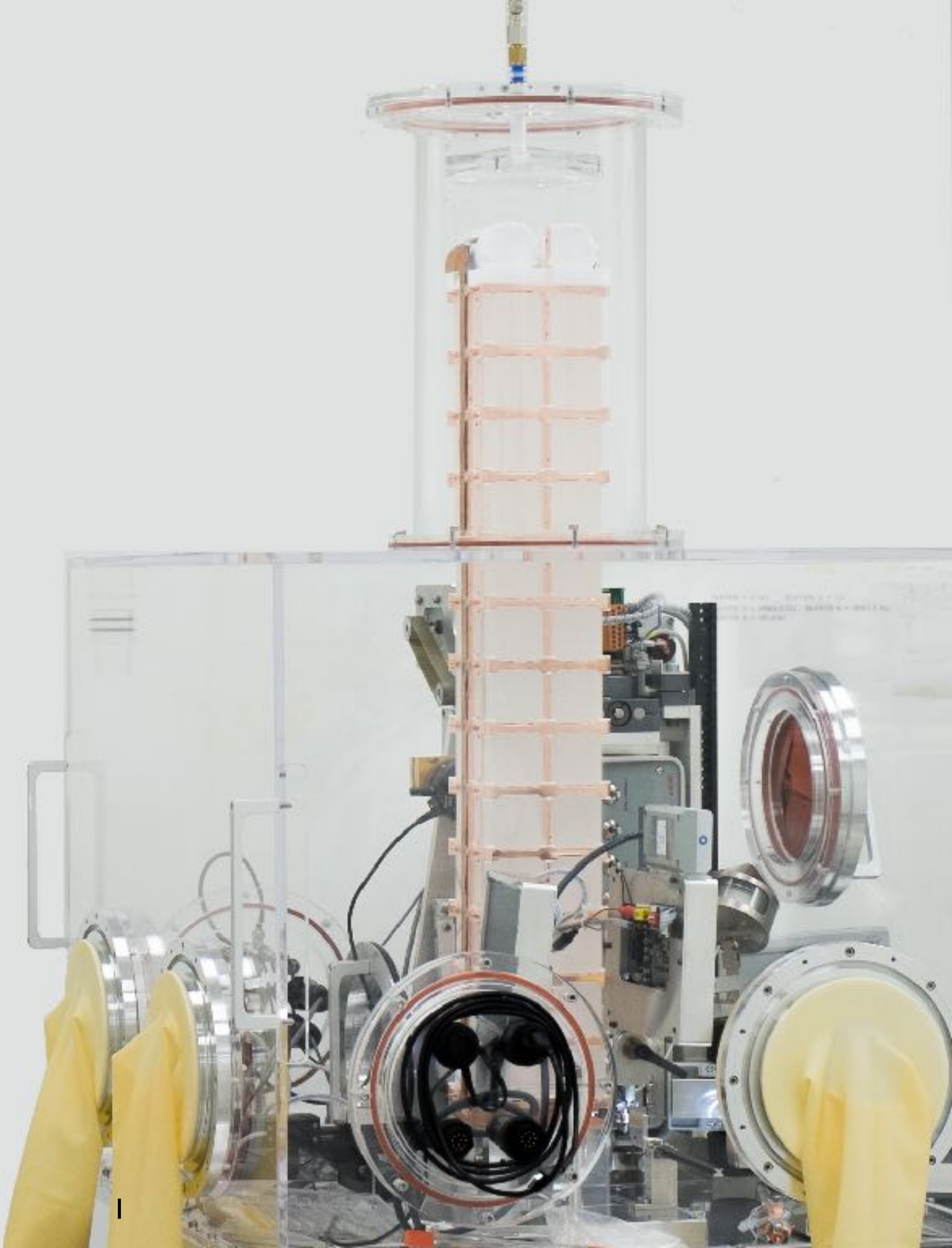
Results from

CUORE



Dr. Laura Gladstone
MIT Laboratory for Nuclear Science

Lake Louise Winter Institute
February 2017

The Experimental Challenge

- These searches require:
  - large target masses
  - long measurement time
  - low backgrounds

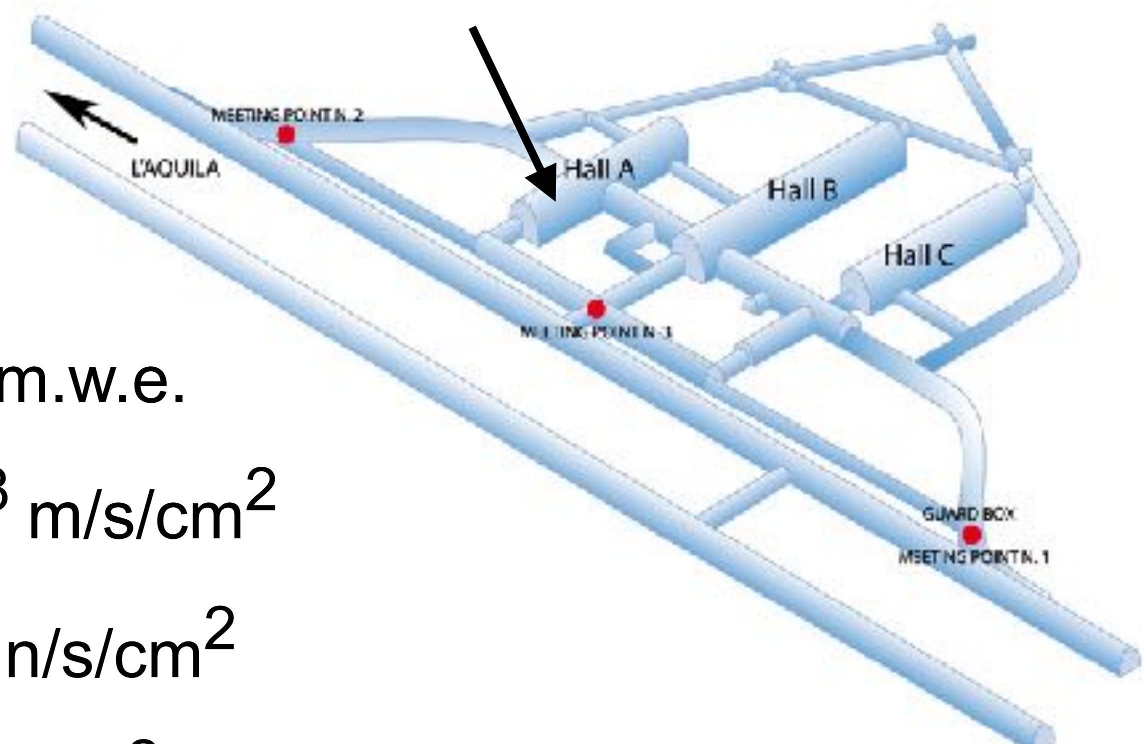
Long Time Scales:

	^{14}C	10^4 years
	^{40}K	10^9 years
	^{232}Th	10^{10} years
	The Universe	10^{10} years
background	Two Neutrino Double Beta	10^{20} years
signal	Neutrinoless Double Beta	$>10^{26}$ years
	Proton Decay	$>10^{34}$ years

Gran Sasso National Lab

Backgrounds from cosmic rays are rare and easily removed from data

CUORE



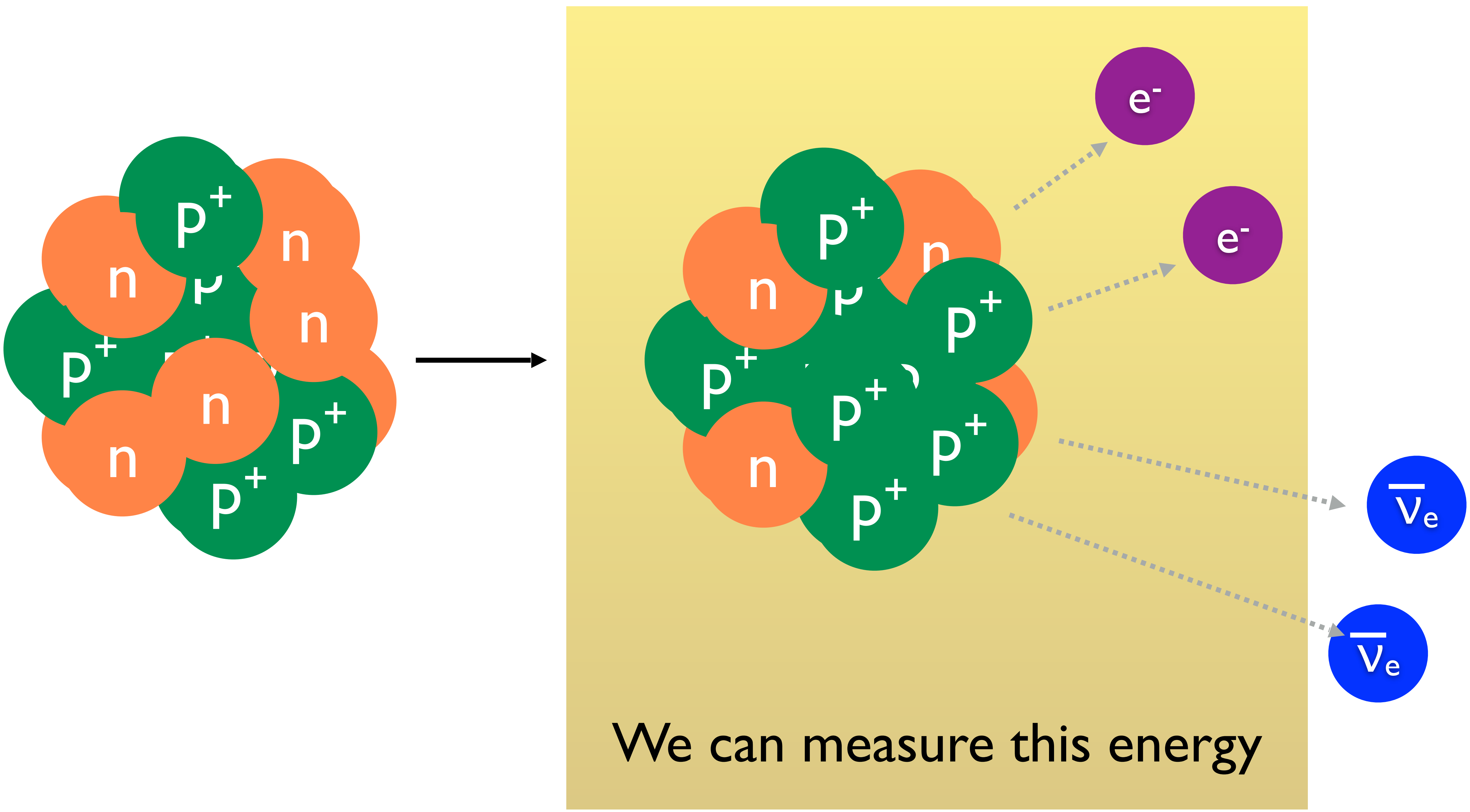
Average depth ~ 3600 m.w.e.

