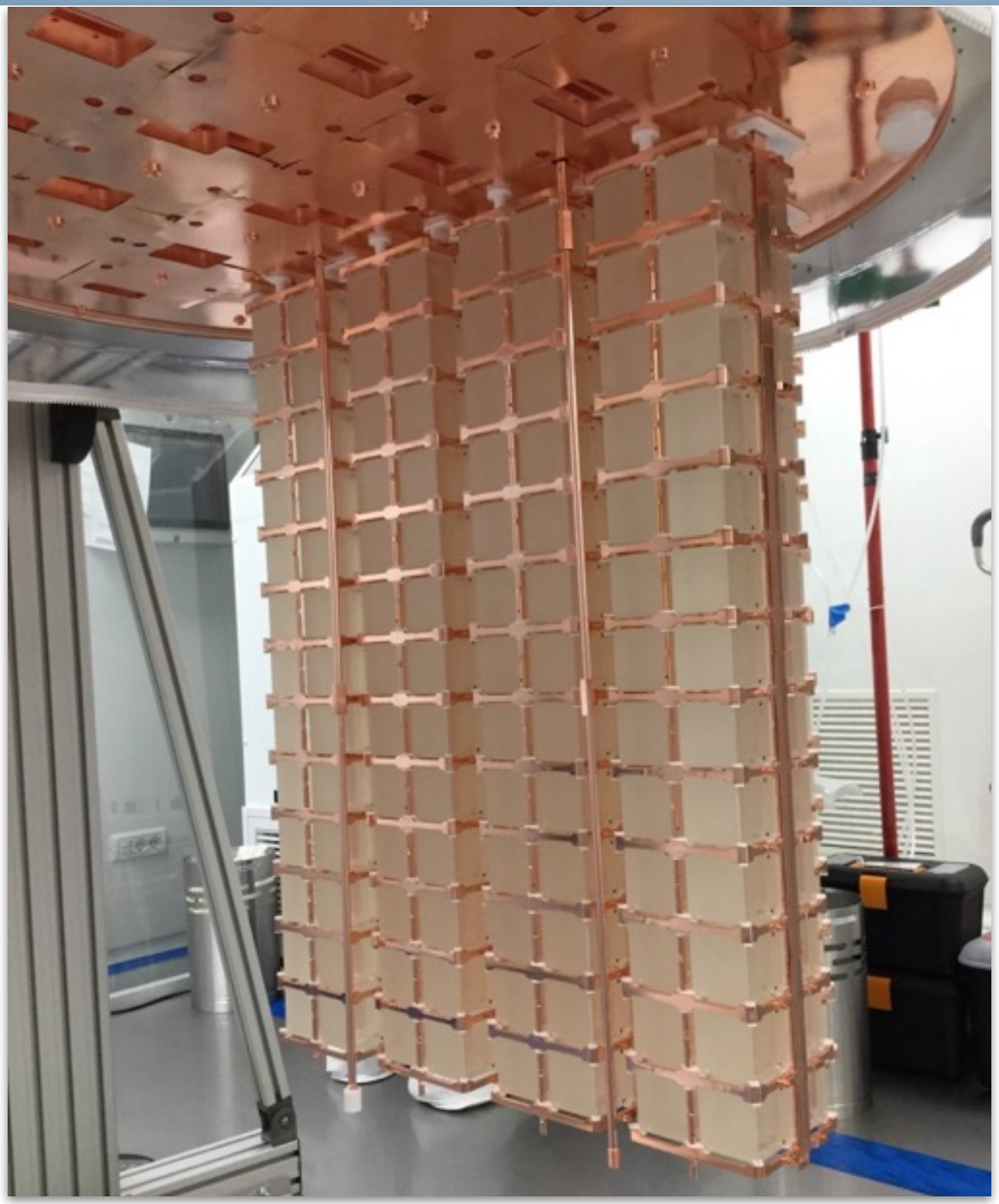
And the Second..



