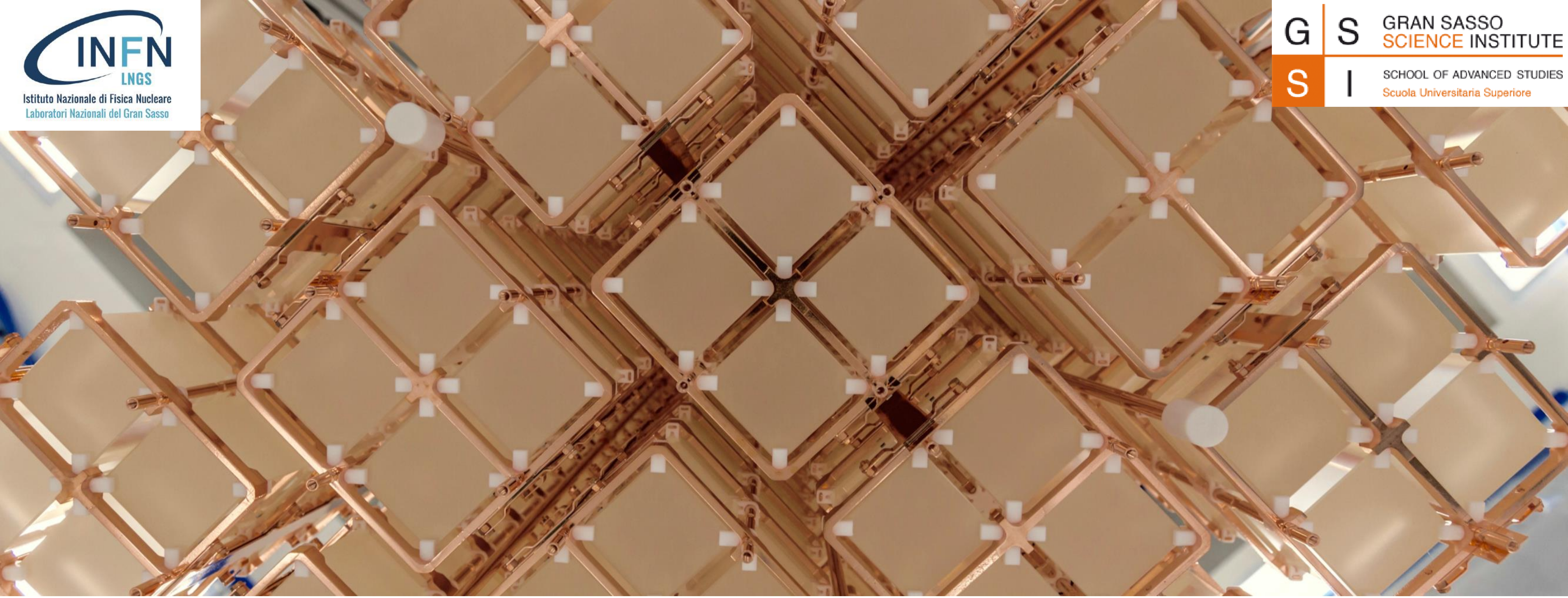


RESULTS FROM THE CUORE EXPERIMENT

ALPS2019

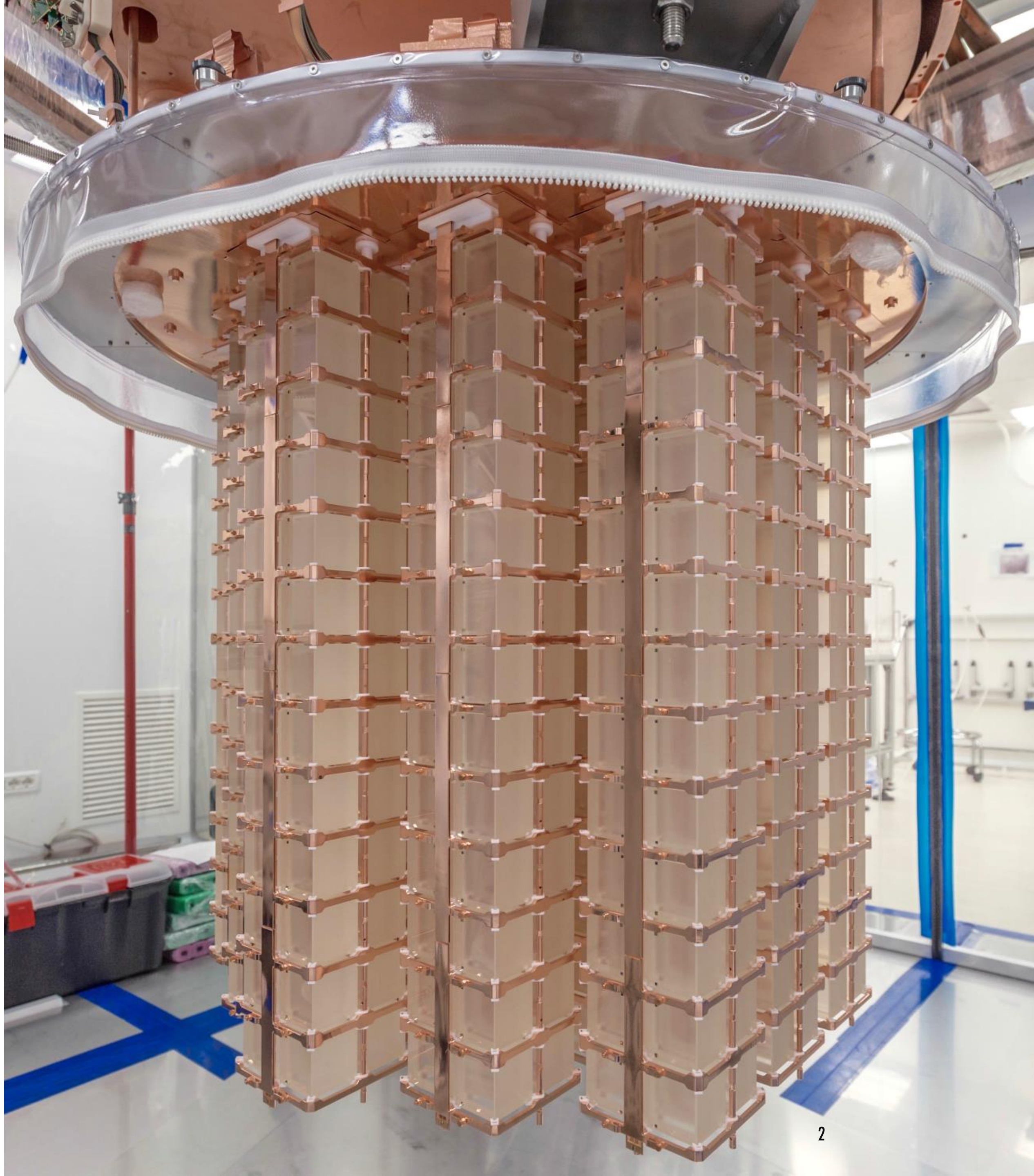
Obergurgl, 23 April 2019

Simone Copello

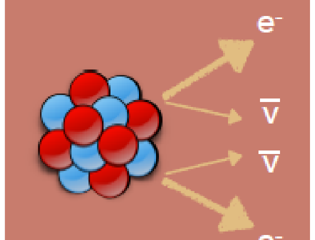
Gran Sasso Science Institute

OVERVIEW

- Double beta decay
- CUORE detector
- Cryostat
- Commissioning
- Detector optimization
- Data analysis
- Results
- Conclusions



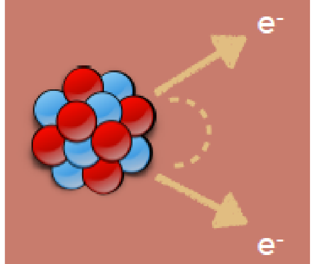
DOUBLE BETA DECAY



Double Beta Decay (ββ)

Is a second order weak interaction, directly observable (and observed) only for few even-even nuclei.