μ flux: $(2.58 \pm 0.3) \cdot 10^{-8}$ m/s/cm^2

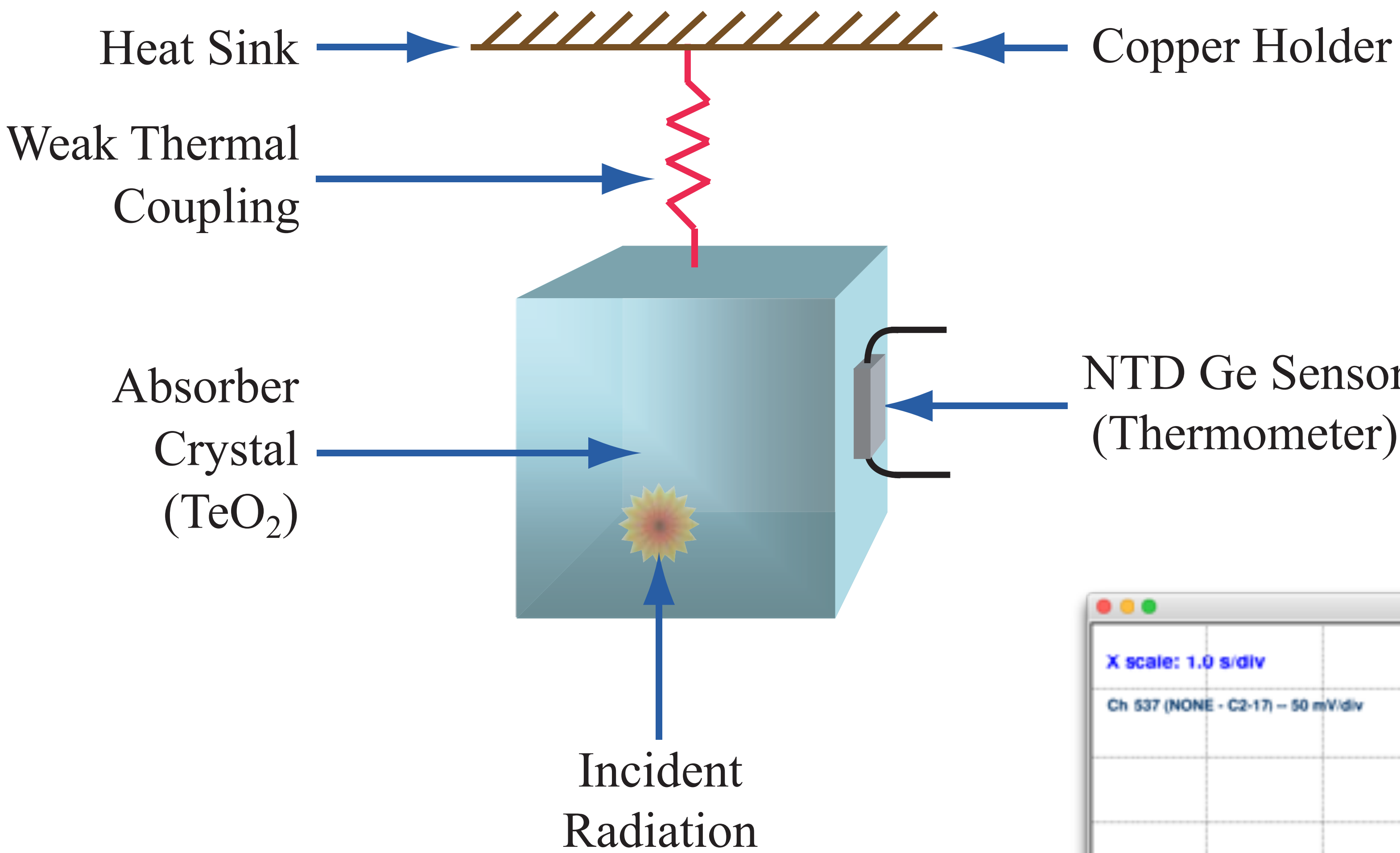
n flux <10 MeV: $3 \cdot 10^{-7}$ n/s/cm^2

γ flux < 3 MeV: 0.73 g/s/cm^2

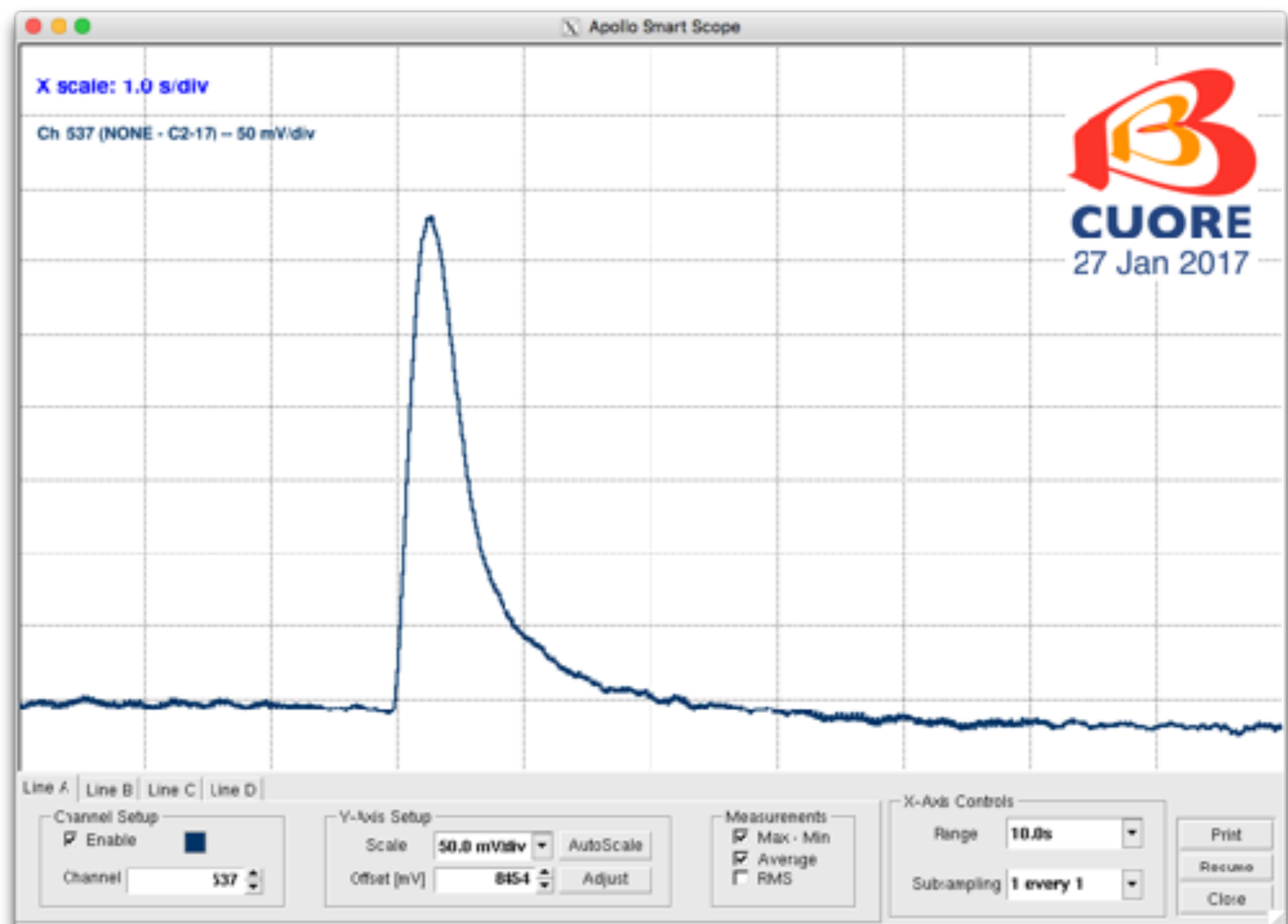
Double Beta Decay



Bolometers measure total heat



First pulse!

