Search for neutrinoless double beta decay of ^{130}Te with CUORE-0 and CUORE

Claudia Tomei (INFN - Roma)
on behalf of the CUORE collaboration

CUORE

EPS-HEP, Venice, July 5-12, 2017

The CUORE Collaboration

- 161 collaborators
  - 117 researchers/authors
    - Associated Institutions: 19

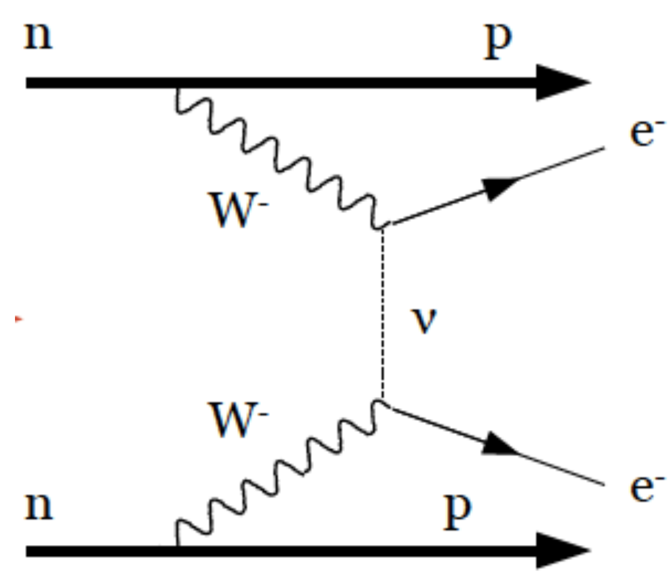
Neutrinoless double beta decay ($0\nu\beta\beta$)

Observation of $0\nu\beta\beta$ would:

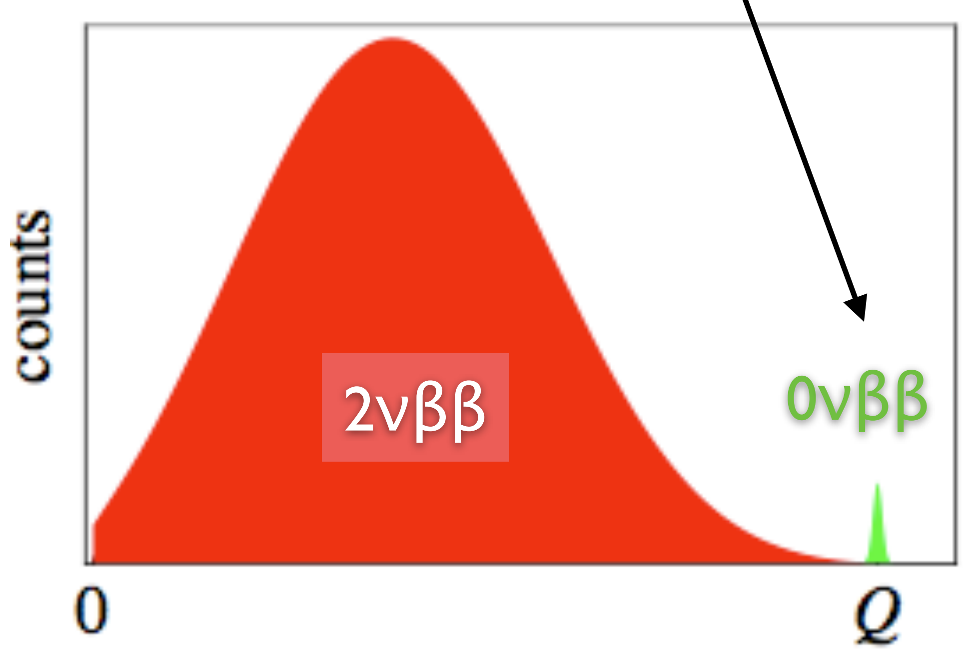
Demonstrate that lepton number is not conserved

Establish neutrinos as Majorana particles

Set constraints on the effective Majorana mass $m_{\beta\beta}$ and provide info on absolute ν mass scale



In the general experimental approach of detecting the sum energy of the two final-state electrons, the signature of $0\nu\beta\beta$ decay is a peak at Q-value ($Q_{\beta\beta}$)



The observable is the half life:

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu}|M^{0\nu}_{\eta}|^2\eta^2$$

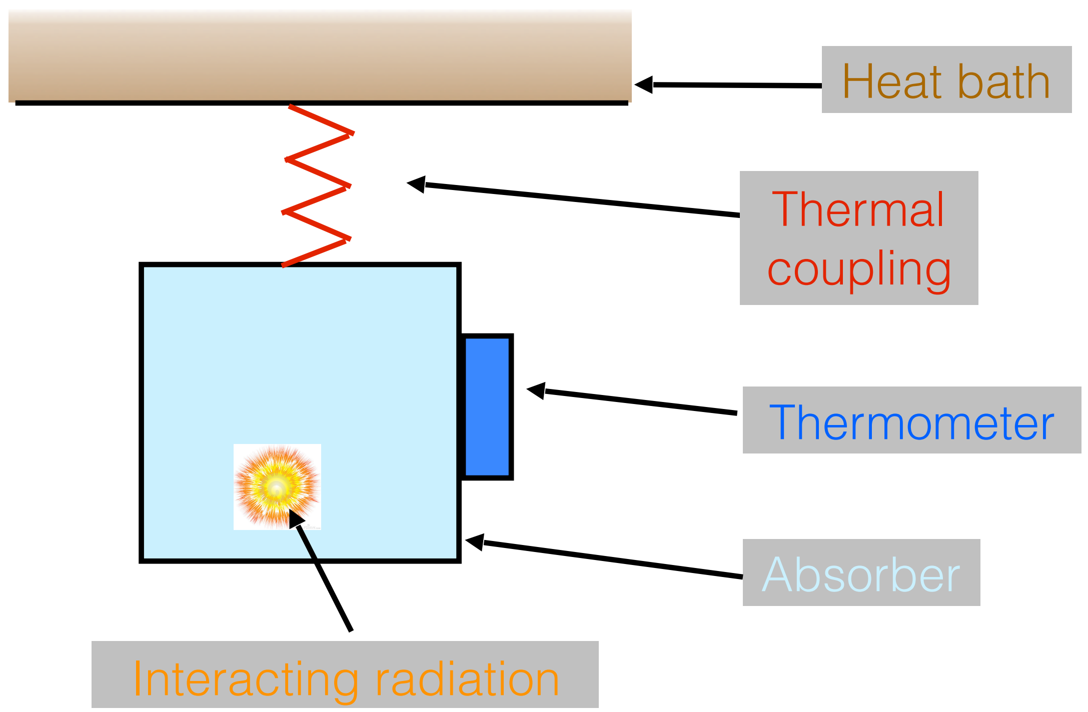
Phase space factor: known with good accuracy from atomic physics

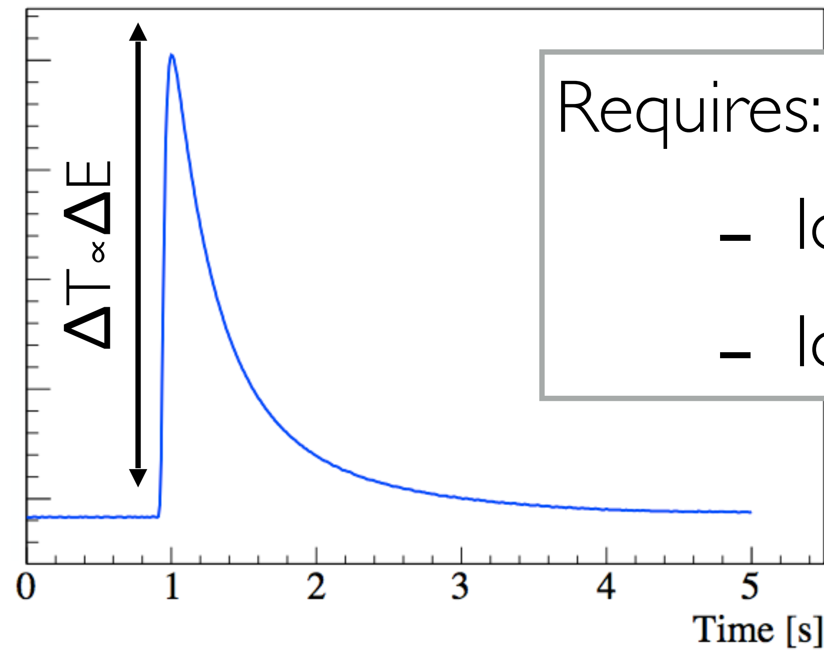
Nuclear matrix element (nuclear physics) is affected by a large uncertainty

Decay mechanism (particle physics)

Thermal detectors

Ultracold crystals function as highly sensitive calorimeters. The energy deposited by a particle interaction in the absorber is converted to a measurable temperature variation.



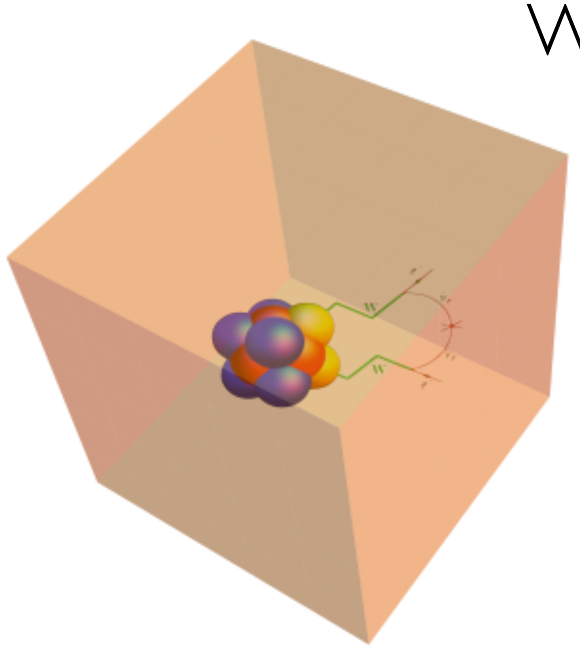


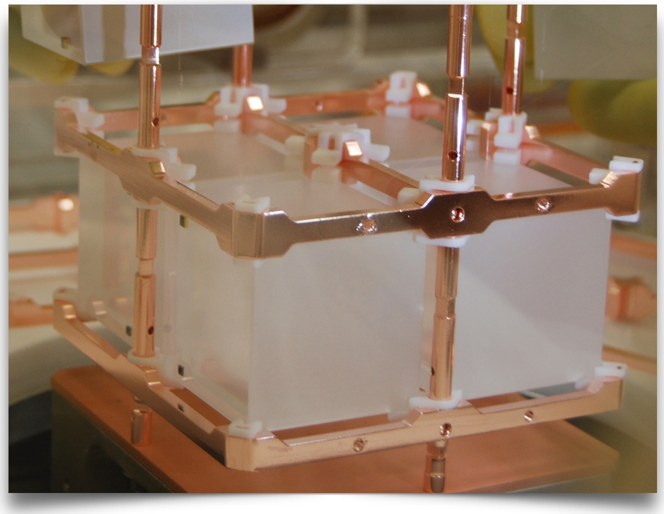
Requires:

- low heat capacity
- low temperatures

Wide choice of detector materials

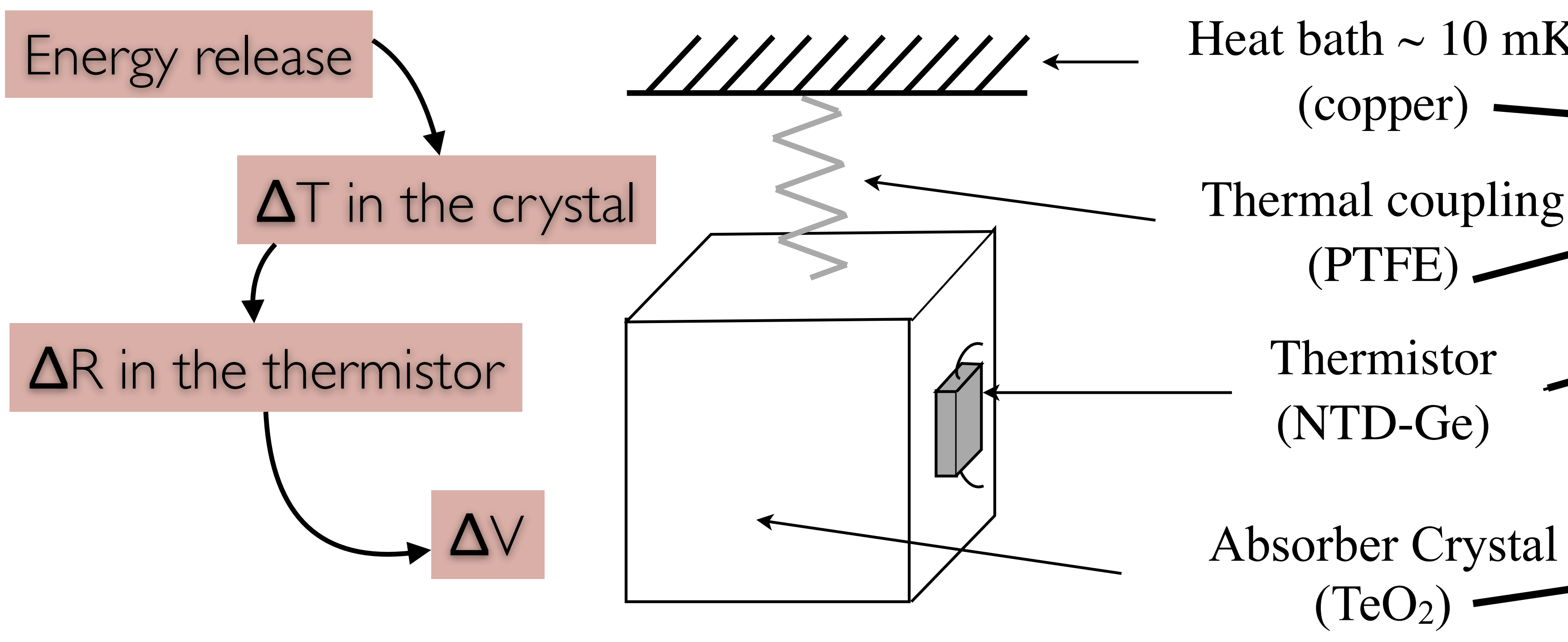
- $2e^-$ mostly contained in the bulk
- excellent efficiency (no energy escape)
- excellent energy resolution
- hard to discriminate signal from background

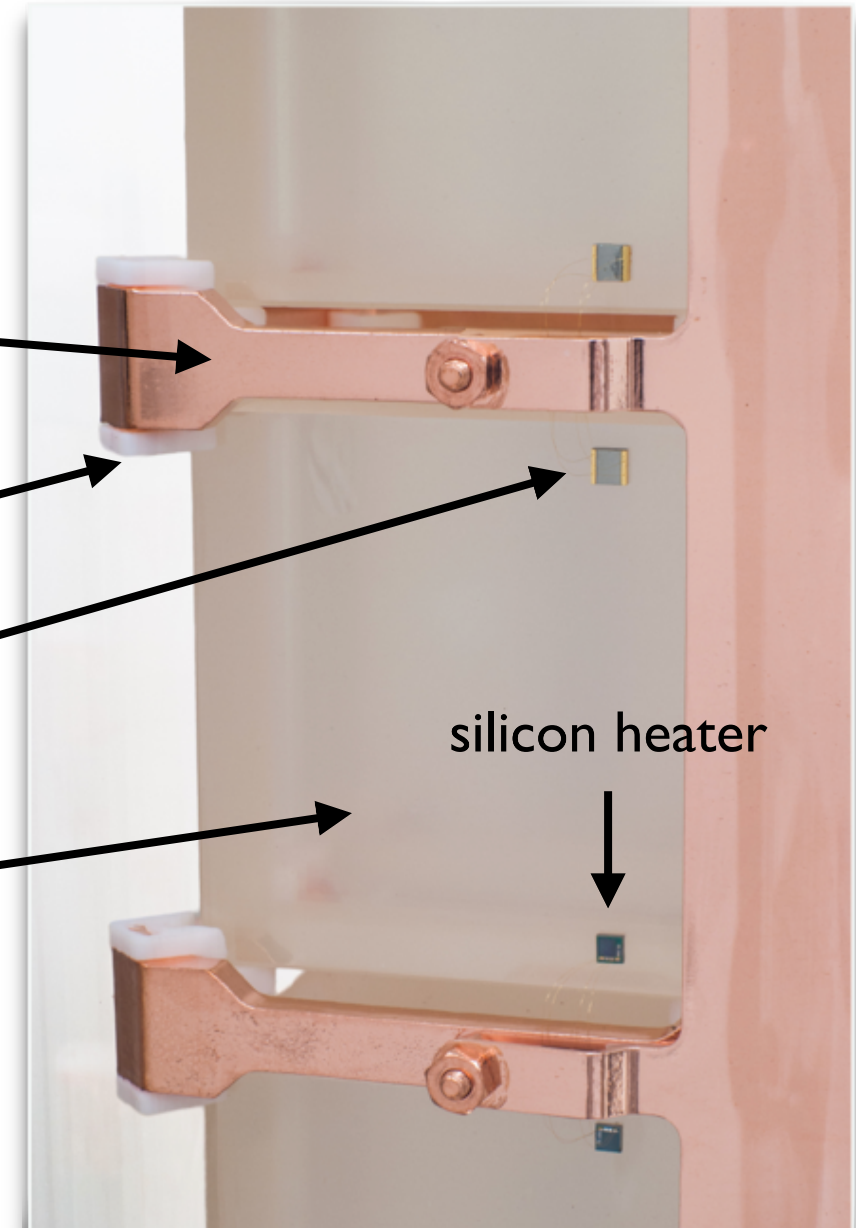




CUORE bolometers for 0νββ decay

CUORE searches for 0νββ of ^{130}Te with TeO_2 bolometers





ΔT_{NTD} ~ 10-20 μK/MeV
$\Delta T_{crystal}$ ~ 100 μK/MeV

ΔV_{NTD} ~ 300 μV/MeV
ΔR_{NTD} ~ 3 MΩ/MeV

TeO_2: Tellurium dioxide

- high natural isotopic abundance (34.2%) of the ββ emitter ^{130}Te (highest among the isotopes of interest)
- excellent energy resolution: 5 keV FWHM @ Q-value (2528 keV) achieved in predecessor experiment CUORE-0