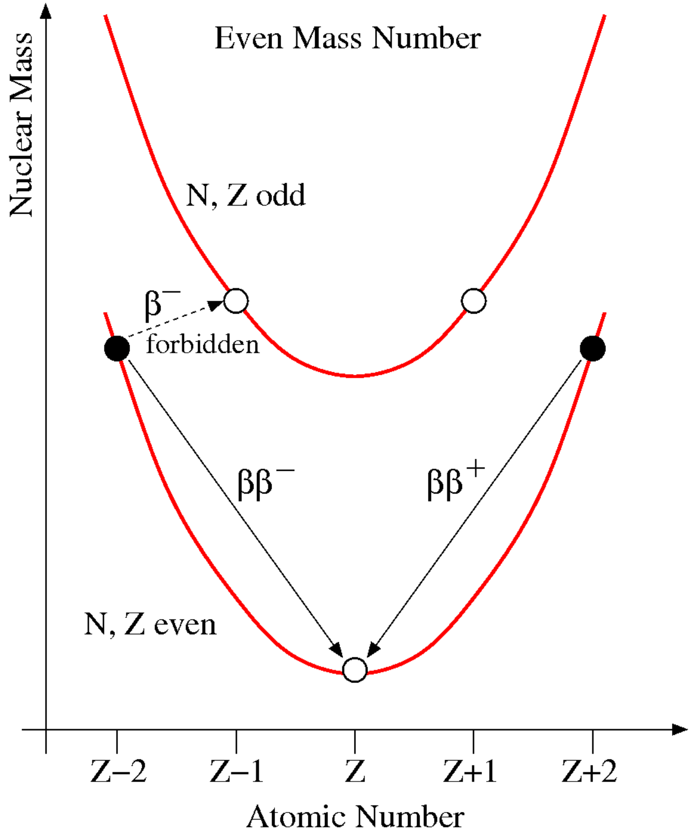
- Allowed by SM ($\Delta L = 0$)
- Observed in several nuclei $\tau_{1/2} \sim 10^{19\text{-}21}$ years



Neutrinoless Double Beta Decay (0νββ)

Is a hypothetical decay with no neutrino emission

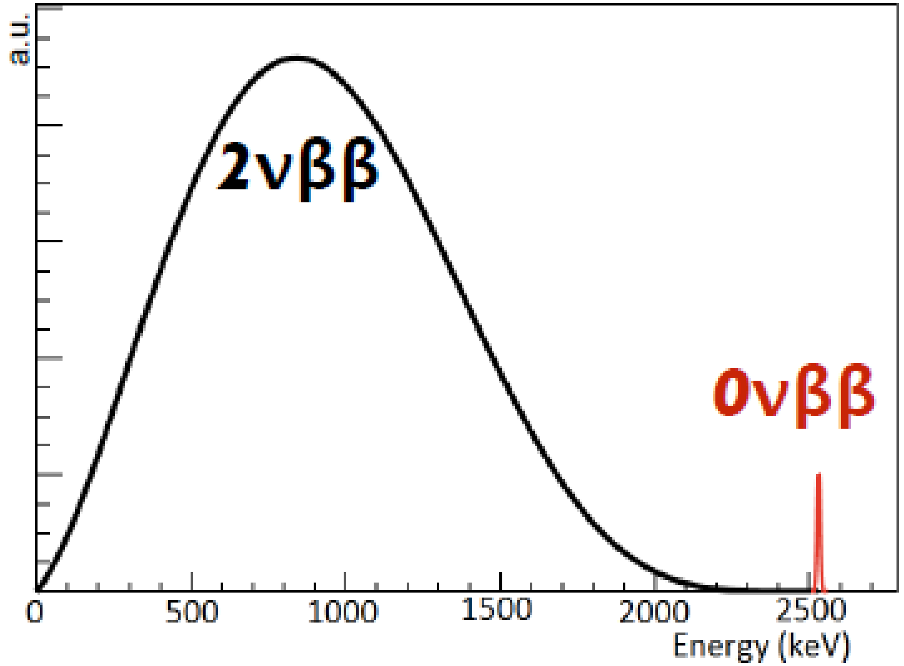
- Beyond SM ($\Delta L = 2$)
- Never observed to date $\tau_{1/2} > 10^{25\text{-}26}$ years



Implication in 0νββ decay observation:

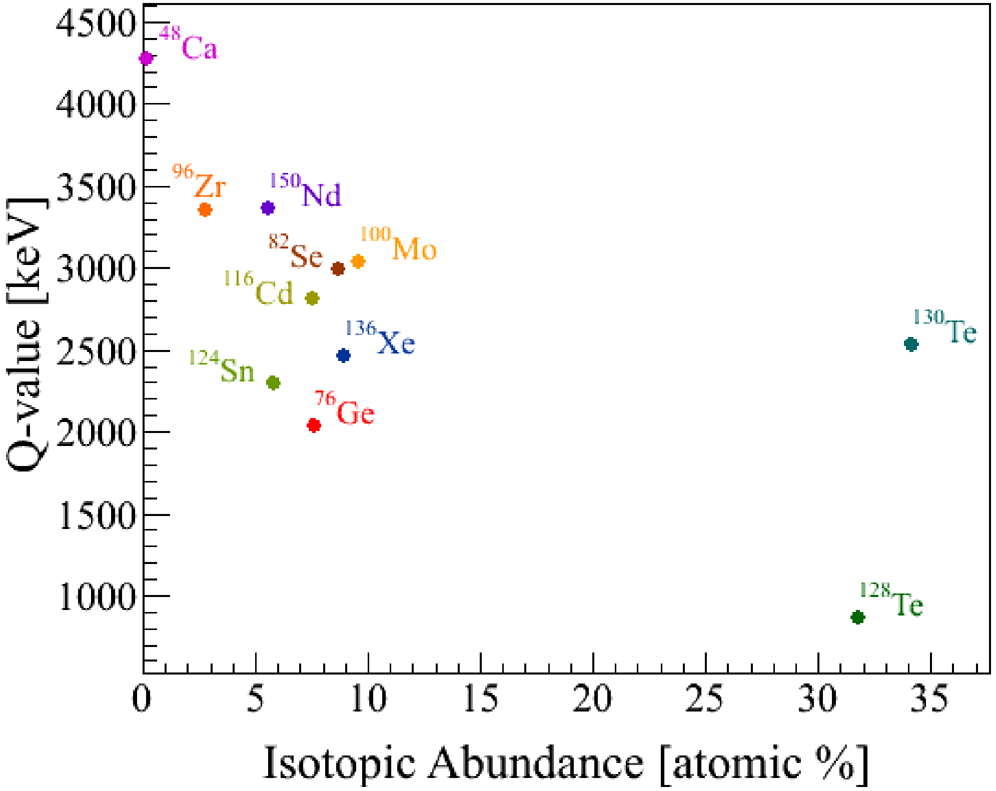
- demonstrate lepton number violation
- establish the Majorana nature of neutrinos
- constrain the absolute neutrino mass hierarchy and scale

DOUBLE BETA DECAY



Signature:
peak at the Q-value of ^{130}Te ββ decay.

2νββ events represent an unreducible background



The isotope of interest for CUORE is ^{130}Te:

- high isotopic abundance (34.17%)
- ^{130}Te within the detector absorber of TeO_2
- Q-value of 2527.515 ± 0.013 keV
- reproducible growth of high quality crystals

DOUBLE BETA DECAY

Experimental sensitivity:

$$T_{0\nu} \propto \sqrt{\frac{M\,t}{B\,E}}$$

M = mass (of the candidate isotope): **206 kg of ^{130}Te**

t = live time: **5 years of data taking** in stable conditions

B = background index: **0.01 counts/keV/kg/yr**

E = energy resolution: **5 keV FWHM at 2.5 MeV**

large exposure (M x t)

- 988 TeO_2 crystals with isotopic abundance of 34.2% for a total mass 206 kg of active material
- foreseen 5 years of data taking

high energy resolution

- noise reduction techniques
- temperature stability
- fine tuning of detectors parameters to optimize the signal to noise ratio

low background

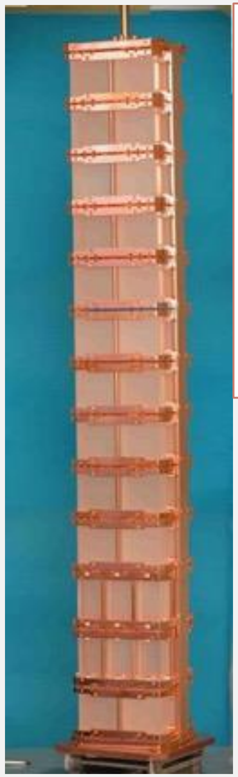
- strict radiopurity criteria on material selection and assembly chain
- passive shields from external and cryostat radioactivity
- Underground laboratory LNGS, Italy