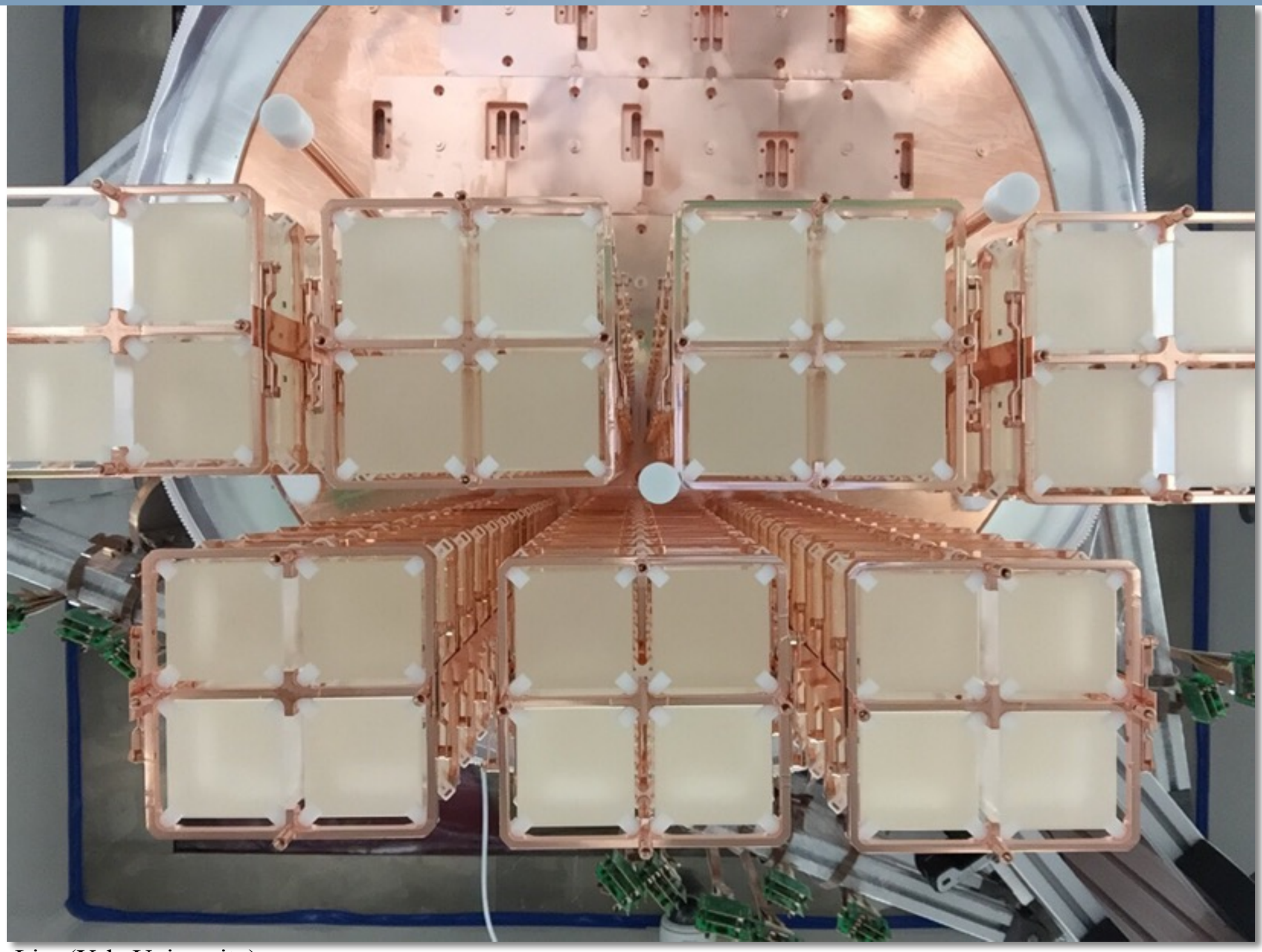
And More!!!!!



And Even More!!!!!



And Even More!!!!!