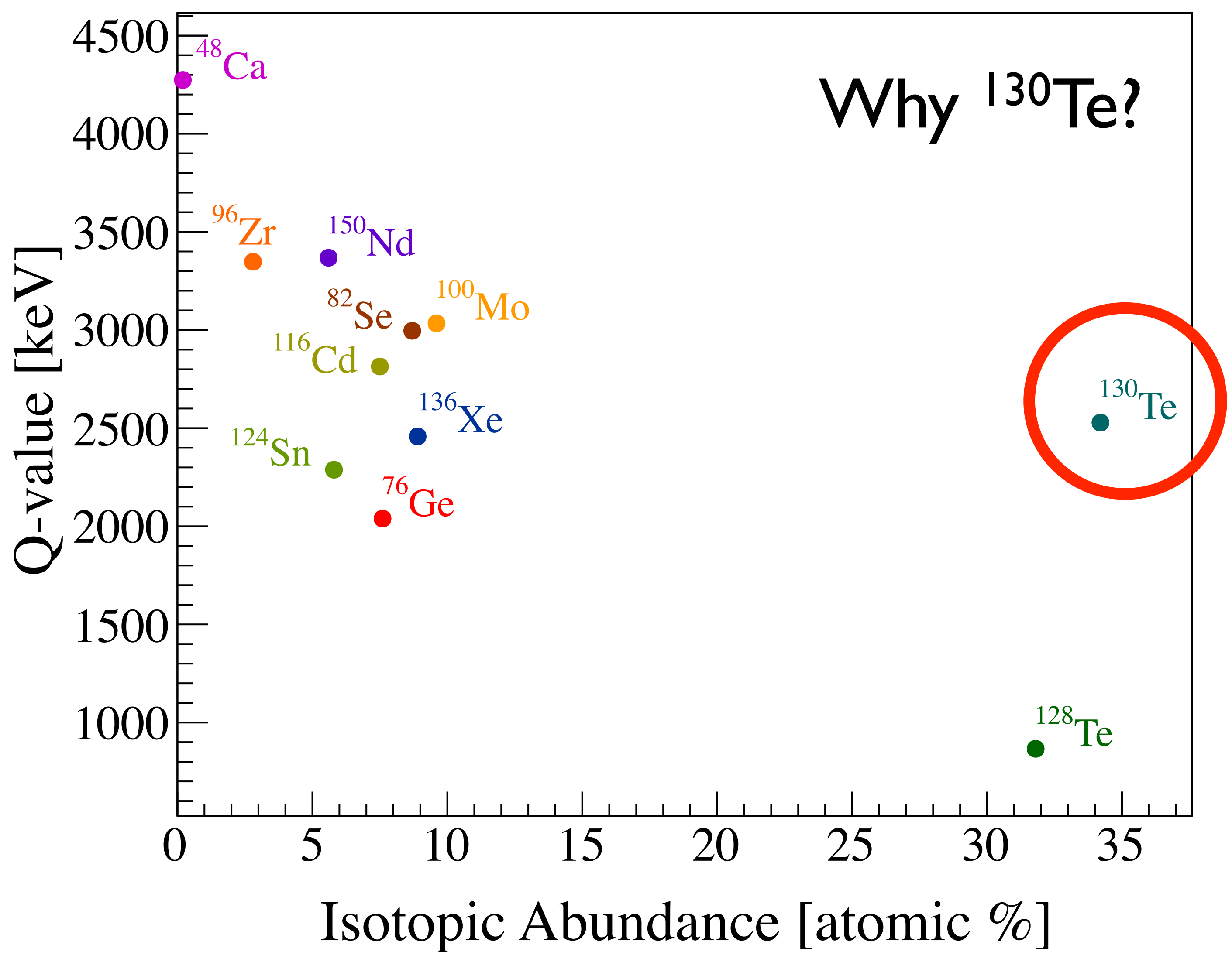


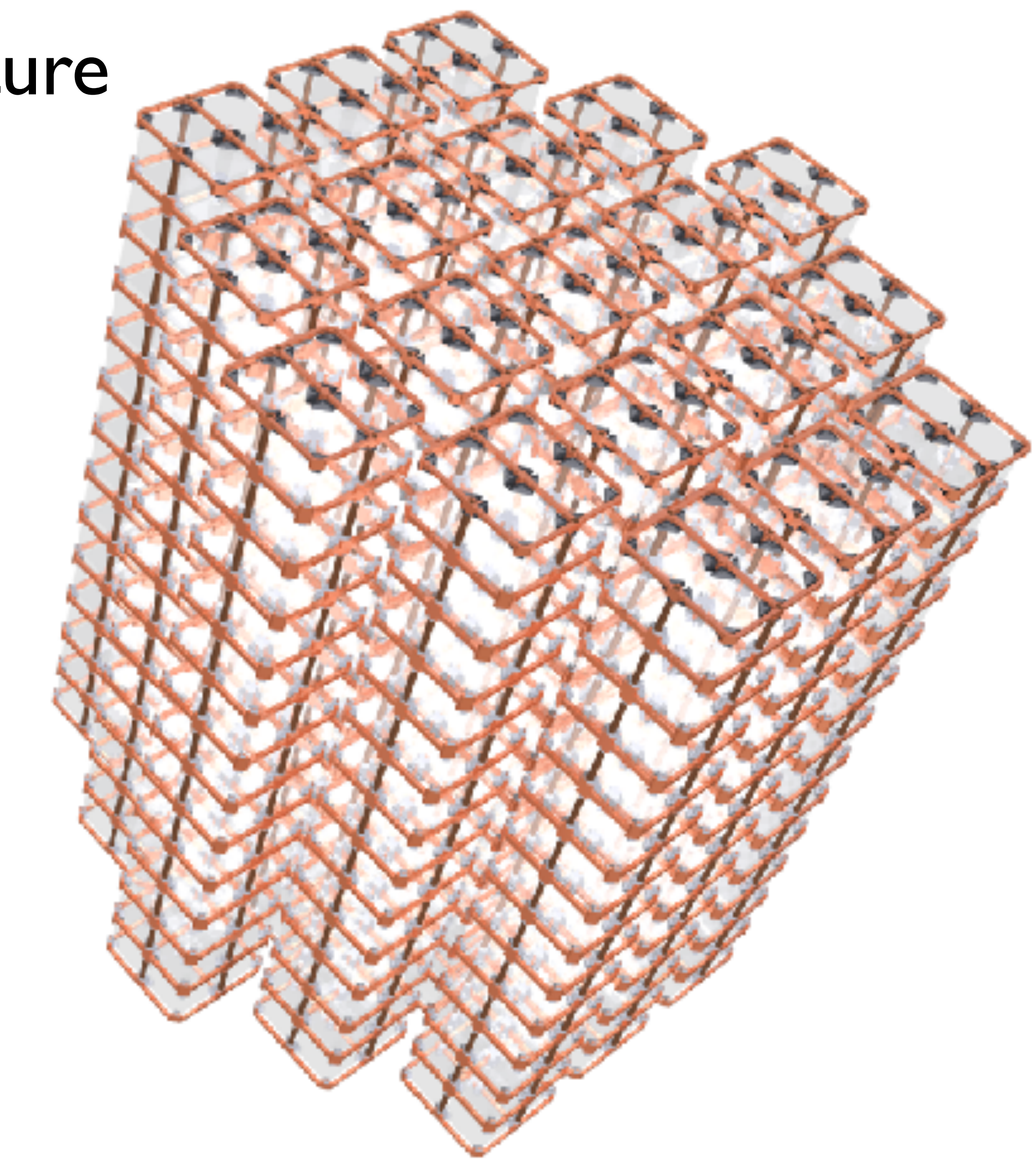
Need a cold environment for:

- low baseline heat
- low heat capacity: $C \propto T^3$

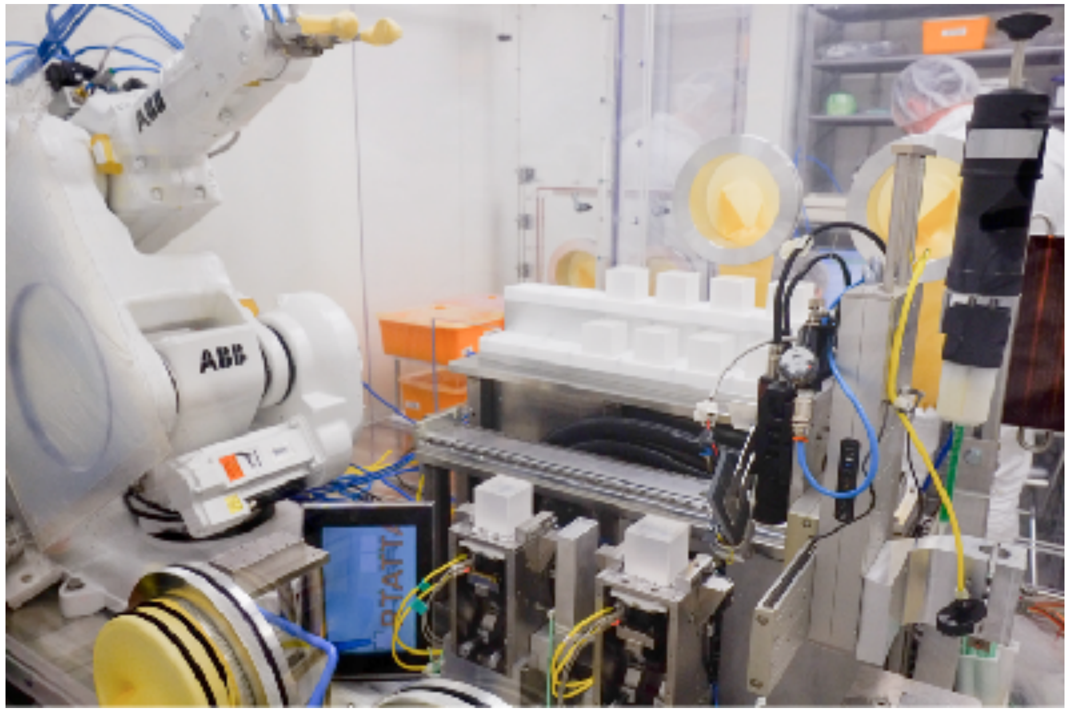
CUORE is an array of bolometers

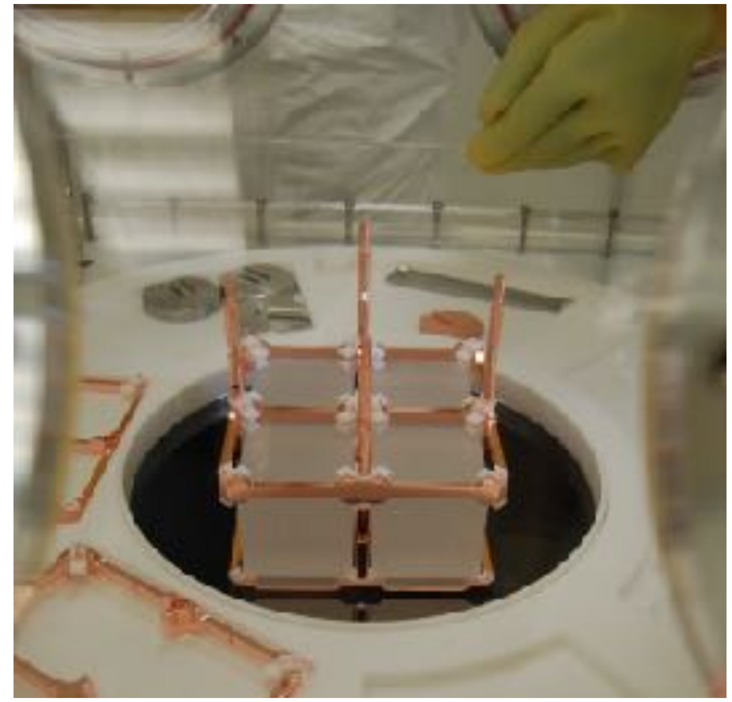
- "Cryogenic Underground Observatory for Rare Events"
- 988 TeO_2 crystals operated as bolometers
- 742kg TeO_2, 206 kg ^{130}Te
- Copper and PTFE (teflon) support structure