Goal: **$T_{1/2}$ (90% C.L.) > 9 x 10^{25} yr ⟷ $\langle m_{\beta\beta} \rangle$ 45 - 210 meV**

European Physical Journal C 77.532 (2017)

CUORE PROJECT

CUORE: Cryogenic Underground Observatory for Rare Events



<u>Cuoricino</u> <u>2003 – 2008</u>

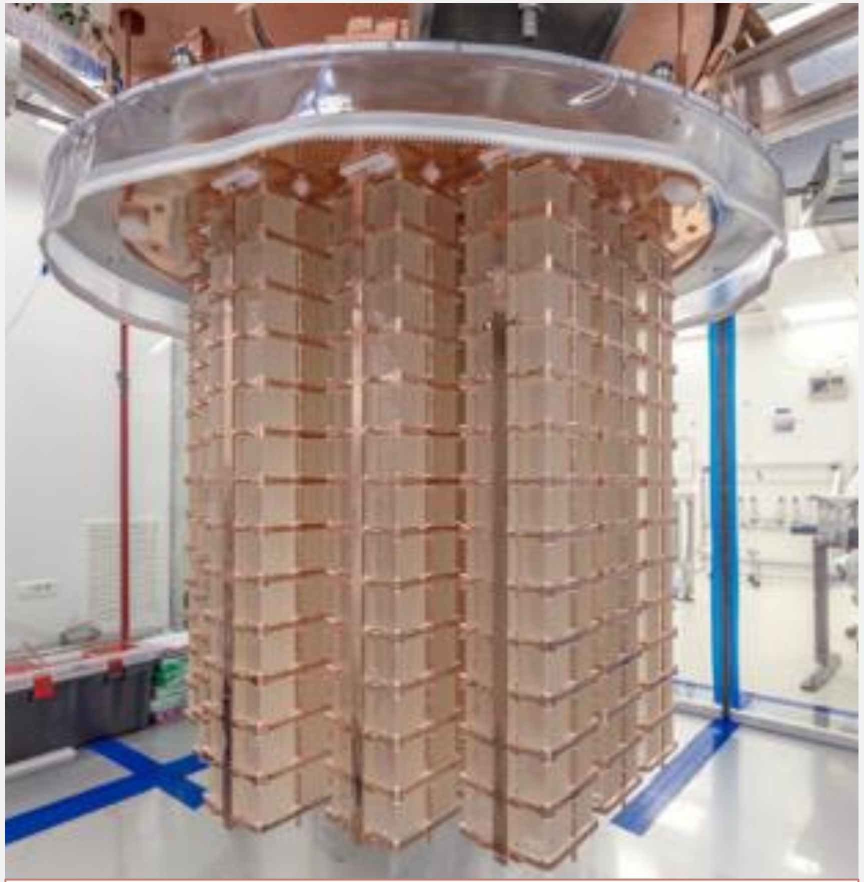
Exp = 19.75 kg yr (^{130}Te)
Bkg = 0.169 c/(kg keV yr)

$T_{1/2} > 2.8 \times 10^{24}$ yr
(90% CL)

<u>CUORE-0</u> <u>2013 - 2015</u>

Exp = 9.8 kg yr (^{130}Te)
Bkg = 0.058 c/(kg keV yr)

$T_{1/2} > 2.7 \times 10^{24}$ yr
(90% CL)



<u>CUORE</u> <u>2017 - ….</u>

Array of 988 (750 g) crystals

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

CUORE

CUORE DETECTOR

A particle interaction in the absorber causes an increase in temperature, measured by the thermistor.

CUORE is an array of <u>19 towers</u>

A tower is an array of 52 independent bolometric detectors

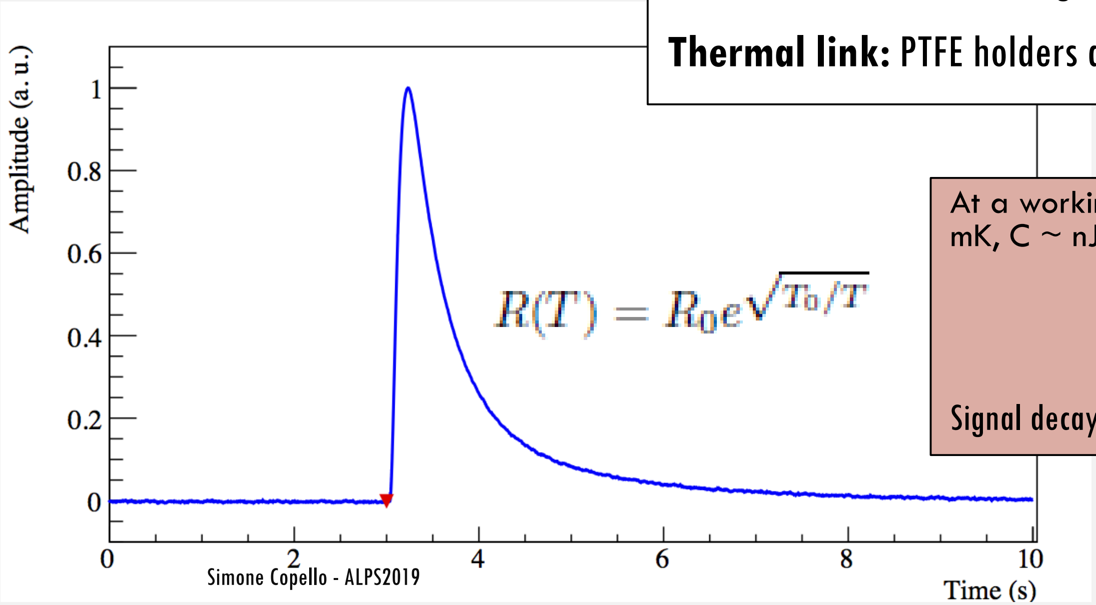
Absorber: 5x5x5 cm^3 TeO_2 crystal

Thermistor: NTD Ge semiconductor

Thermal bath: Cu structure (cryostat)

Joule heater for thermal gain calibration

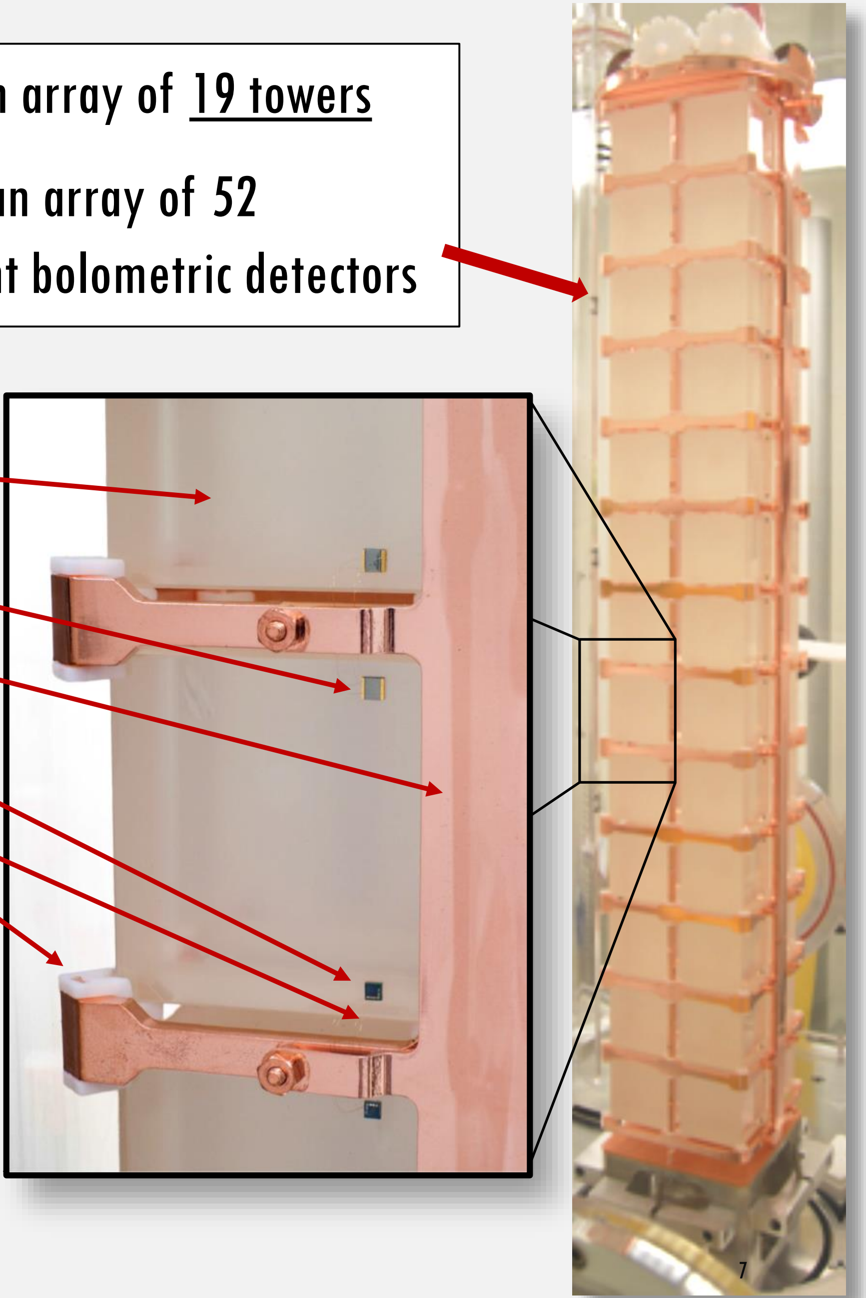
Thermal link: PTFE holders and gold wires