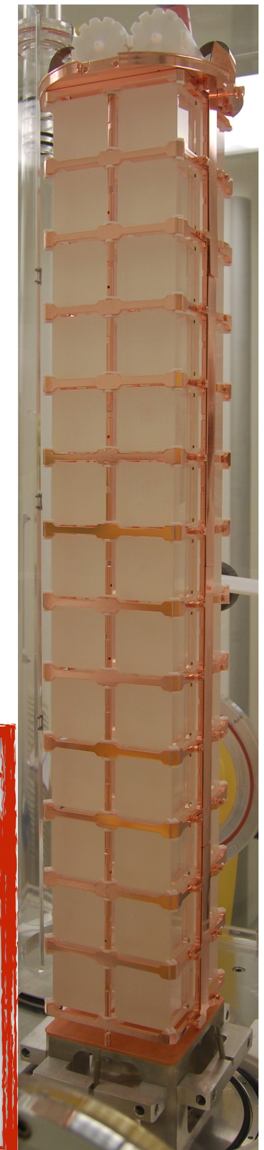
Arrays of TeO_2 bolometers

Cuoricino
2003 - 08

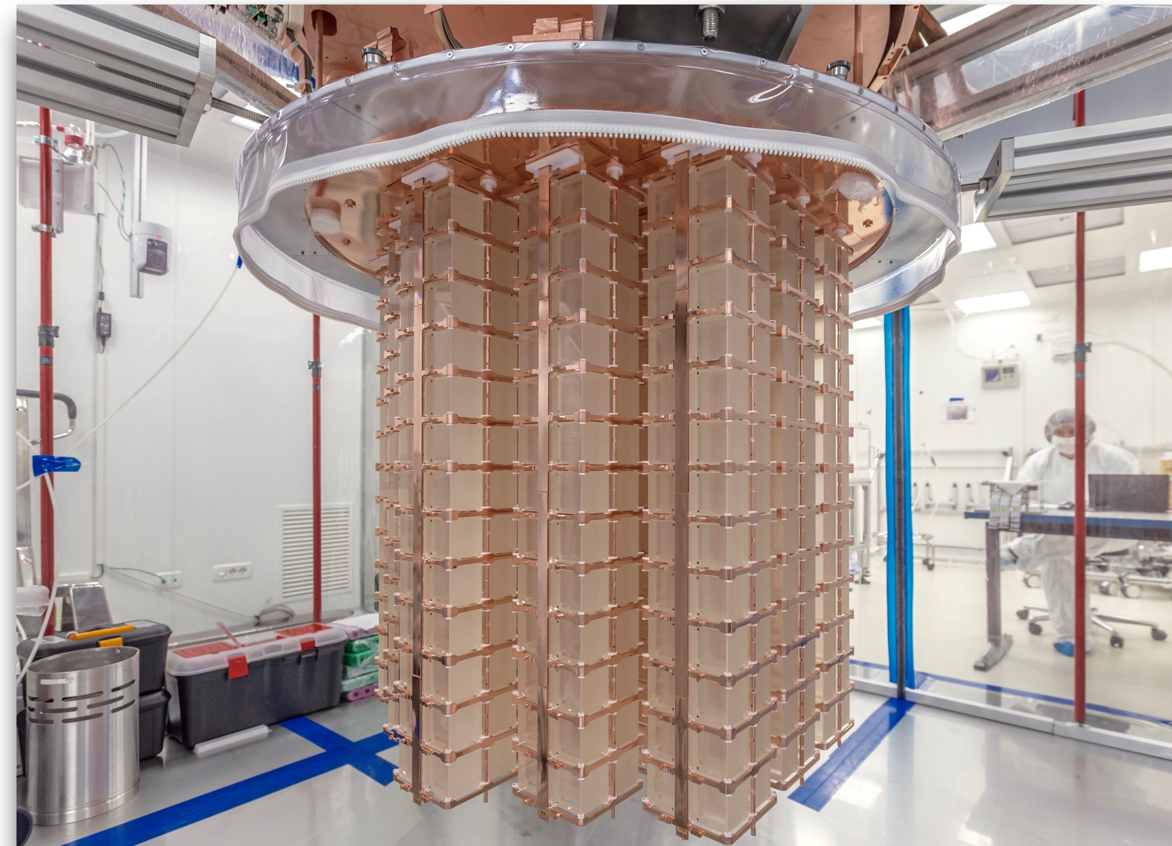
Exp = 19.75 kg y of ^{130}Te
Bkg = 0.169 c/(kg keV y)
$T_{1/2}$ > 2.8×10^{24} y (90% CL)

CUORE-0
2013 - 2015

Exp = 9.8 kg y of ^{130}Te
Bkg = 0.058 c/(kg keV y)
$T_{1/2}$ > 2.7×10^{24} y (90% CL)



Same cryostat:
combined 90% C.L. limit $T_{0\nu} > 4.0 \times 10^{24}$ yr



Array of 988 5x5x5 cm^3 (750 g) TeO_2 crystals:

- 19 towers - 13 floors - 4 crystals per floor
- 742 kg total mass - 206 kg of ^{130}Te

CUORE (2017 -)
New custom cryostat
Bkg GOAL = 0.01 c/(kg keV y)
FWHM GOAL = 5 keV @ Q-value

Experimental sensitivity to 0νββ

Half-life corresponding to the minimum number of detectable signal events above background at a given C.L.

Detector mass

Isotopic abundance

Measuring time

$$T_{0\nu} \propto i.a. \sqrt{\frac{M \cdot T}{\Delta E \cdot b}}$$

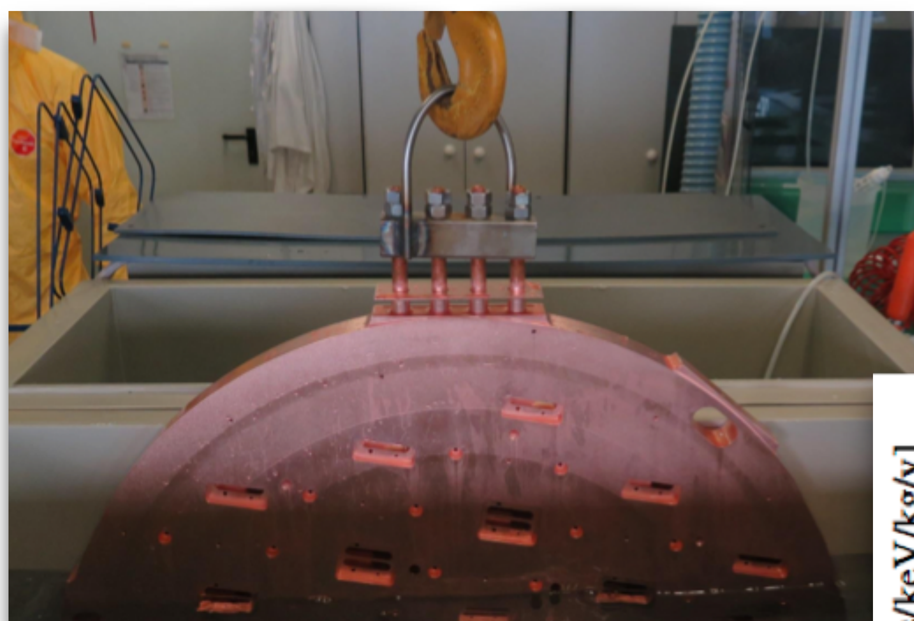
Energy resolution

Background

Reducing the background (if you can't discriminate against it) is the challenge

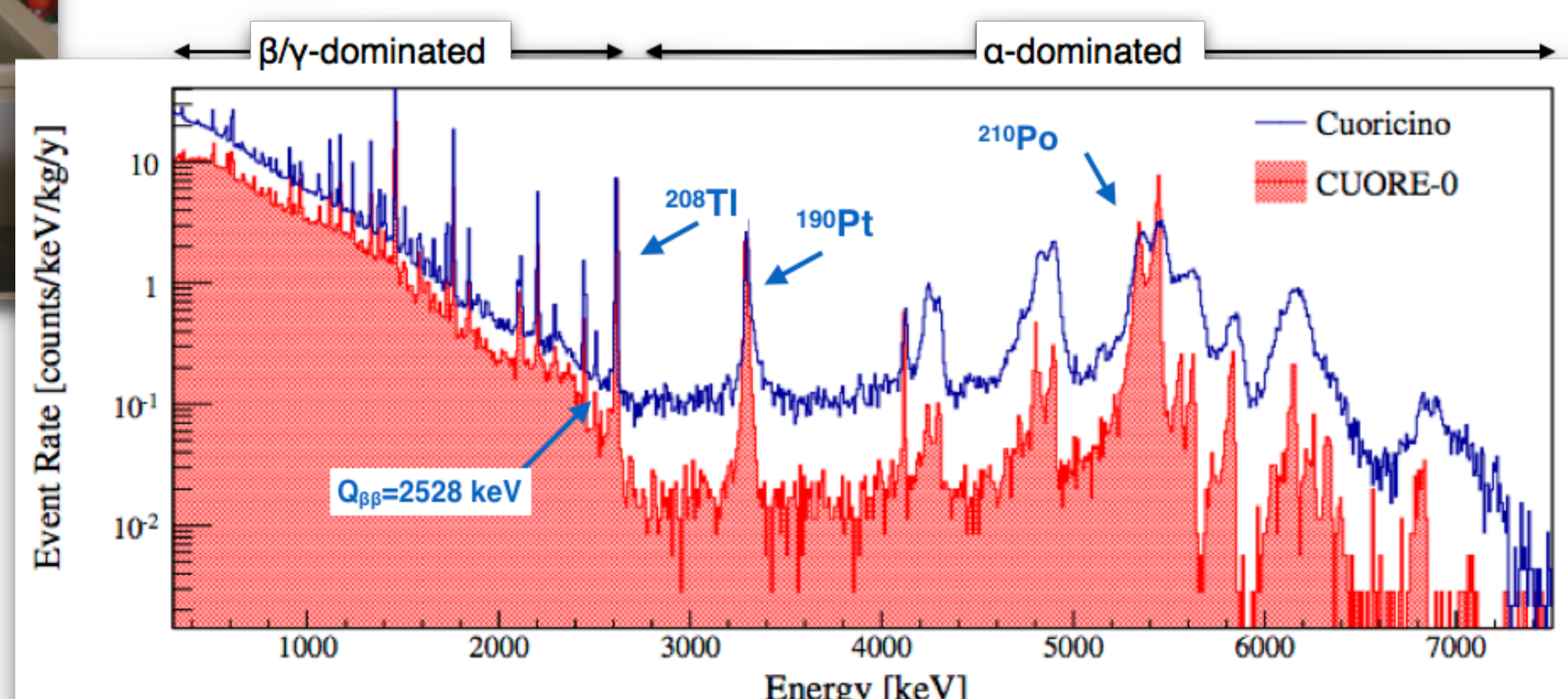
CUORE cleaning

- strict radiopurity control protocol to limit bulk and surface contaminations in crystal production (@SICCAS - Shanghai)
- transportation at sea level to LNGS in vacuum bags + boxes
- Stored underground in nitrogen fluxed cabinets

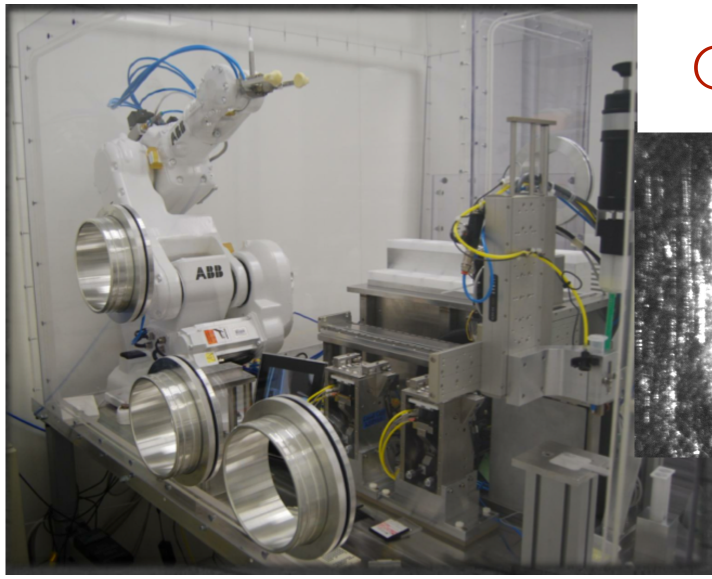


- TECM (Tumbling, Electropolishing, Chemical etching, and Magnetron plasma etching) cleaning for copper surfaces + packaging in vacuum