Detector Construction



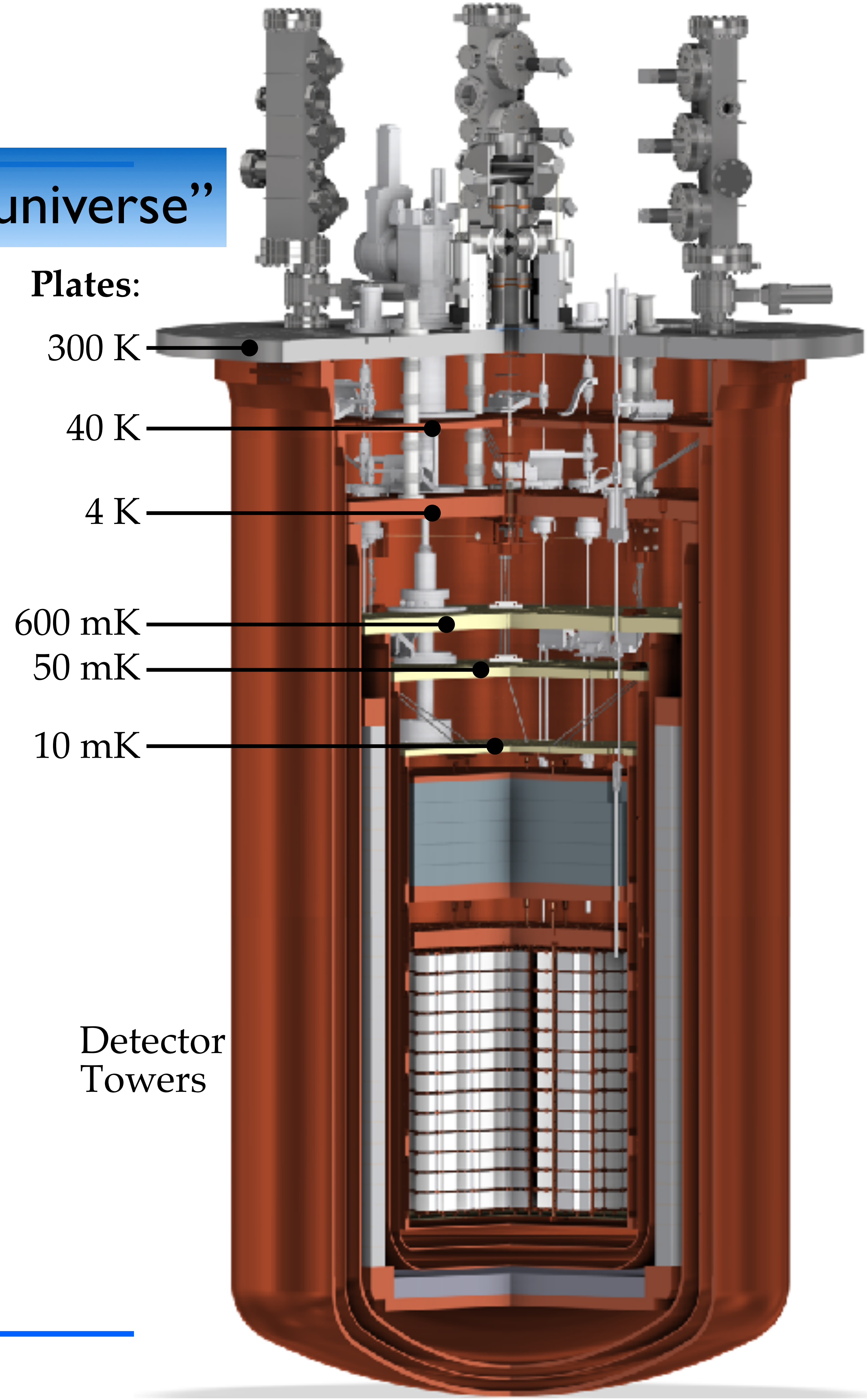


- Ultra-pure source materials
- Ship, don't fly, to Gran Sasso
- Apply sensors and heaters with a robotic arm to ensure consistency
- Only handle crystals in N_2 environment

CUORE Cryostat

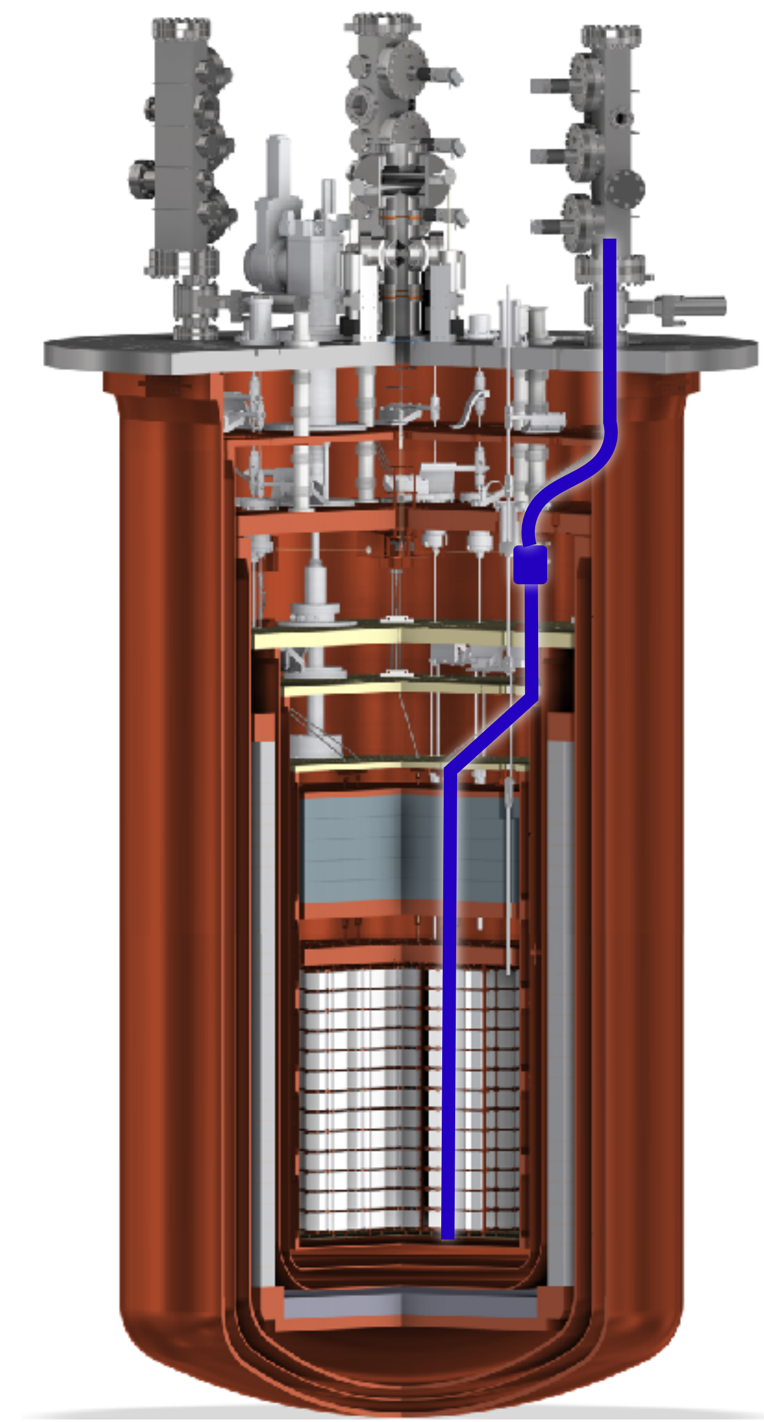
"The coldest cubic meter in the known universe"

- Long term stability, completed March 2016
- Helium dilution cooling and 5 pulse tubes
- Cooling power: 3mW @10mK
  - 300K to 4 K ~ 2.5 weeks
  - 4K to 10 mK ~ 1/2 week
- Lots of shielding:
  - 2.1t modern lead @50mK
  - 4.6 t roman lead @4K
  - 35 cm external lead
  - 18 cm PET, 2cm H_3BO_3



Detector Calibration System

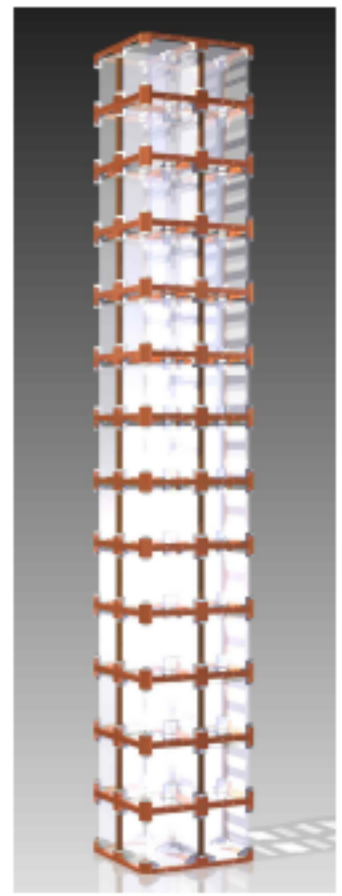
- For CUORE, we use:
  - Constant-energy pulsers to measure detector stability and correct for variations in detector gain
  - ^{232}Th γ-ray sources every ~month (239 keV to 2615 keV)
- Sources are outside cryostat during physics data-taking and lowered into cryostat and cooled to 10 mK for calibration
- Sources are put on strings and are lowered under their own weight
- A series of tubes in the cryostat guides the strings



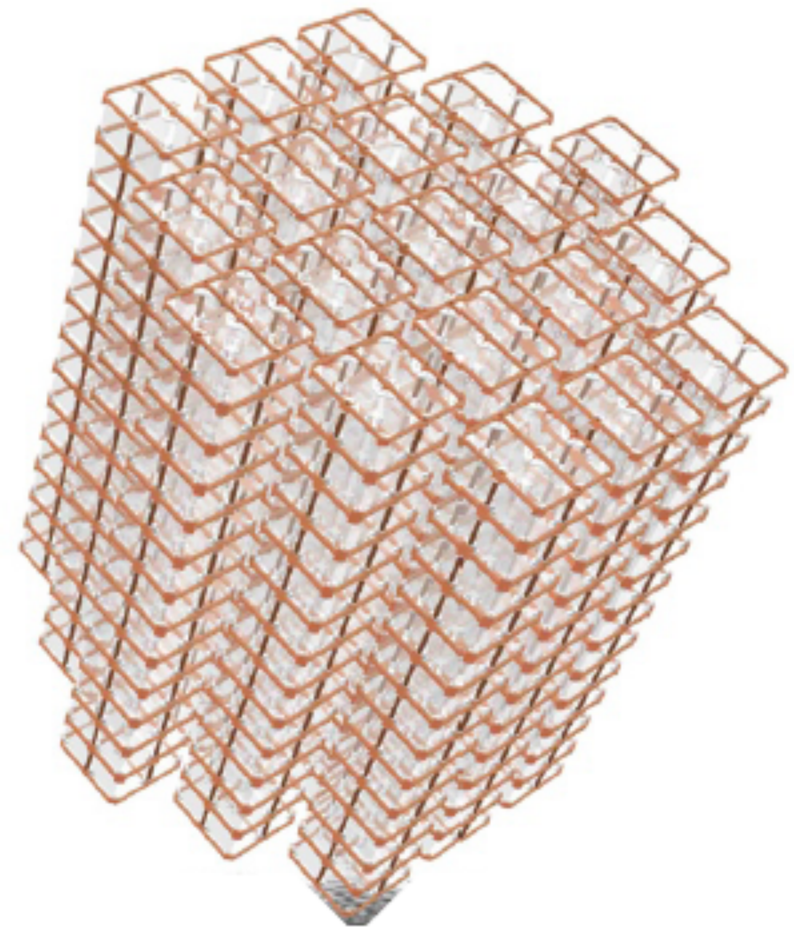
NIM A **844**, 32 (2017), arXiv:1608.01607