At a working temperature of 10 mK, C ~ nJ/K

$$\frac{\Delta T}{E} \sim \frac{100\ \mu K}{MeV}$$

Signal decay time ~1 s



CRYOGENIC INFRASTRUCTURE

Hall A @ LNGS

Suspension system (minus-K®)

Main Support Plate

Cryostat

External lead shield

Polyethylene

Concrete walls

Seismic isolators

The CUORE detector is hosted in a cryogen free cryostat:

- Operating temperature ~ 10-15 mK
- Designed to guarantee extremely low radioactivity and low vibrations environment

The cryostat is suspended inside a clean room, and the external shielding (~70 ton) can be lifted up before the data taking.

CUORE CRYOSTAT

The biggest cryogen free cryostat ever built.

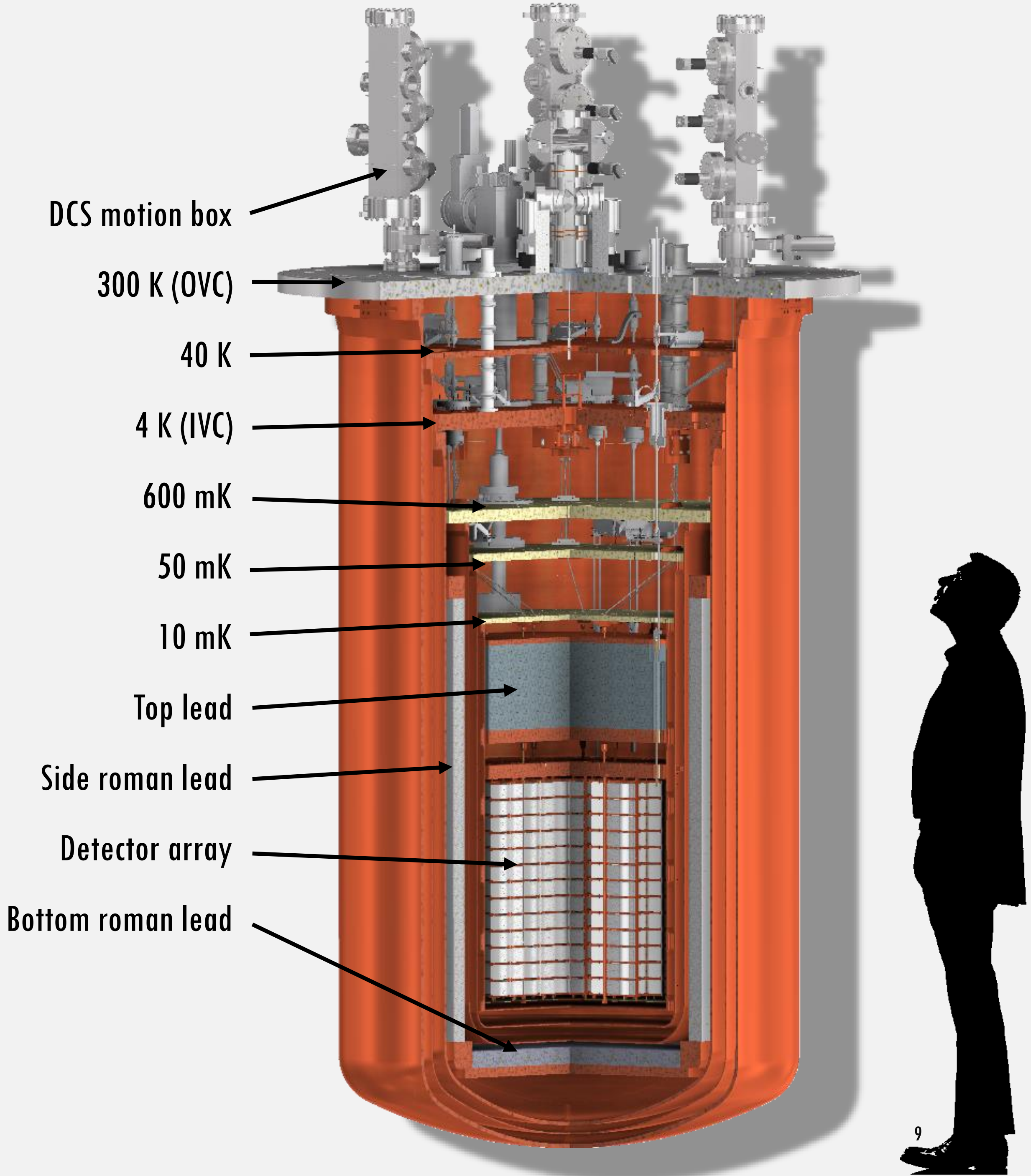
Paper under submission (arXiv:1904.05745)

Total mass: ~30 tons

- Mass < 4K: ~15 tons
- Mass < 50 mK: ~3 tons
- Mass at ~10 mK: ~1 ton

Cool down procedure:

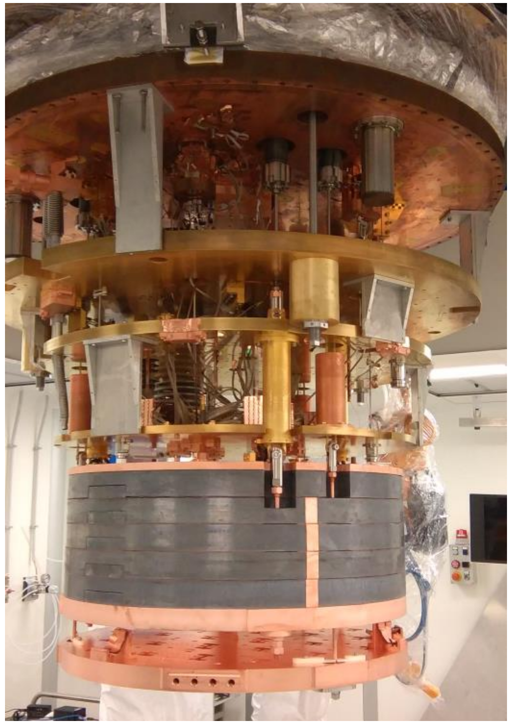
- Fast Cooling System (^{4}He) down to ~50 K
- 5 Pulse Tubes down to ~4 K
- Dilution refrigerator (^{4}He + ^{3}He) down to ~10 mK (working temperature)