Beyond CUORE: CUPID

CUPID: CUORE Upgrade with *Particle IDentification*

Detector Building Strategies
- Large total mass
- Ultra-low background
- Good energy resolution

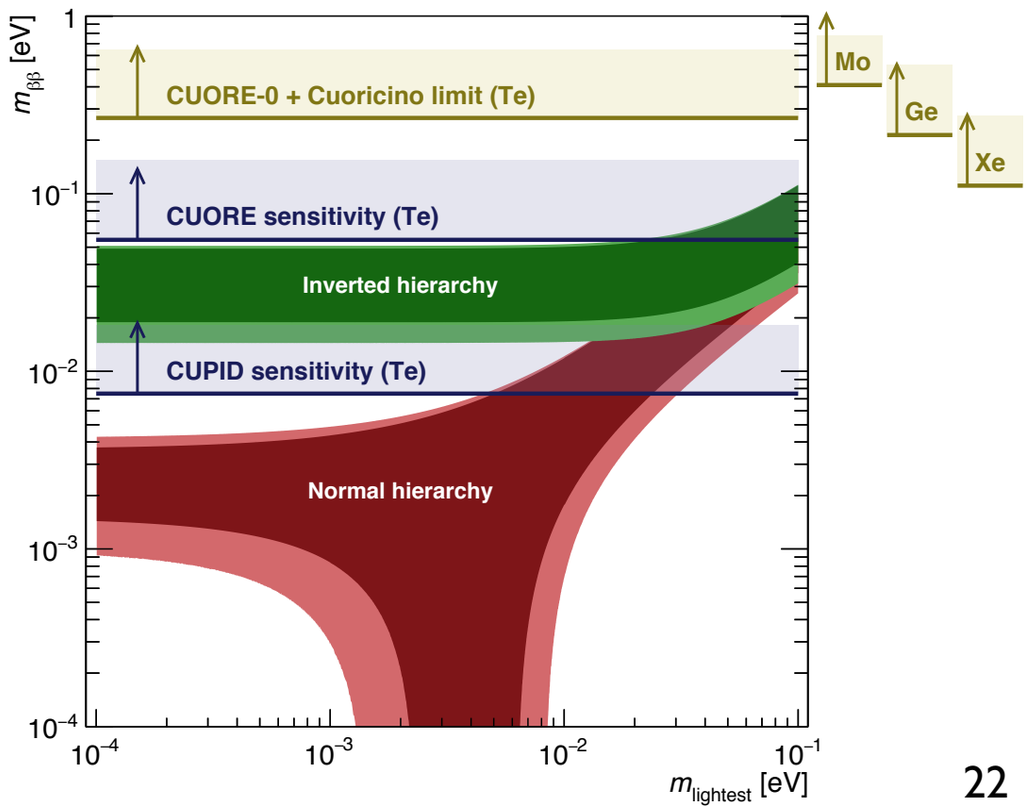
PID →

- The same CUORE cryostat
- Different isotopes/sensors
- Further background reduction

- Goal: Explore entire Inverted hierarchy
  - $T_{1/2}^{0\nu\beta\beta}$ sensitivity: (2–5)×10^{27} yr in 10 yr
  - $m_{\beta\beta}$ sensitivity: 6–20 meV

arxiv:1504.03599

- Various R&D efforts (scintillating bolometers, enrichment of Te, and active veto) are actively on-going



Summary

- TeO_2 bolometers offer well-established and competitive techniques to search for $0\nu\beta\beta$ and other rare event searches
- CUORE-0, the first tower assembled using the new technique developed for CUORE, demonstrated that CUORE goal is within reach
- CUORE-0 also reported the most stringent limit on the half-life of $0\nu\beta\beta$ from Te, with the combined results from the predecessor experiment, Cuoricino
- More physics analyses on CUORE-0 data are well underway including $2\nu\beta\beta$ and WIMP dark matter annual modulation search
- CUORE detector installation is on-going **now** and data-taking will begin before the end of 2016
- The future effort of CUORE, CUPID, will completely explore Inverted hierarchy with less background

CUORE Collaboration

(Oct. 2, 2015 @ LNGS)

Extra Slides