Generations of Bolometer Experiments

Cuoricino
2003–2008
11 kg ^{130}Te



CUORE-0
2012–2014
11 kg ^{130}Te



CUORE
2013–2018
206 kg ^{130}Te

CUORE-0: 0νββ decay results

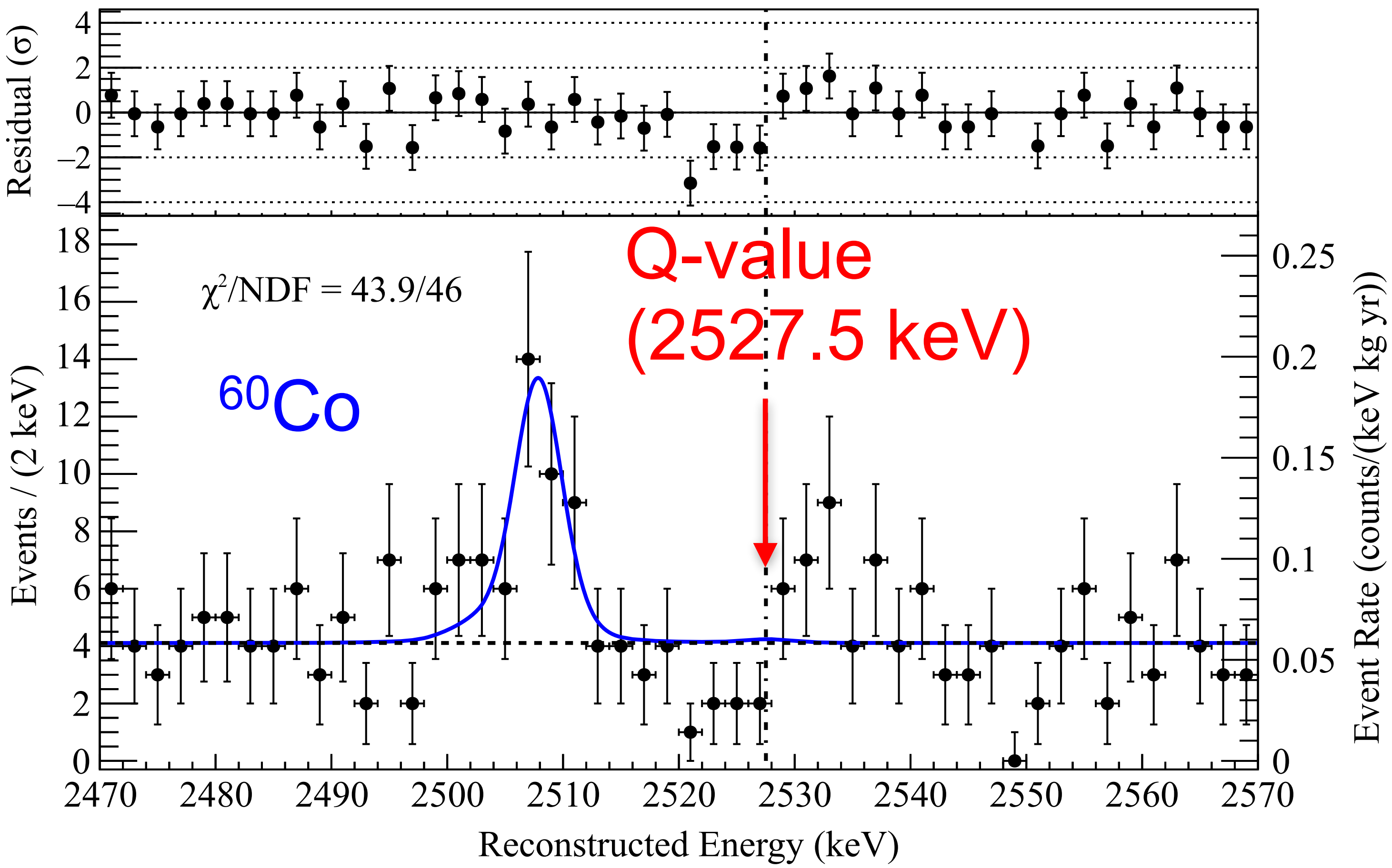
CUORE-0 regained the Cuoricino limit in 40% of the lifetime

Combined with Cuoricino: $\mathbf{T_{1/2}^{0\nu\beta\beta}\,(^{130}Te) > 4.0 \times 10^{24}}$ **y (90% CL)**

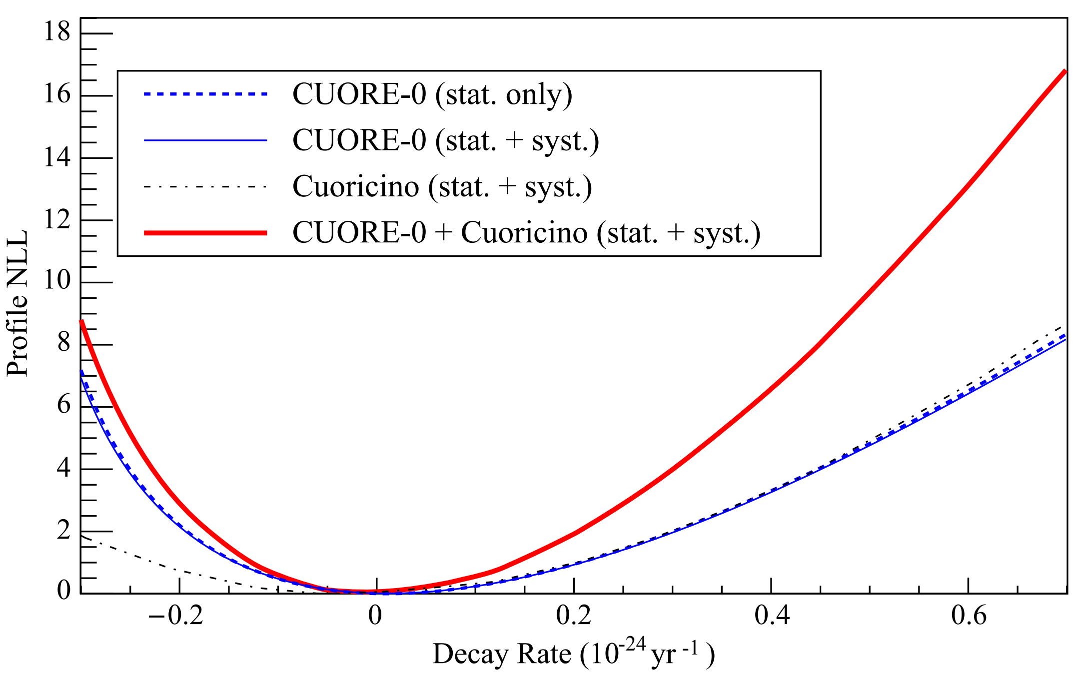
Effective Majorana Mass: $\mathbf{m_{\beta\beta}}$ **<(270-650) meV**

Validated data blinding for CUORE

CUORE analysis testbed



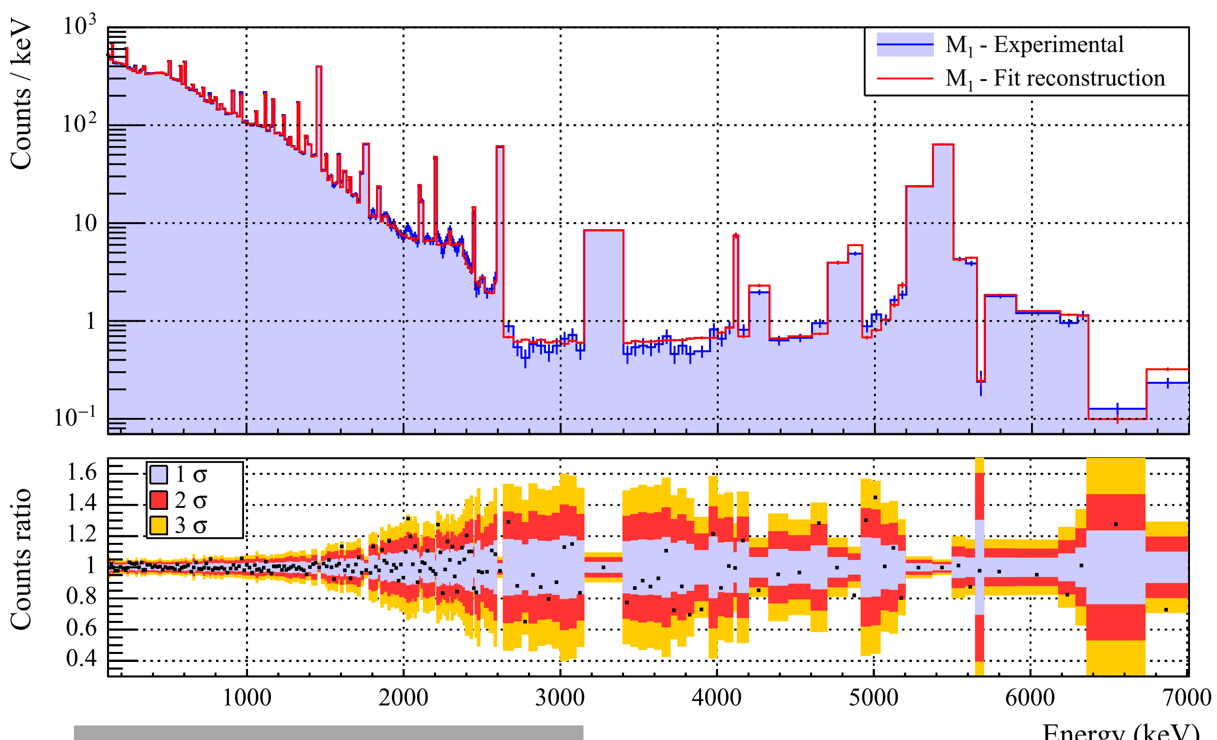
Phys. Rev. C 93, 045503 (2016)