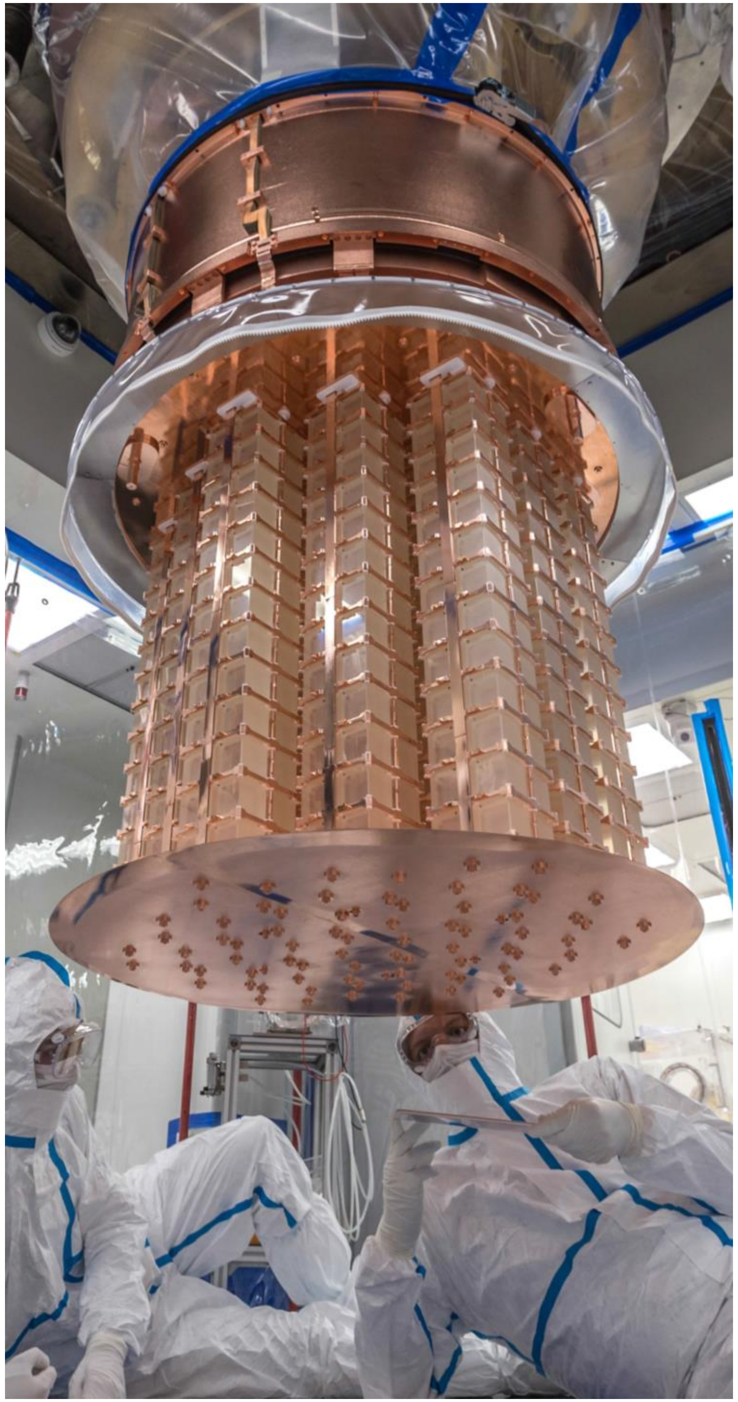


COMMISSIONING

- Tower assembly performed in N_2 atmosphere to prevent contamination from Rn
- Lateral and bottom shielding with 6 cm-thick ^{210}Pb – depleted roman lead
- Cryogenic system commissioning completed in March 2016:
  - Stable base temperature @ 6.3mK
  - Cooling power: > 3µW @10mK
- The 19 towers were installed in a radon free clean room. It took about one month. Only 4 out of 988 channels were lost during the installation.

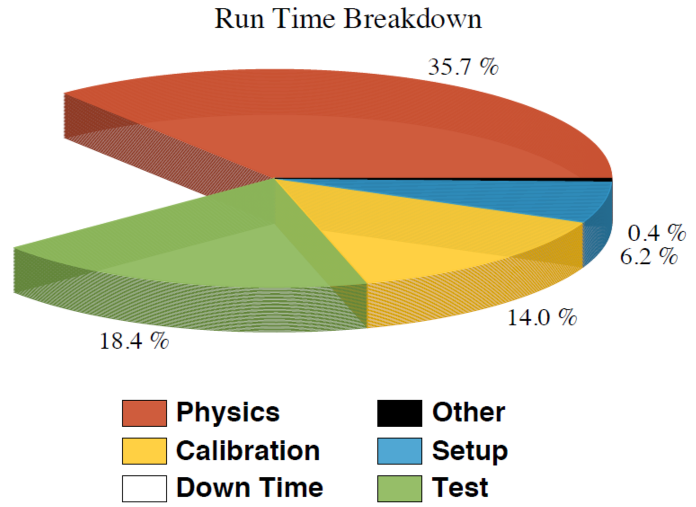
In September 2016 we were ready to cool down



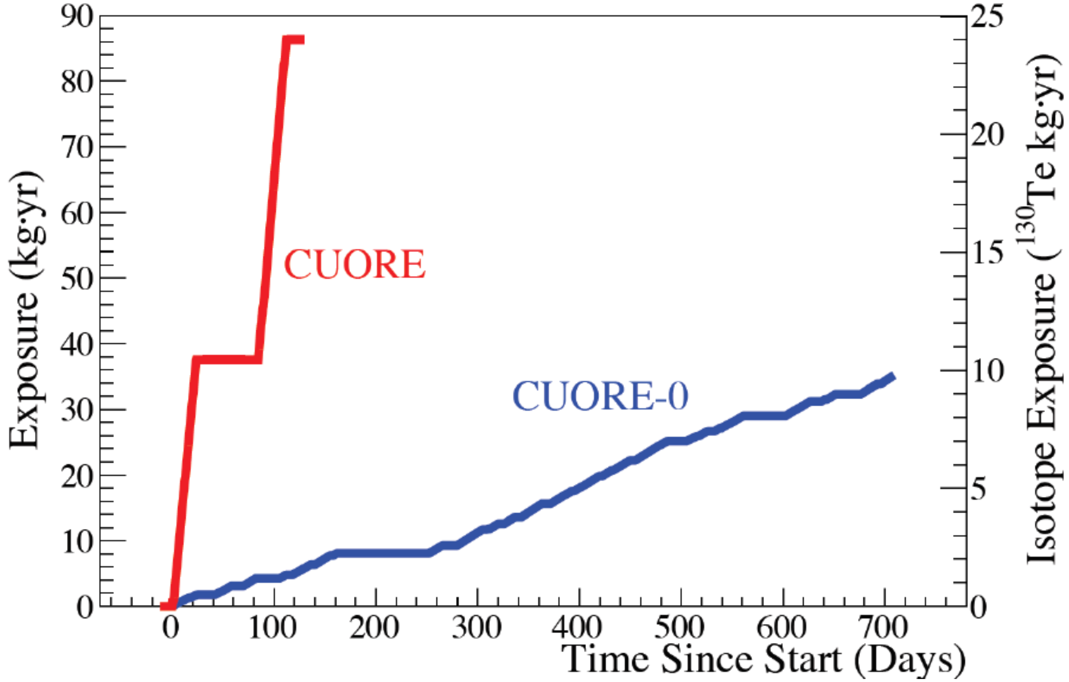


FIRST DATA RELEASE

- CUORE surpassed CUORE-0 exposure in about 3 weeks of data taking
- Collected 86.3 kg·yr of TeO_2 splitted in two datasets
- 99.6% of channels active (984/988)



- 92% of channels passing analysis cuts
- Energy resolution of 7.7 keV FWHM
- Signal efficiency of ~80%
- Average rates per channel: calibration: ~50 mHz, physics: ~6 mHz



Reconstructed energy (keV)