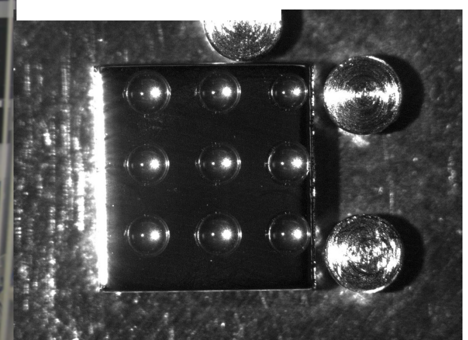
Radioactive contaminations make most of the background in the ROI

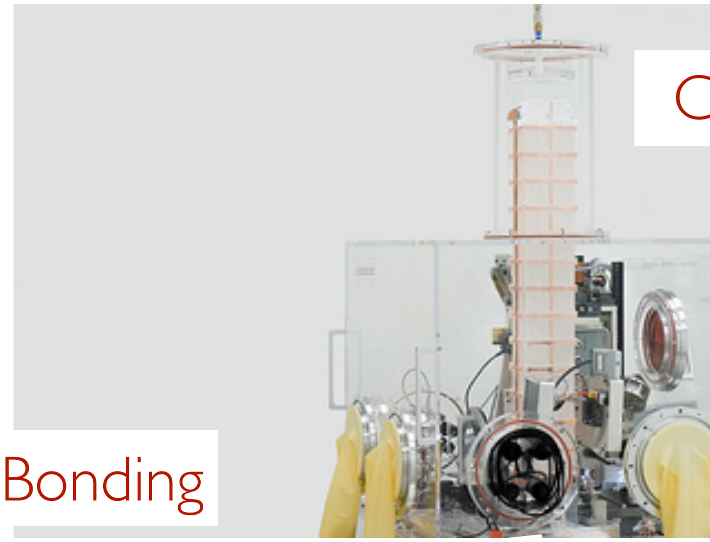


CUORE assembly @ CTAL



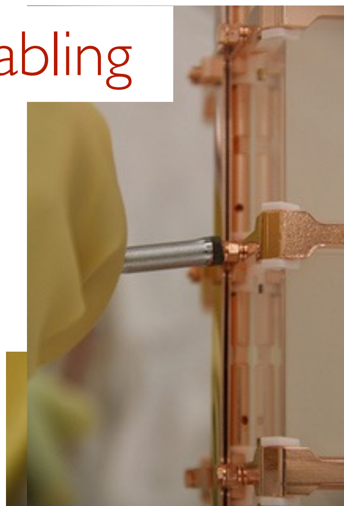
Gluing

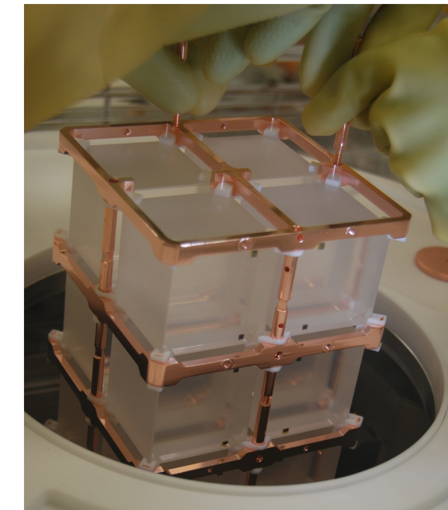




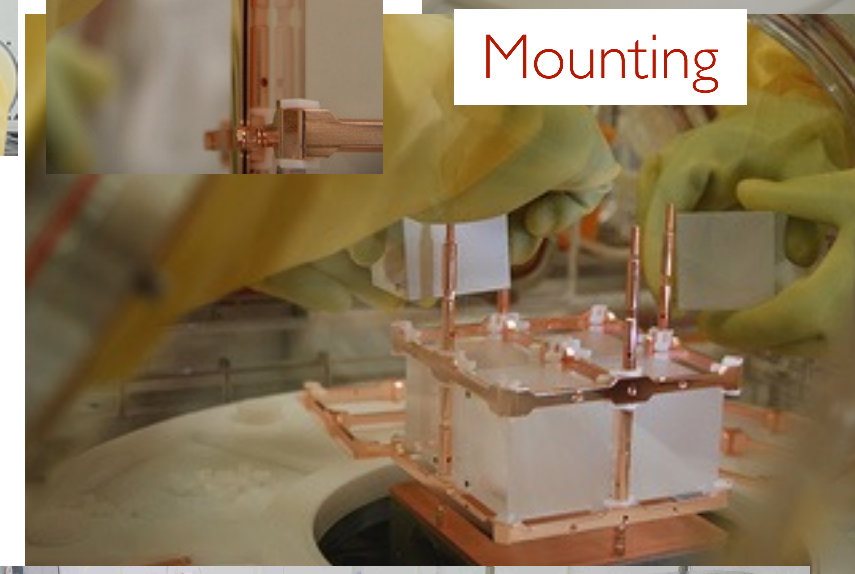
Bonding

Cabling

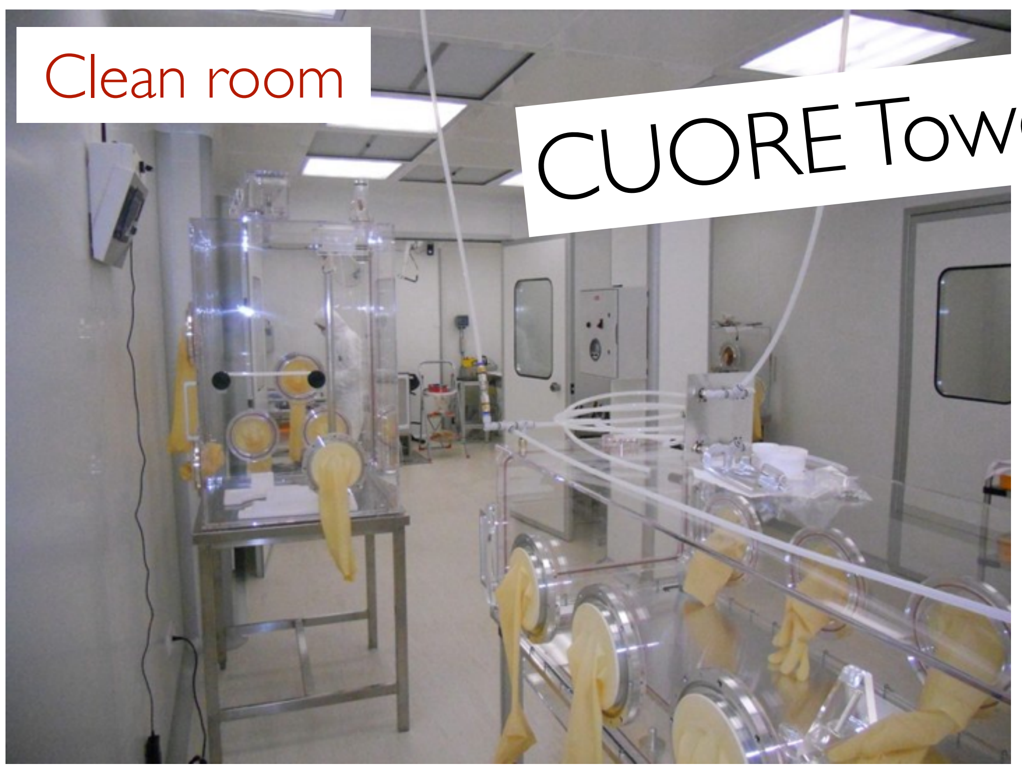




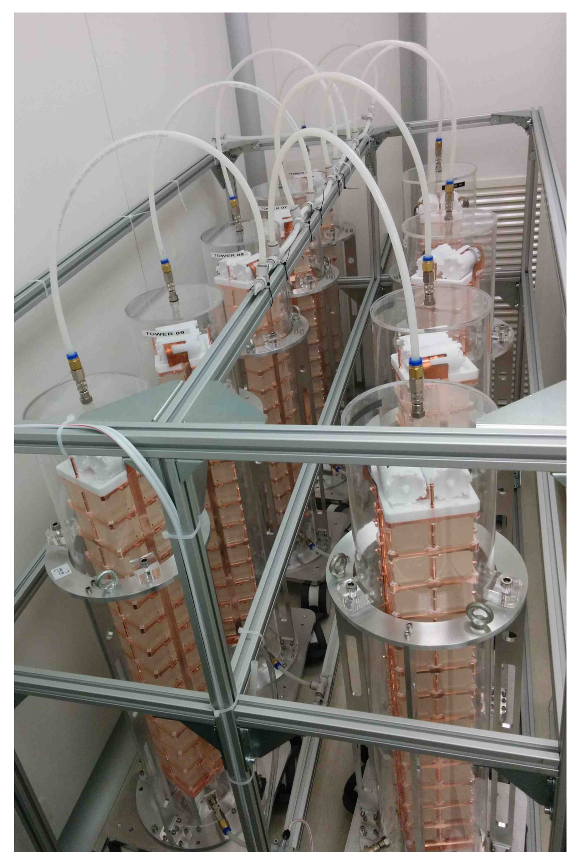
Mounting



Clean room



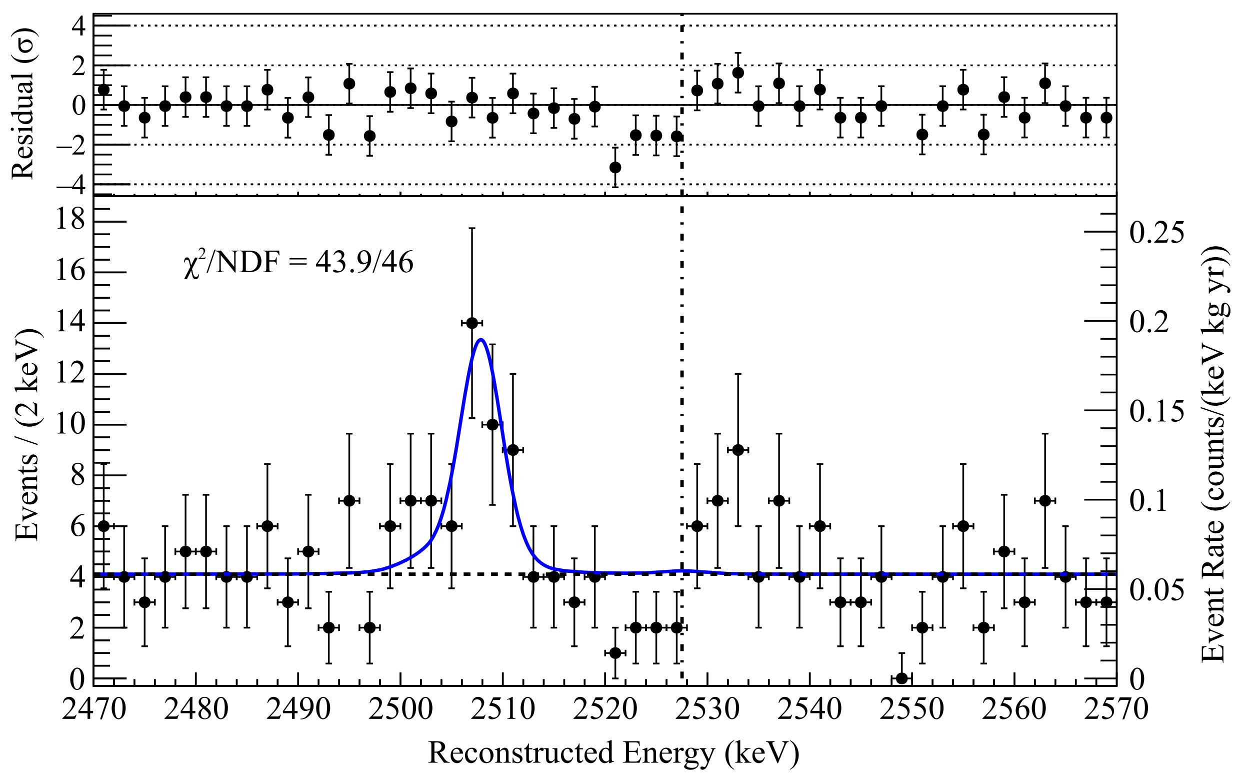
CUORE Tower Assembly Line



Assembly of all the 19 CUORE towers completed in 2014