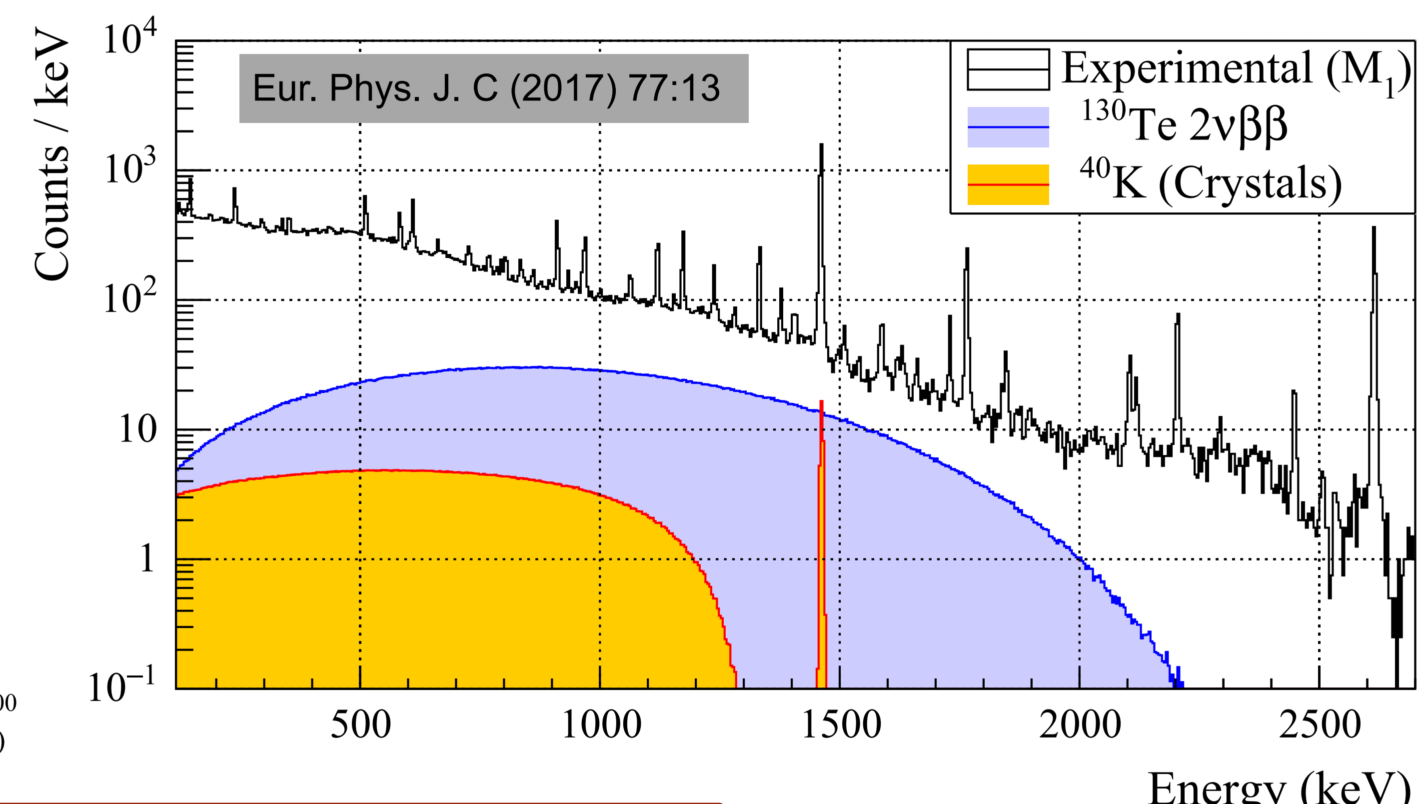
Phys. Rev. C 93, 045503 (2016)
Phys. Rev. Lett. 115, 102502 (2015)

CUORE-0 backgrounds and 2vbb

- MC-background model separates surface & bulk contamination
  - environmental gammas, muons, and neutrinos
- Find contamination levels from material screening ICPMS, HPGe counter, neutron activation analysis
- Bayesian fit to CUORE-0 data with priors from screening



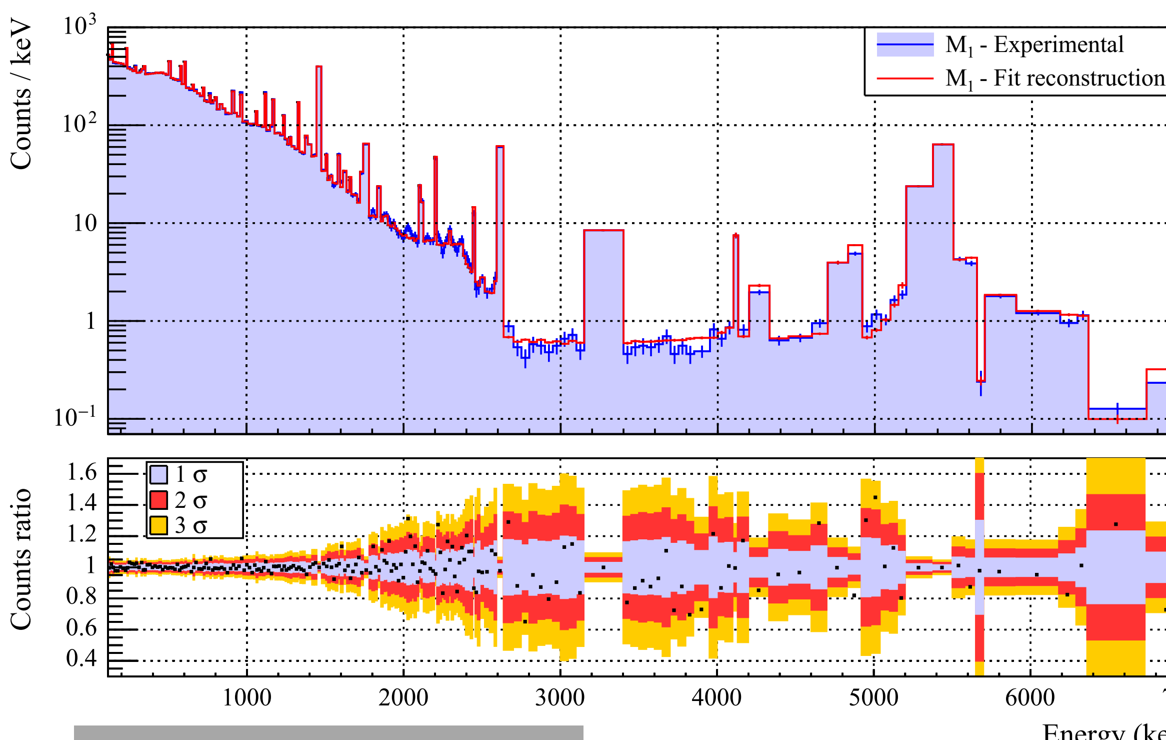
Eur. Phys. J. C (2017) 77:13



$$T_{1/2}^{2\nu\beta\beta} = [8.2 \pm 0.2(\text{stat.}) \pm 0.6(\text{syst.})] \cdot 10^{20}\text{y}$$

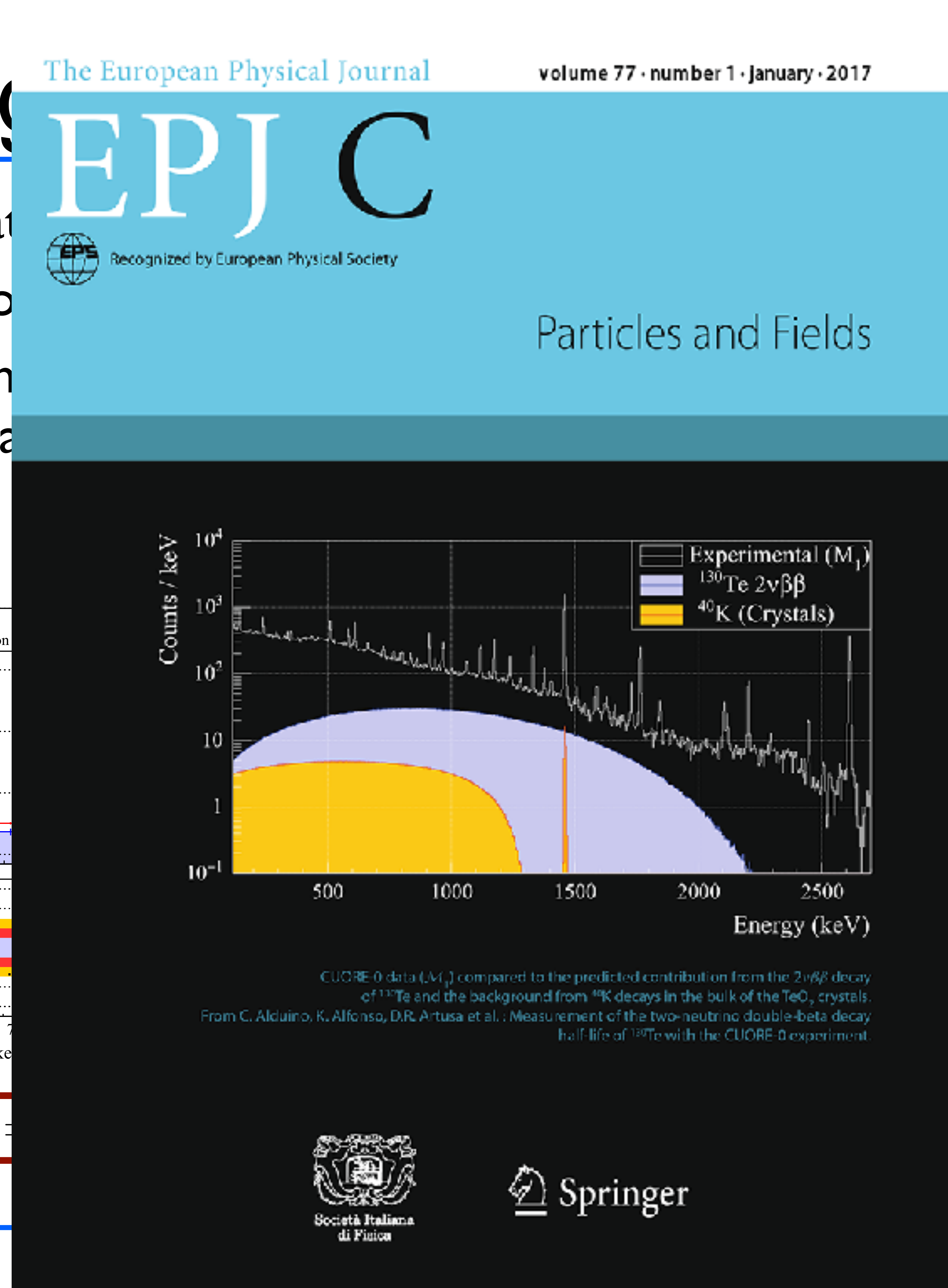
CUORE-0 backg

- MC-background model separat
  - environmental gammas, muo
- Find contamination levels from counter, neutron activation ana
- Bayesian fit to CUORE-0 data