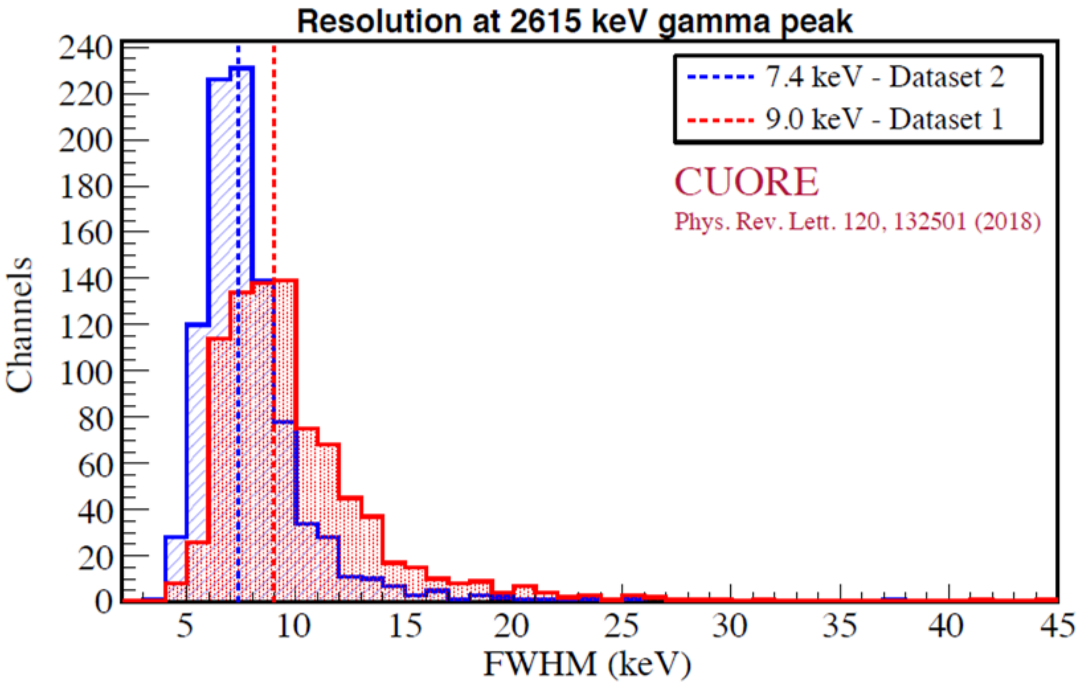
DETECTOR OPTIMIZATION

Temperature scan:
Chose temperature that optimizes the signal and at the same time allows to work with the designed thermistor resistance (this analysis @ **15 mK**)

Working point and Load Curves:
scan to choose the best bias current to feed each channel thermistor: linear behaviour for small temperature variations maximization of signal to noise ratio optimization of pulse amplitude

Optimization of trigger thresholds:
Trigger thresholds ranging from 20 to a few hundred keV

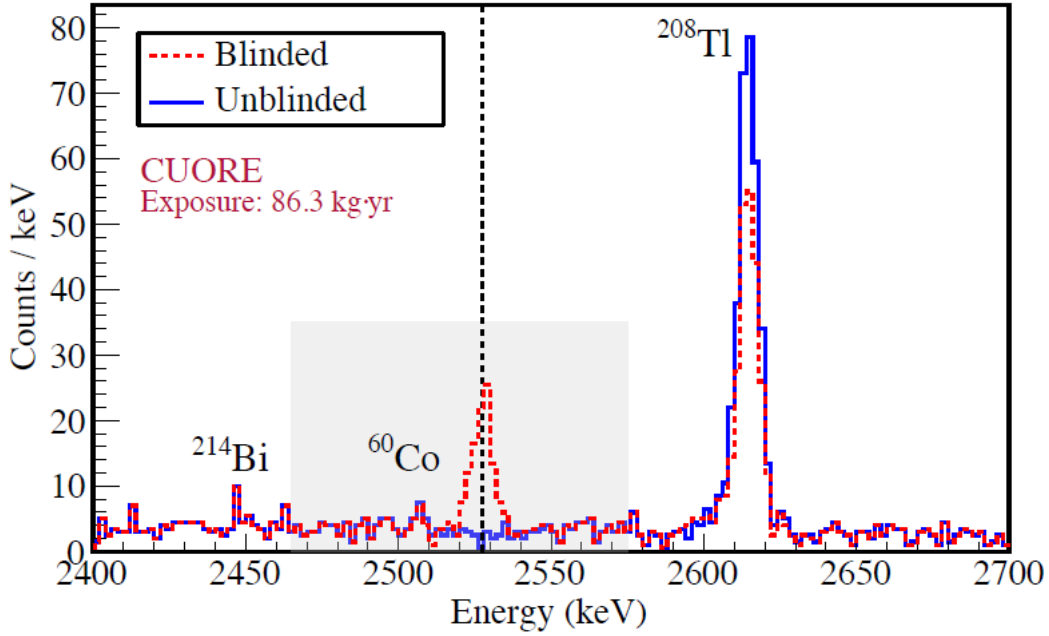
Attenuation of Pulse tube induced vibrations:
The 5 Pulse Tubes are synchronized in the minimum noise phase configuration *Cryogenics 93 (2018) 56–65*



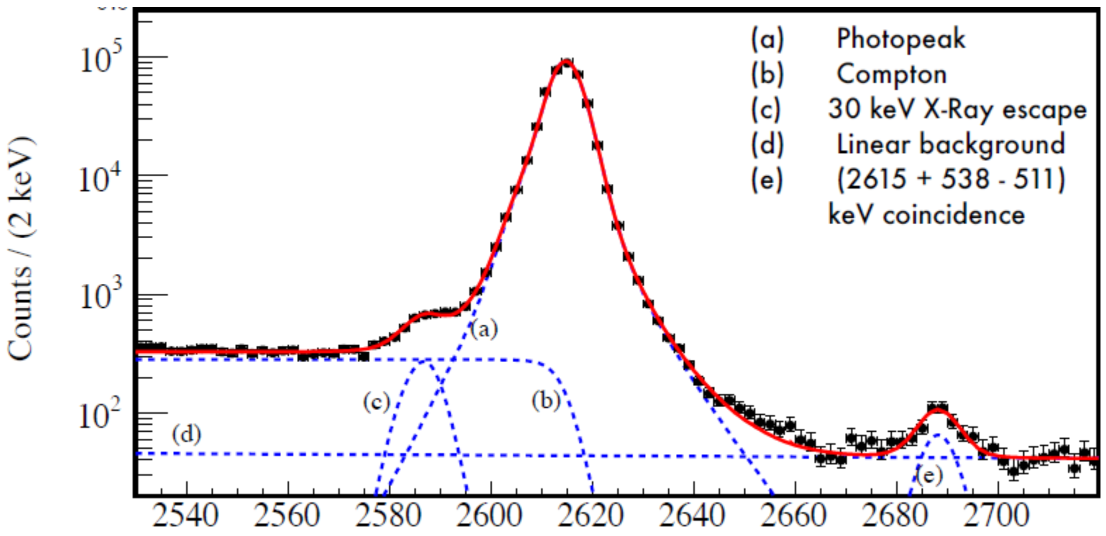
ANALYSIS

Main steps are:

- Amplitude Evaluation
- Thermal gain stabilization
- Energy calibration
- Select events with multiplicity = 1
- Pulse shape analysis selection
- Blinding
- Line shape fit



Tl peak, sum over all the active channels



0νββ RESULTS

- ^{60}Co peak position: (2506.4 ± 1.2) keV
- Background index is consistent with expectations:
  (1.4 ± 0.2) x 10^{-2} cnts/(keV·kg·yr)
- Median expected sensitivity
  $T^{0\nu}_{1/2} = 7.0 \times 10^{24}$ yr

Signal decay rate best fit:

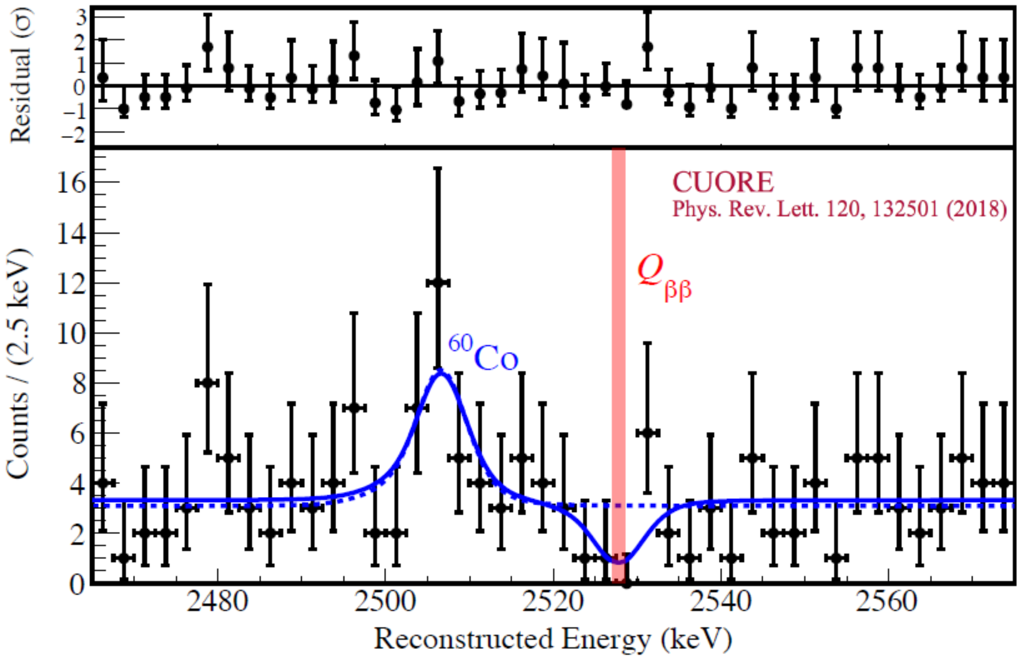
$$\Gamma^{0\nu} = (-1.0\ ^{+0.4}_{-0.3}\ (stat) \pm 0.1\ (syst)) \times 10^{-25}\ yr^{-1}$$

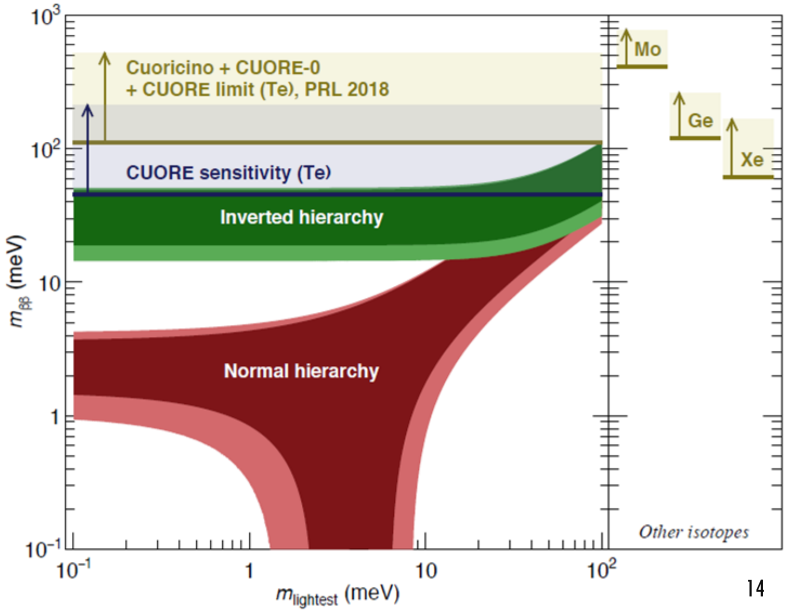
Combined limit (CUORE+CUORE-0+Cuoricino):

$T^{0\nu}_{1/2} > 1.5 \times 10^{25}$ yr ⟷ $m_{\beta\beta} < 110 - 520$ meV

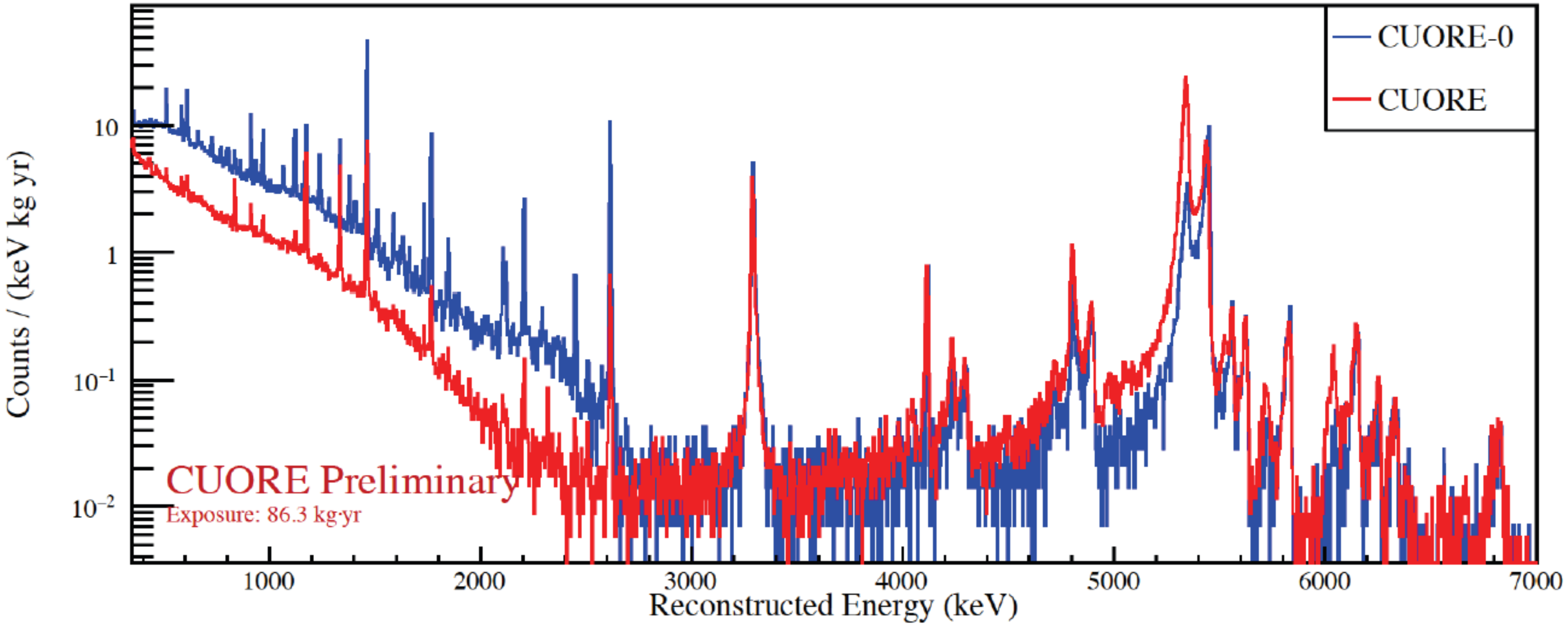
PRL 120, 132501 (2108)

UEML fit in the ROI (2465 - 2575) keV:





BACKGROUND MODEL



- γ background significantly reduced
- Backgrounds consistent with expectations
- ^{210}Po excess appears to be from shallow contamination in copper around the detectors
- Current estimated contribution to ROI at the level of ~ 10^{-4} cnts/(keV kg yr)

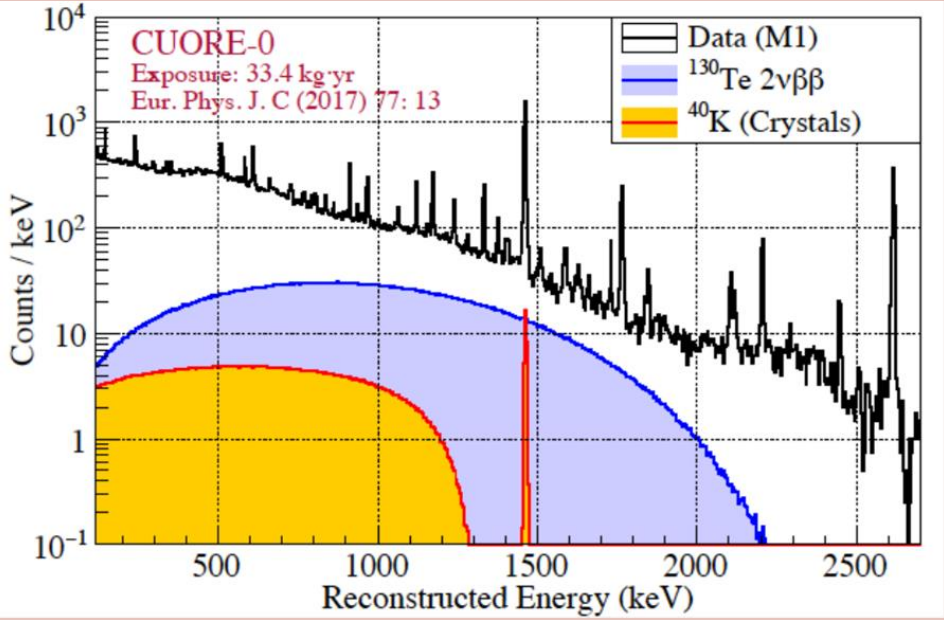
The background model is able to reconstruct the major features of the observed spectrum in CUORE