CUORE-0 results

CUORE-0 was the first CUORE-like tower & CUORE technical prototype, assembled from detector components manufactured, cleaned and stored following CUORE protocols.



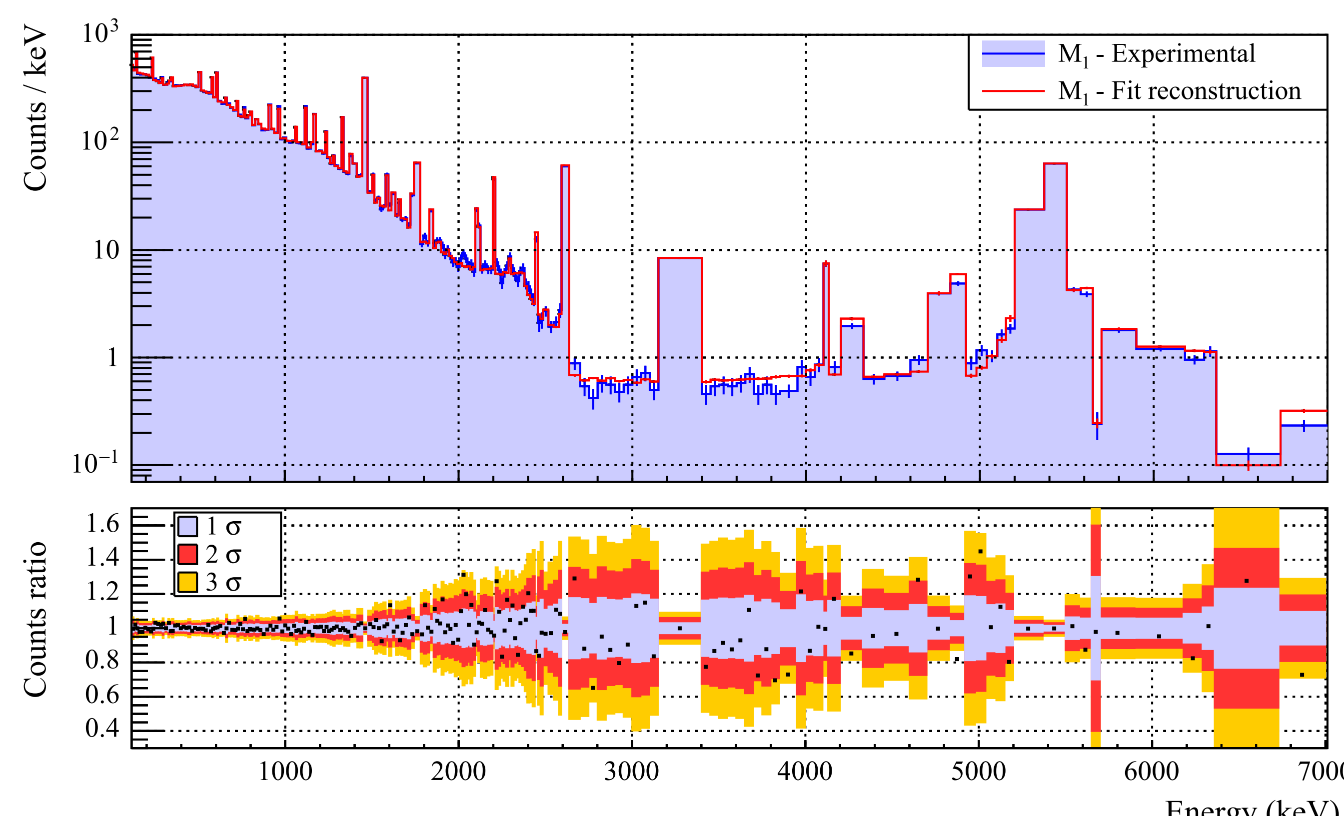
Physical Review Letters **115**, 102502 (2015)

CUORE-0 + Cuoricino 0νββ limit :

$$T_{1/2} > 4.0 \times 10^{24}\ \mathrm{y}\ (90\%\mathrm{C.L.})$$

$$\Delta E = 5.1 \pm 0.3\ \mathrm{keV\ FWHM}$$

CUORE FWHM GOAL REACHED!

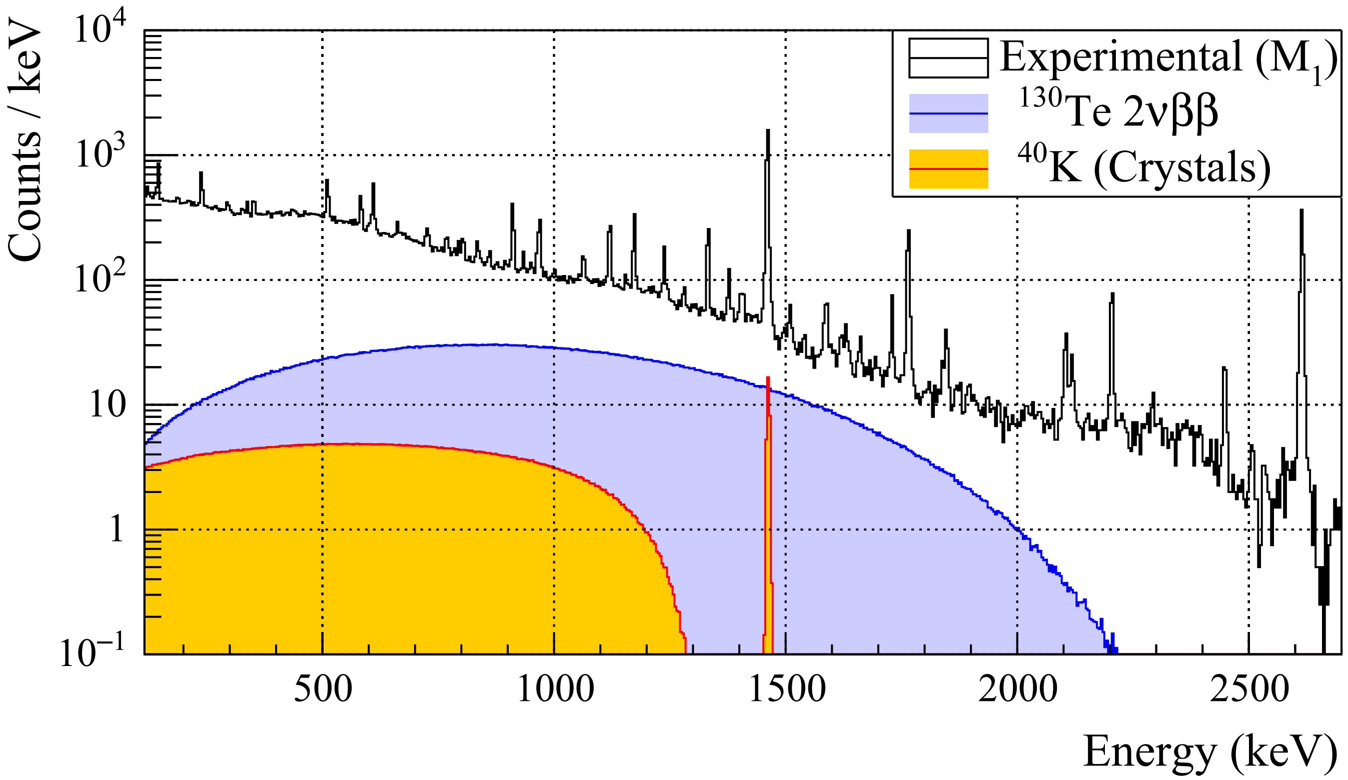


European Physical Journal C **77**, 13 (2017)