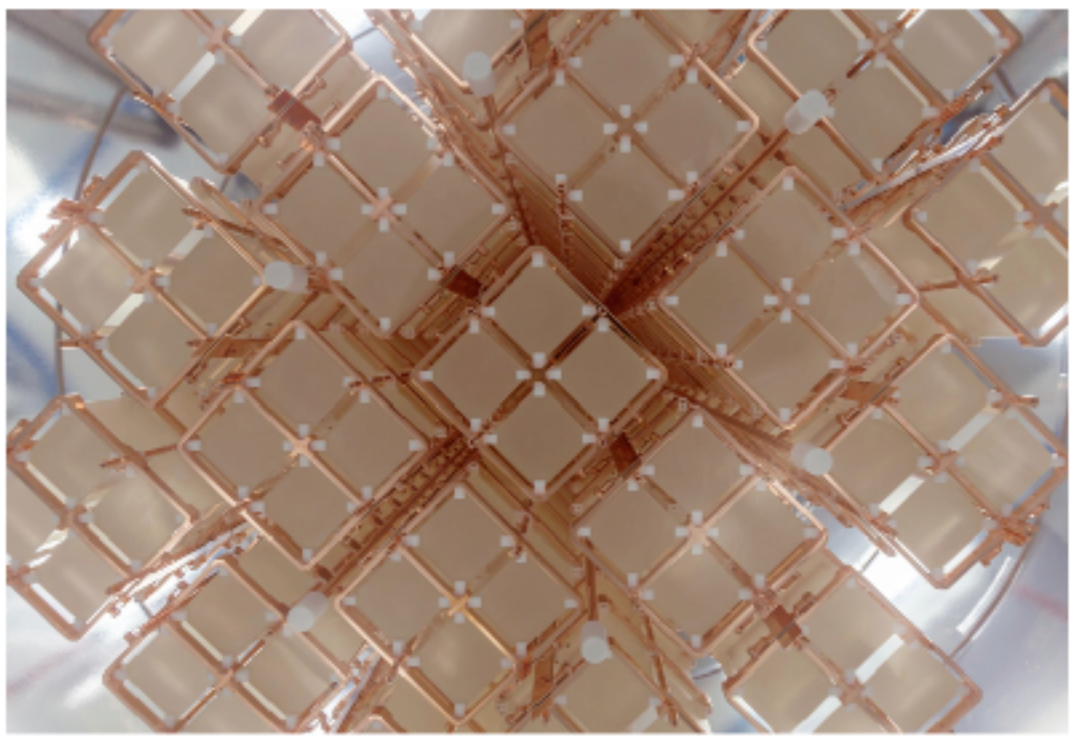
Eur. Phys. J. C (2017) 77:13

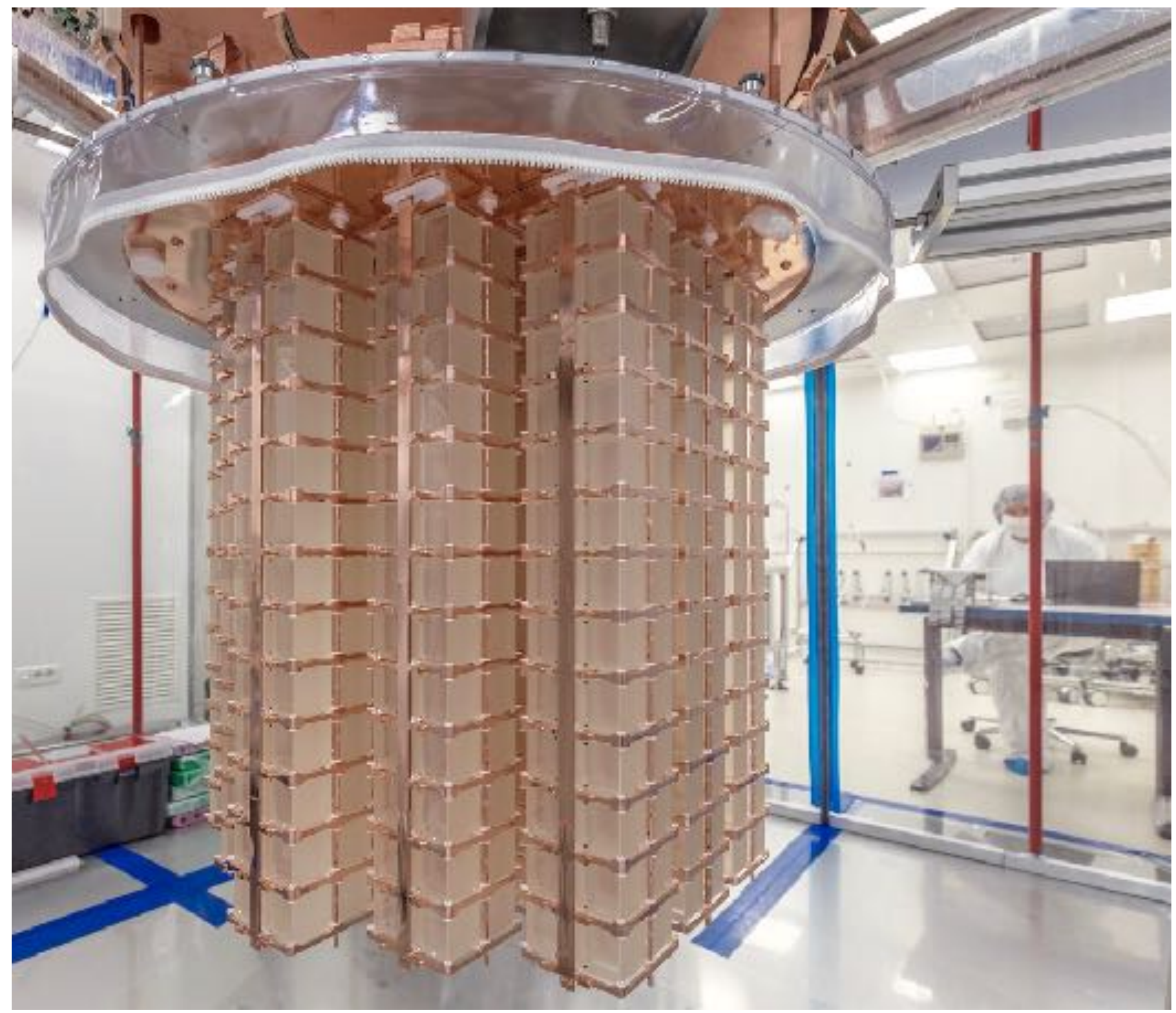
$T_{1/2}^{2\nu\beta\beta} = [8.2$



Detector Installation, Aug 2016

- Towers installed into the cryostat, the process took 1 month





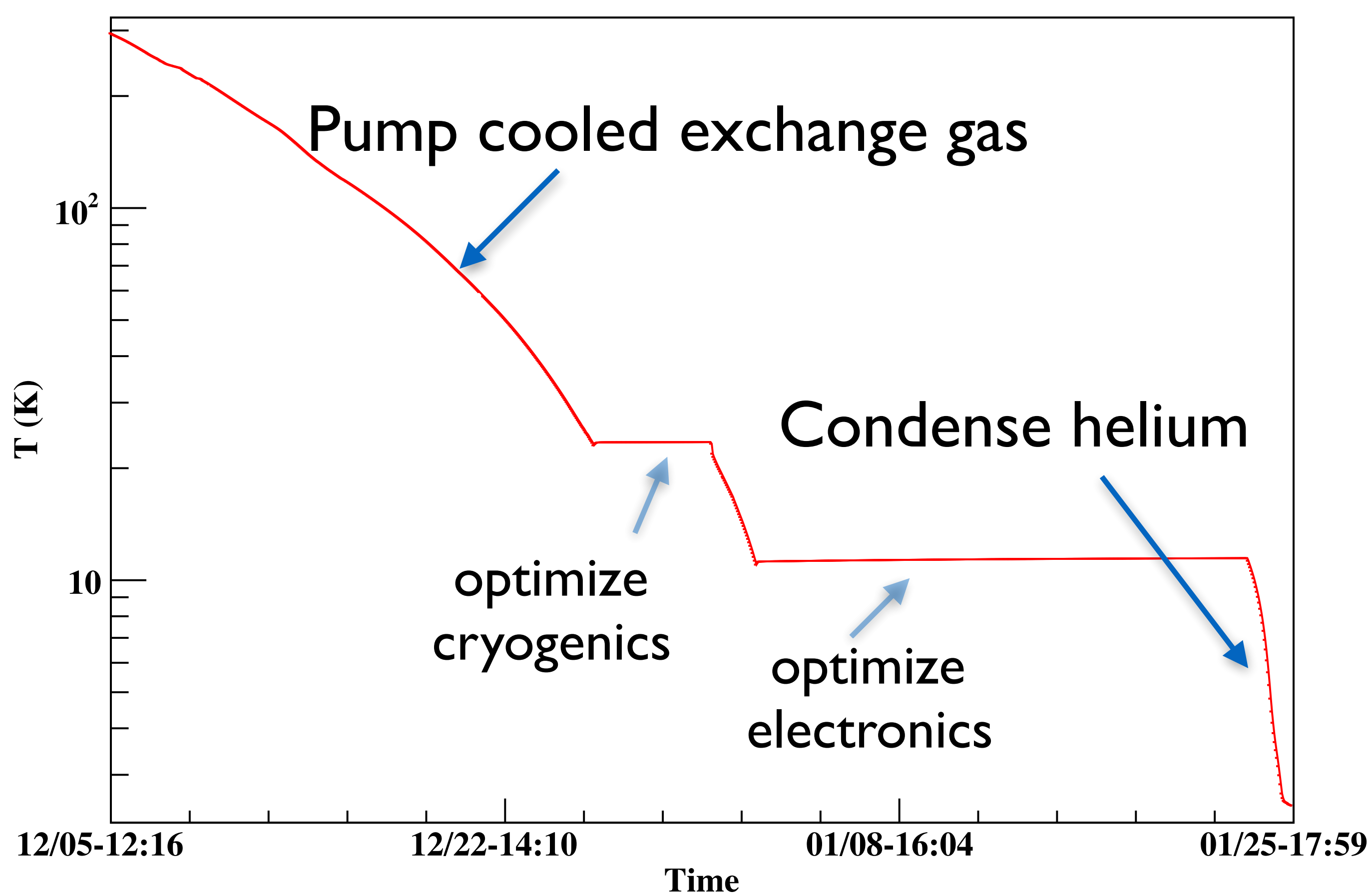
Cooling and commissioning

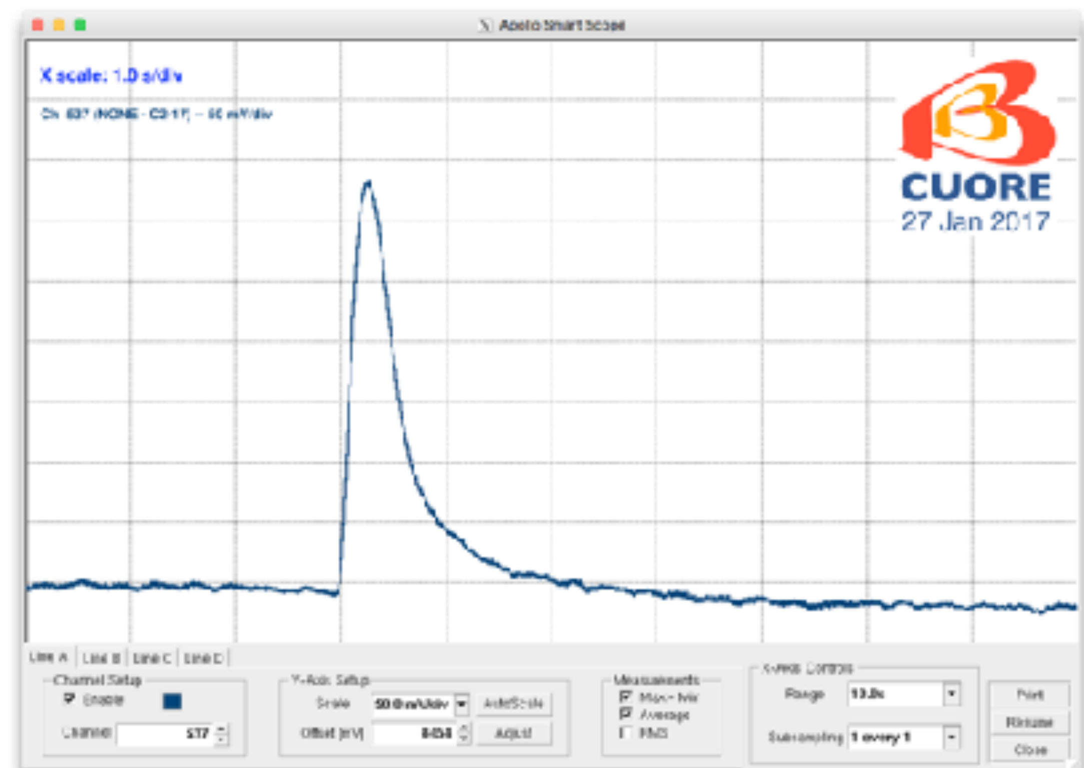
Start Dec 5

Base temperature (~7-8 mK) on Jan 26

First pulses: Jan 27

Diode thermometer at 10mK plate