CUORE

2νββ RESULTS

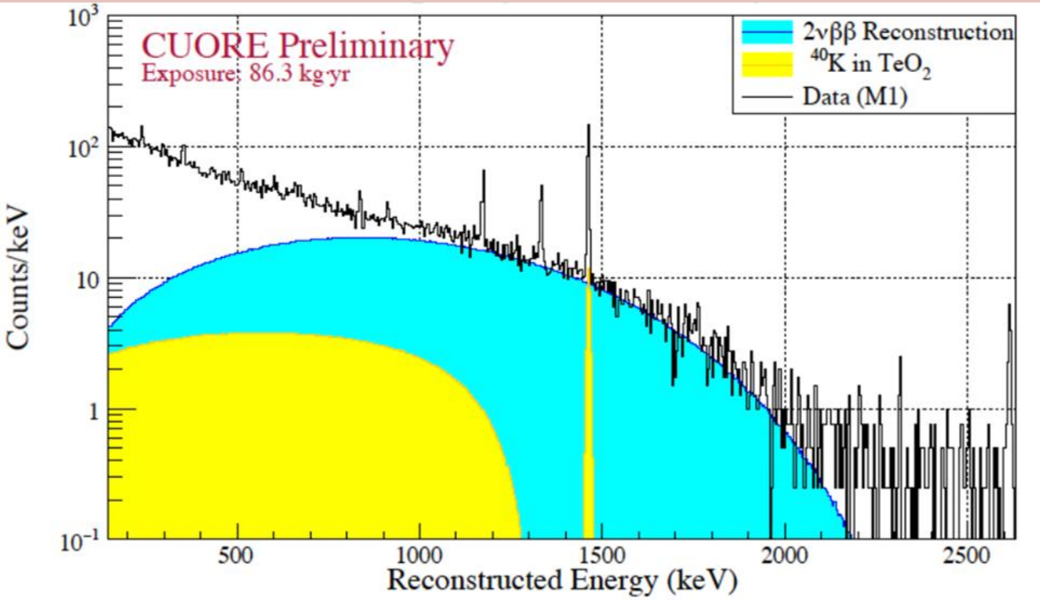
Paper in preparation

In **CUORE-0**, 2νββ decay spectrum accounts for ~20% of the signal in the range 1-2 MeV



$T^{2\nu}_{1/2}$ = [8.2 ± 0.2 (stat.) ± 0.6 (syst.)] x 10^{20} yr

In **CUORE**, Data is split in outer and inner layer and M1 and M2 spectra. The 2νββ spectrum accounts for nearly all of the signal in the range 1-2 MeV in M1 in the inner 252 channels



$T^{2\nu}_{1/2}$ = [7.9 ± 0.1 (stat.) ± 0.2 (syst.)] x 10^{20} yr

NEMO: $T^{2\nu}_{1/2}$ = [7.0 ± 0.9 (stat.) ± 1.1 (syst.)] x 10^{20} yr

CONCLUSIONS

The first result from the CUORE experiment

- Published in 2018 on PRL 120, 132501

Scientific:

- Most stringent limit on 0νββ decay half-life of 130Te to date
- Most accurate measurements of 2νββ decay half-life of ^{130}Te

Technical:

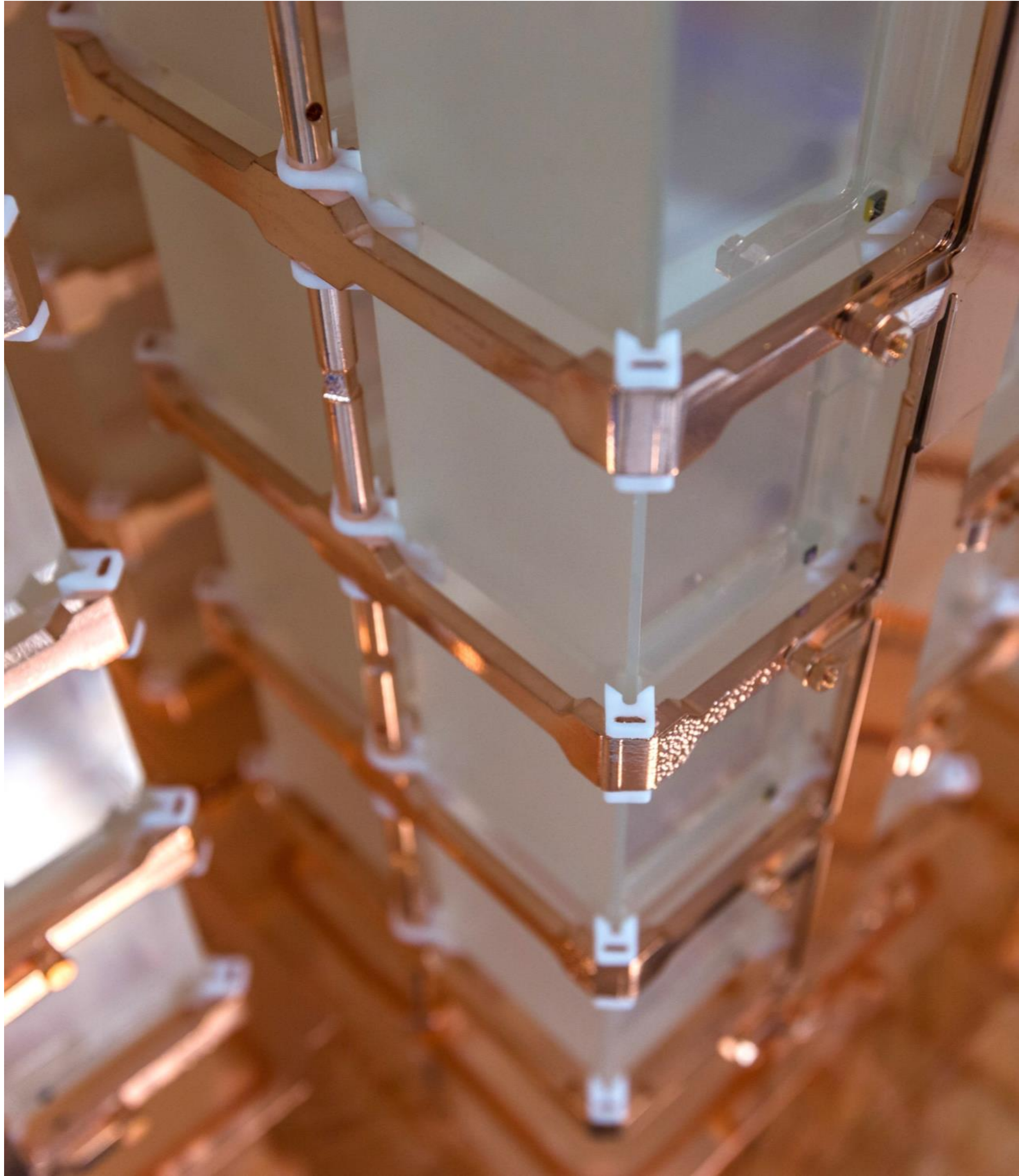
- operation of the world's first ton-scale bolometric detector
- construction and operation of the world's largest and most powerful dilution refrigerator

The present:

- Analysis ongoing on the data collected in 2018 at 11mK
- New 2019 dataset just started

The future:

- 5 years of live time planned
- New analyses (dark matter, axions…)
- CUPID (CUORE Upgrade with Particle Identification)



THANK YOU!