CUORE-0 background model

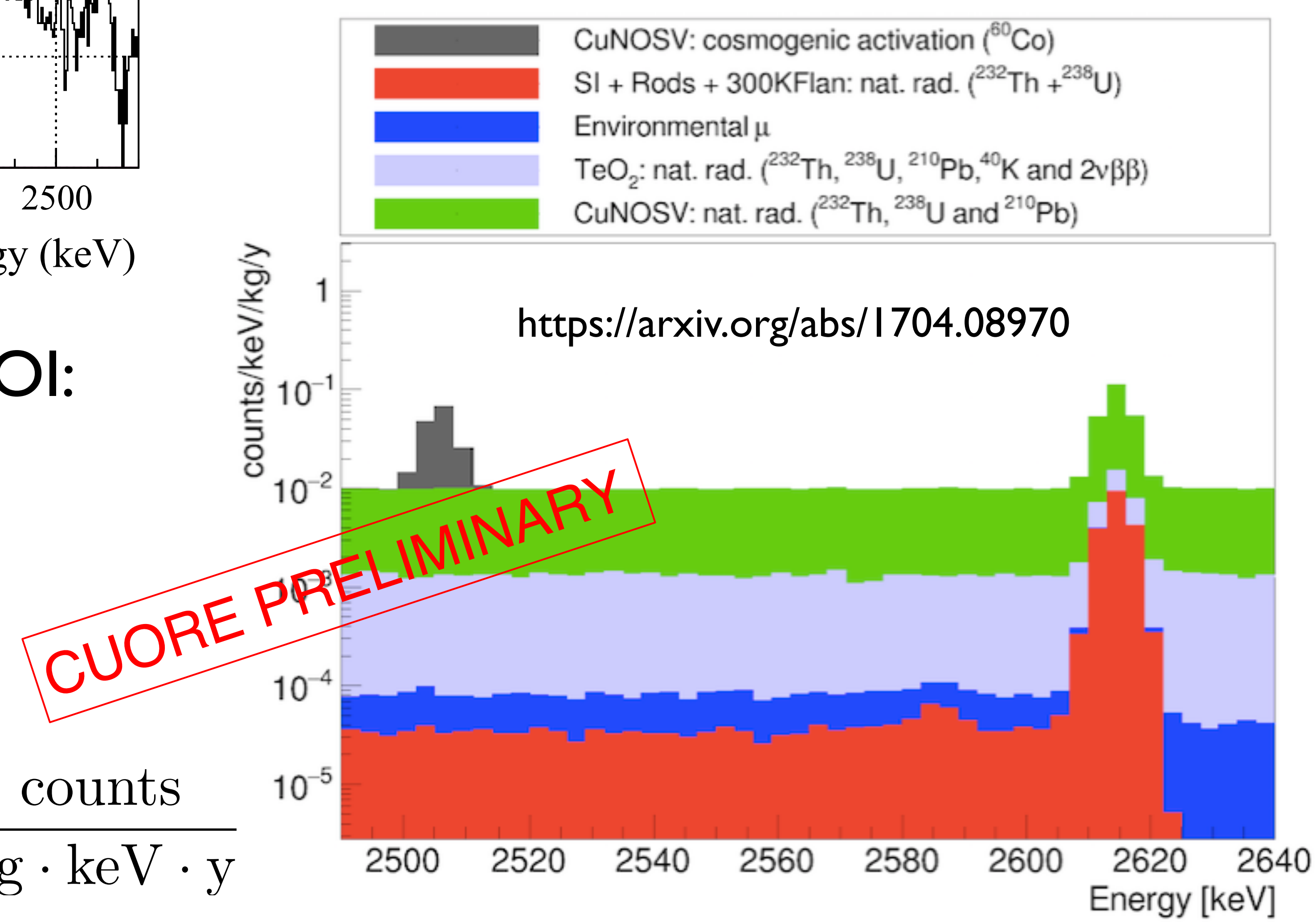
>50 background sources identified and ascribed to parts of the setup.
Contamination levels from material screening
Geant4 simulated background model.
Bayesian fit to the CUORE-0 spectrum with priors from screening.

CUORE-0 $2\nu\beta\beta$ measurement and extrapolation to CUORE bkg in ROI



European Physical Journal C **77**, 13 (2017)

$T_{1/2}$ = [8.2 ± 0.2 (stat.) ± 0.6 (syst.)] × 10^{20} y
most precise measurement of the $2\nu\beta\beta$ half-life



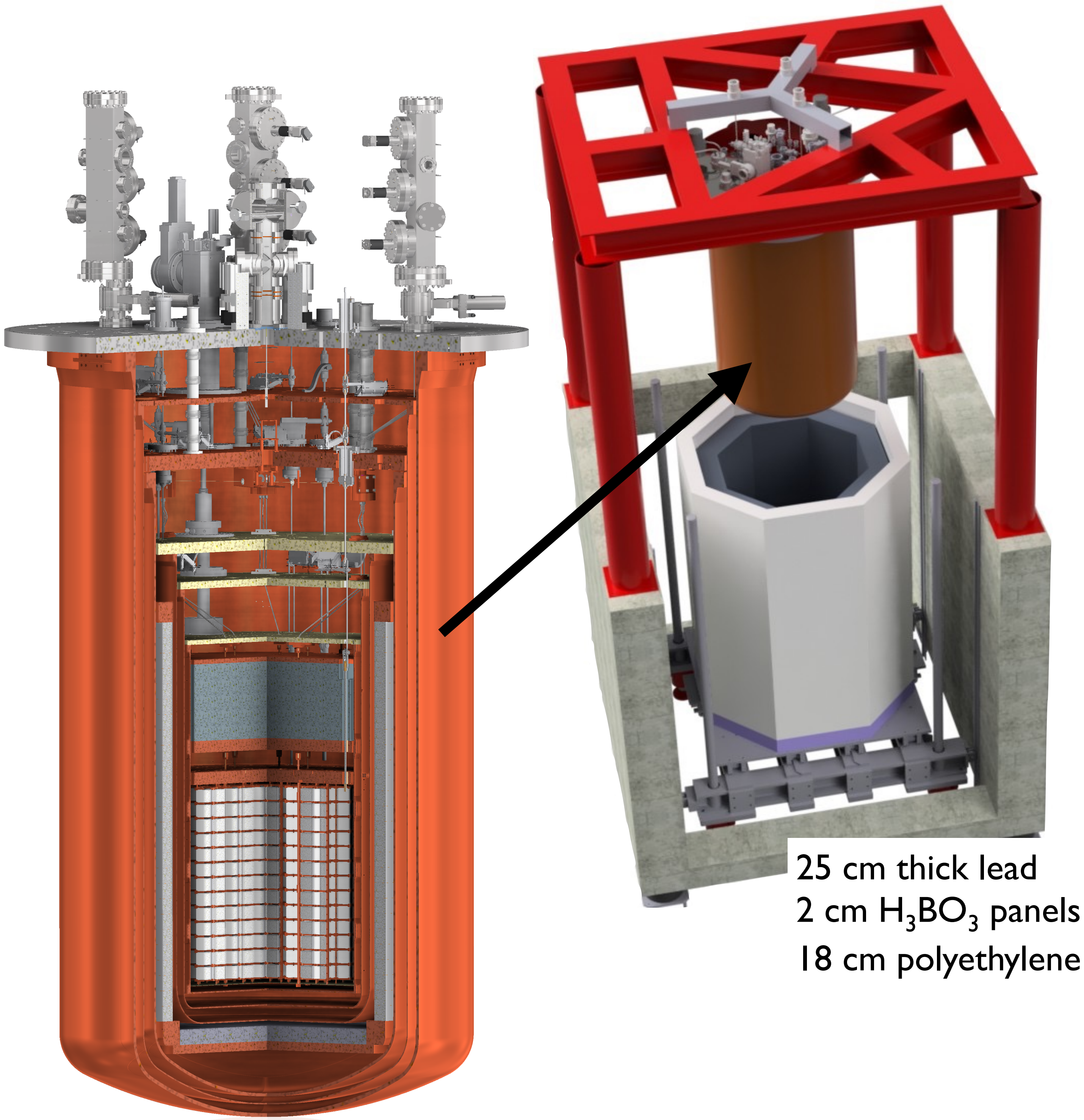
CUORE background model in the ROI:

Projection based on MC simulation of:

- environmental bkg @ LNGS
- material screening for CUORE
- bkg sources from CUORE-0 model

$$[1.02 \pm 0.03(\text{stat.})^{+0.23}_{-0.10}(\text{syst.})] \times 10^{-2} \frac{\text{counts}}{\text{kg} \cdot \text{keV} \cdot \text{y}}$$

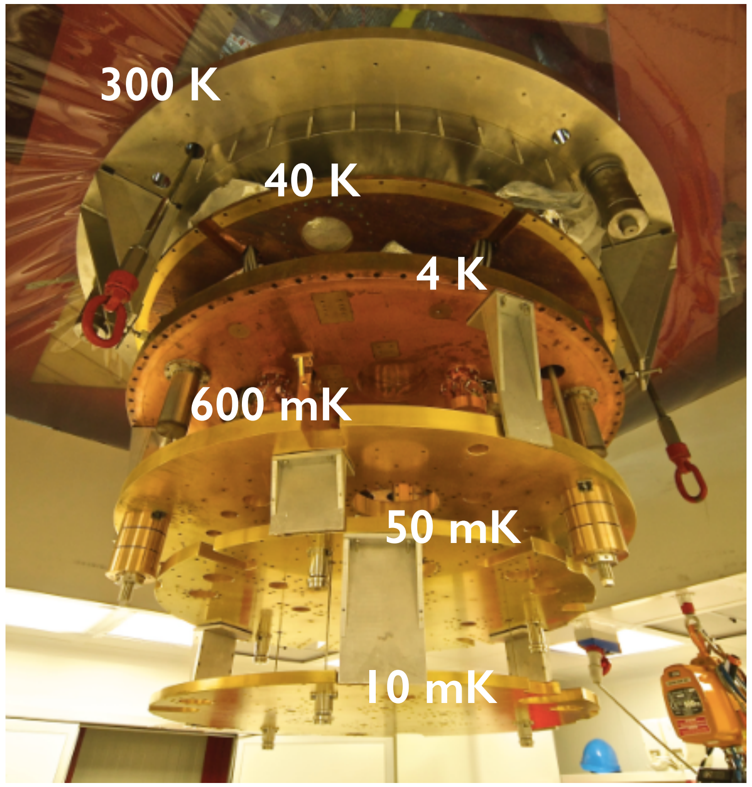
CUORE cryostat



The challenge: operate a huge bolometric array, in an extremely low radioactivity and low vibrations environment.

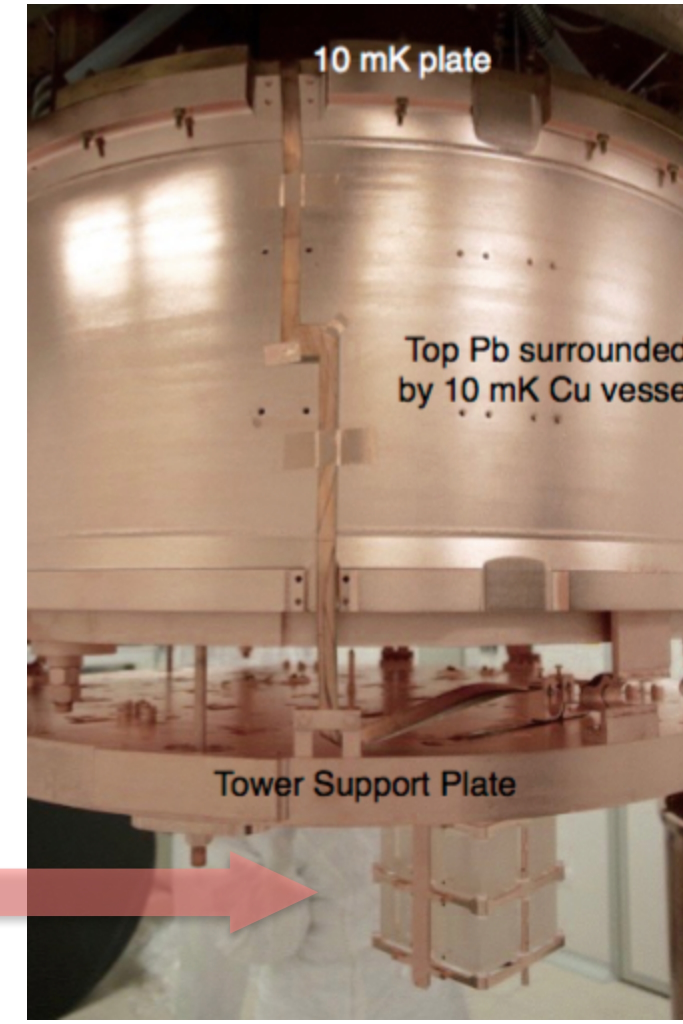
- T~10 mK stable, Size ~ 1 m^3
- Custom made pulse tube dilution refrigerator and cryostat.
- Radio-pure material and clean assembly to achieve low background at ROI
- Independent suspension of the detector array from the dilution unit: smaller vibrational noise.

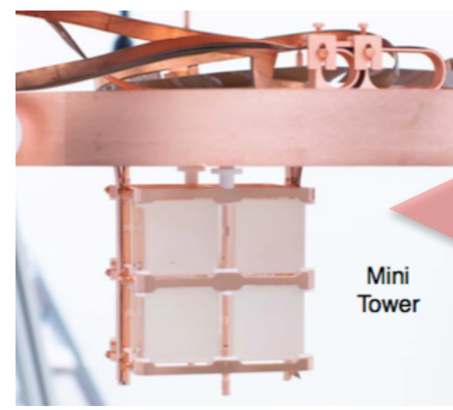
Cryogenic system commissioning

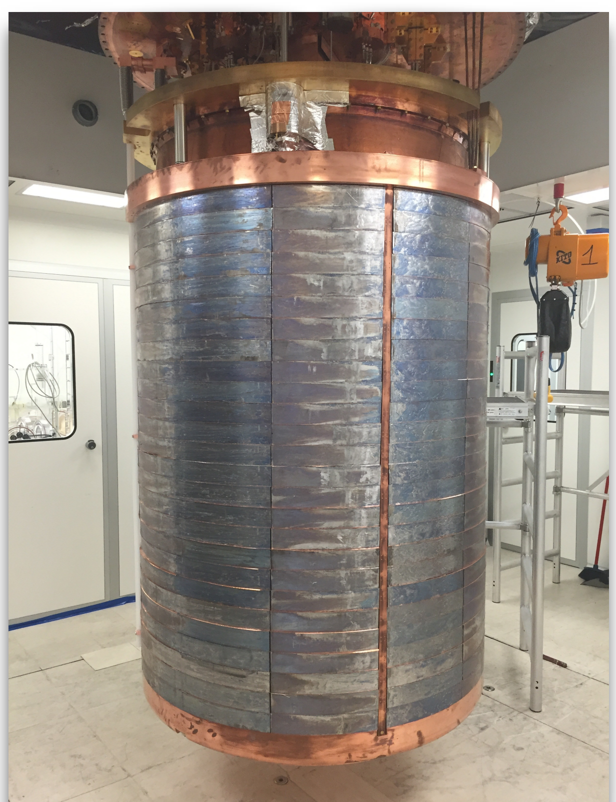


Completed in March 2016
All the components well thermalised at the different stages

Stable base temperature @ 6.3 mK on month scale.



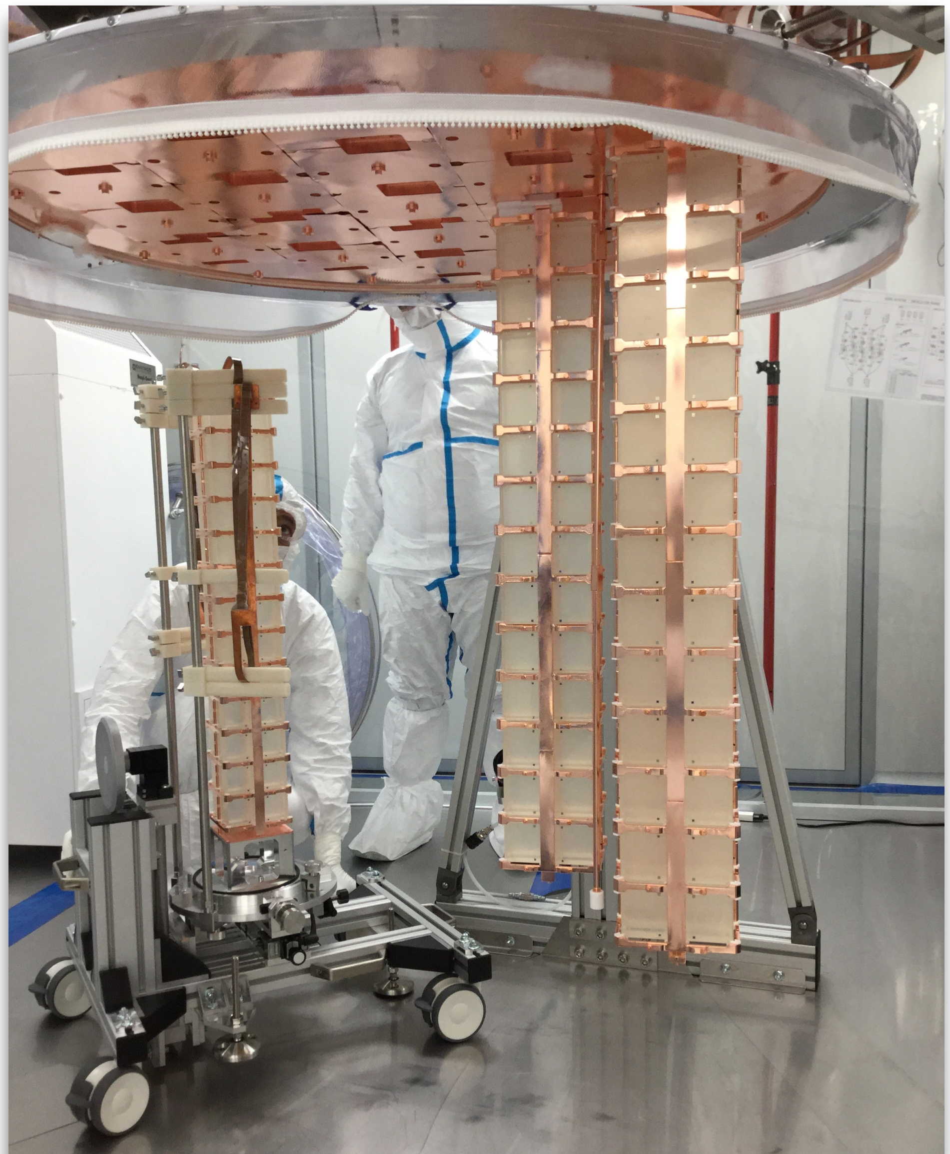




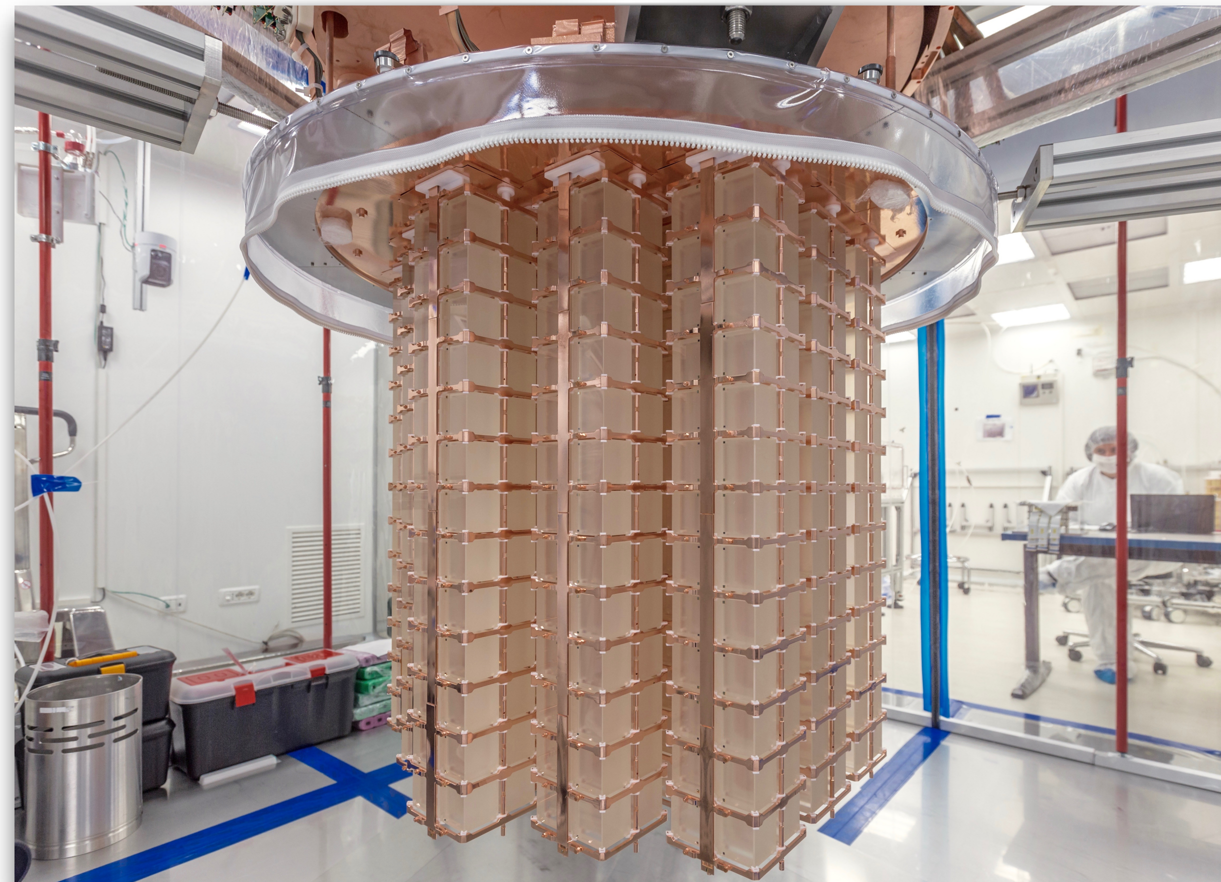
Commissioned electronics, DAQ and detector calibration systems on 8 detectors array (Mini-Tower).
No "unaccounted" background sources.

CUORE detector installation

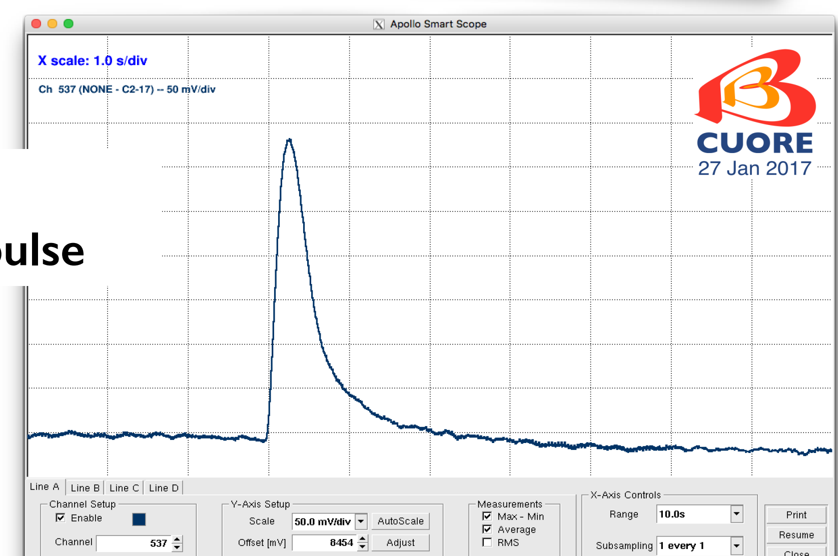
Performed in a radon-free clean room



Installation completed in August 2016



27.01.2017
Observation of first pulse

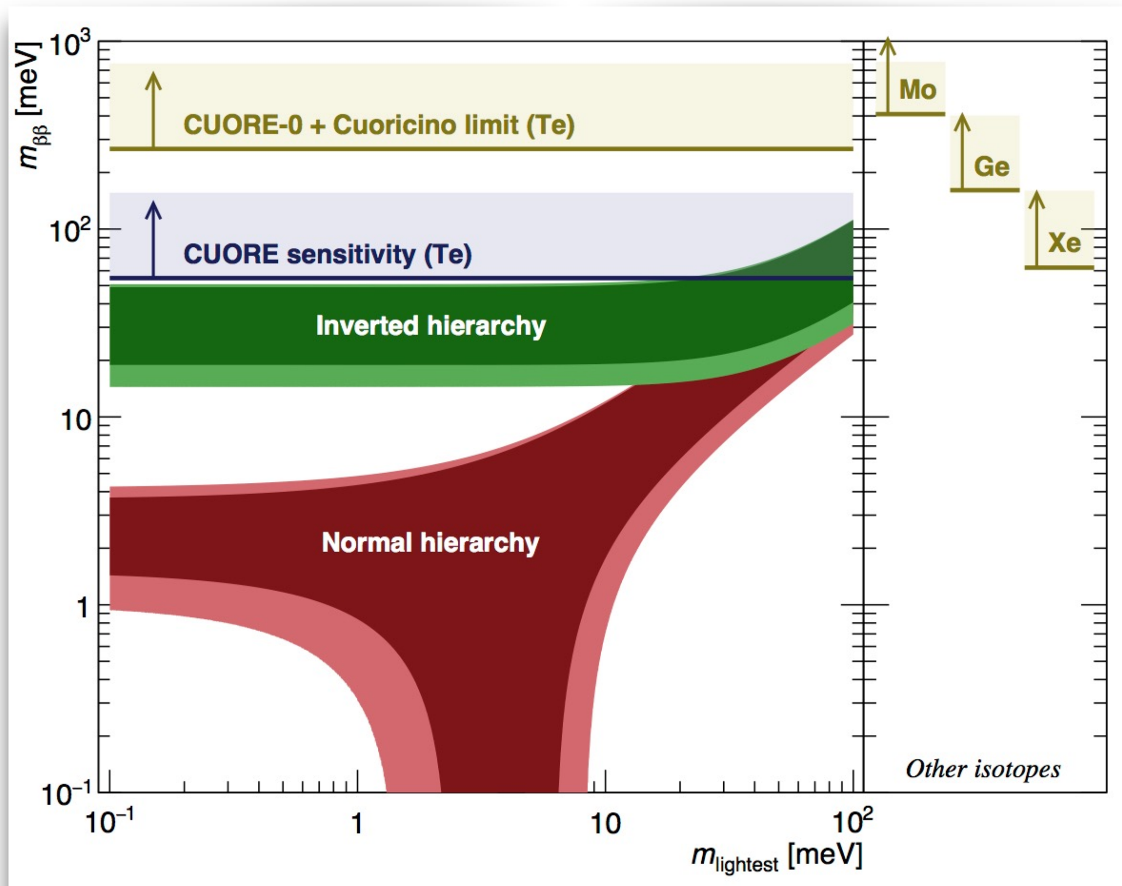


Sep. - Nov. cryostat closure
Cooldown started on Dec. 5 2016
Data taking started on April 2017

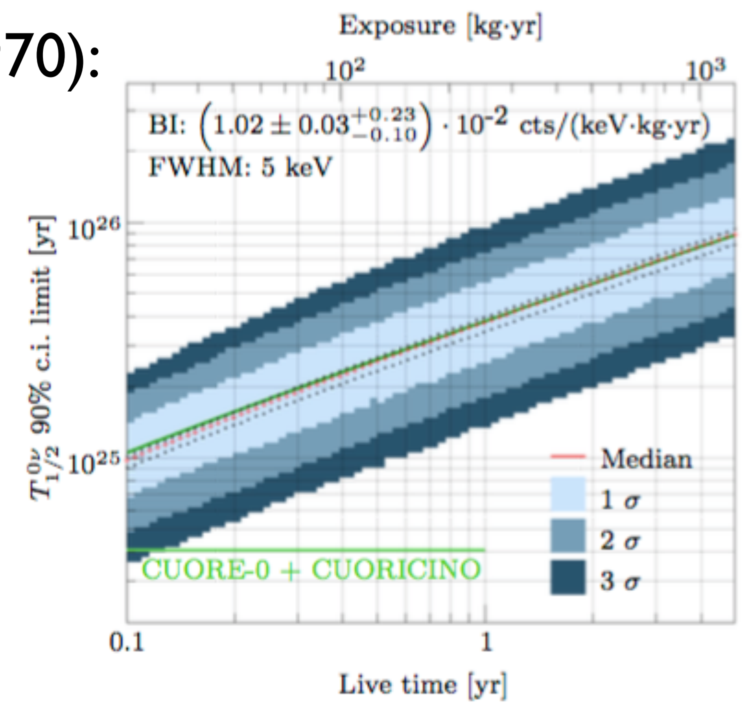
CUORE expected sensitivity

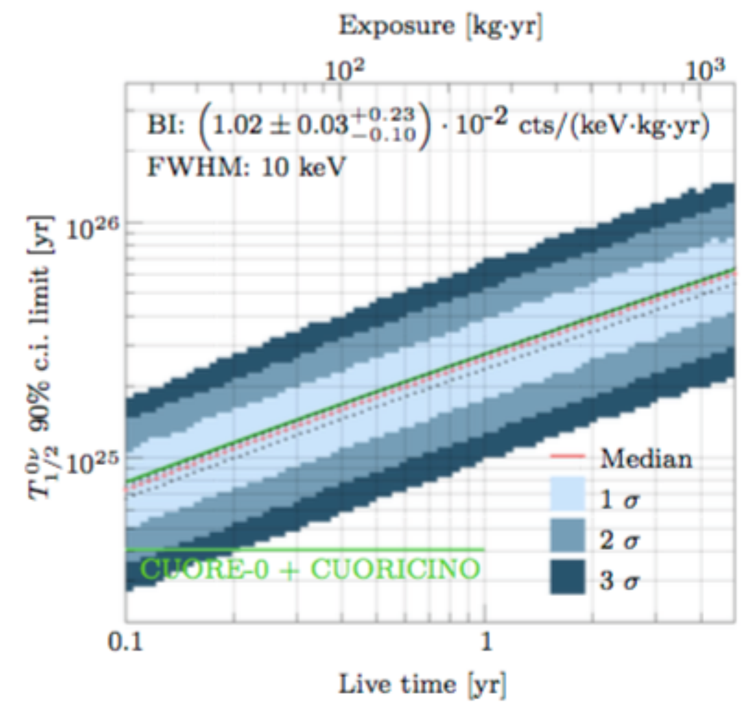
With background index (from arXiv 1704.08970):

$$[1.02 \pm 0.03(\text{stat.})^{+0.23}_{-0.10}(\text{syst.})] \times 10^{-2} \frac{\text{counts}}{\text{kg} \cdot \text{keV} \cdot \text{y}}$$



$$m_{\beta\beta} < 50 - 130 \text{ meV}$$





FWHM: 5keV
exclusion sensitivity (90% C. L.)
- $2 \cdot 10^{25}$ yr after 3 months
- $9 \cdot 10^{25}$ yr after 5 years

discovery potential (3σ)
- $7 \cdot 10^{24}$ yr after 3 months
- $4 \cdot 10^{25}$ yr after 5 years

CUORE R&D to increase sensitivity

CUPID = Cuore Upgrade with Particle IDentification
see Fabio Bellini's talk in this session.

Conclusions

TeO_2 bolometers offer a well-established, competitive technique in the search for neutrinoless double beta decay

CUORE-0

Achieved its energy resolution and background level goals, surpassing Cuoricino sensitivity in half the time.

Validated CUORE assembly technology and background model.

Most stringent limit on ^{130}Te half-life.

Most precise measurement of 2$\nu\beta\beta$ half-life in ^{130}Te.

CUORE:

First 0$\nu\beta\beta$ cryogenic experiment at ton-scale.

Detector installation completed, successful cool down.

CUORE IS TAKING DATA: physics results very soon $\Longrightarrow$ TAUP 2017.