Coming weeks:

- Tune the thermistor working points
- PID temperature stabilisation system
- Analyze and optimize the noise spectrum

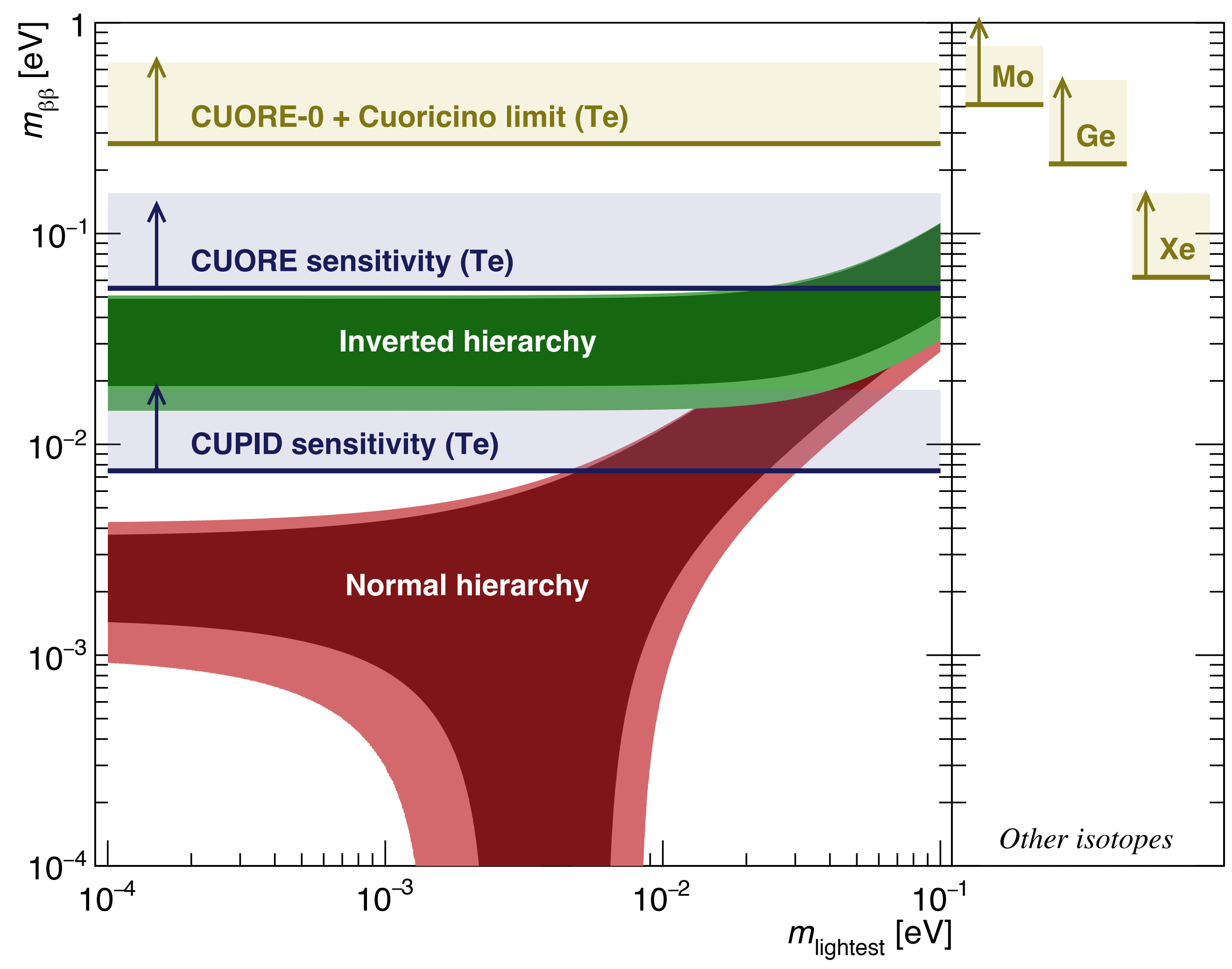
Projected Sensitivity

CUORE:

- $\triangle E_{FWHM} \leq 5$ keV @ 2615 keV
- Bg = 0.01 c/keV/kg/y
- $T_{1/2}$ (5 years, 90% C.L.) > 9.5 x 10^{25} y
- Effective Majorana mass 50-130 meV.

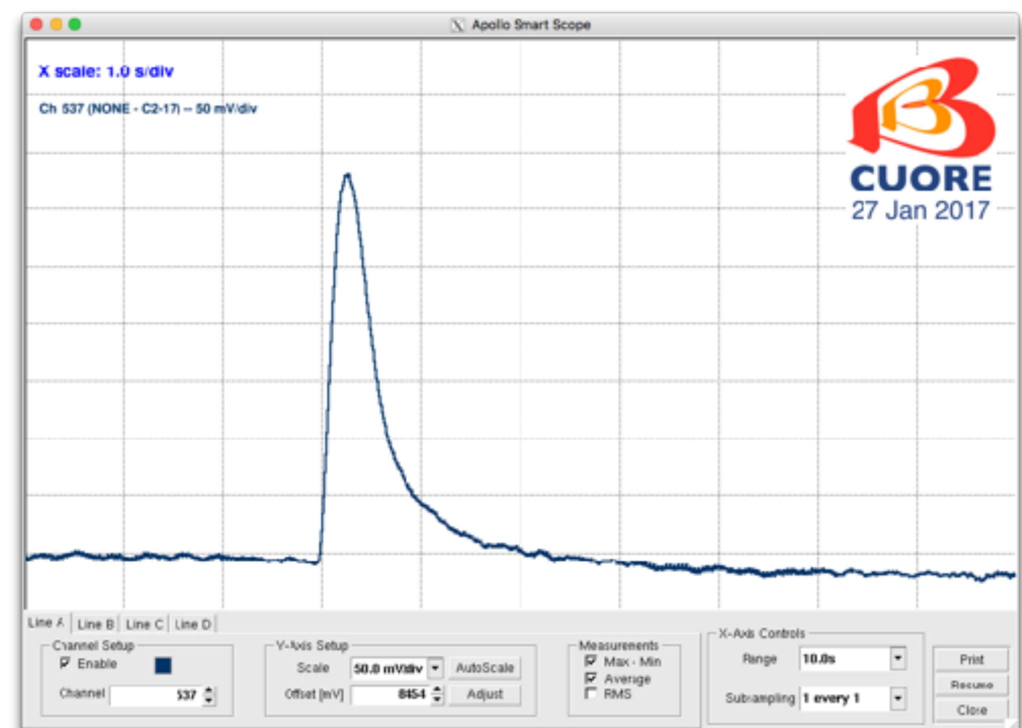
CUPID to cover the Inverted hierarchy

- Enriched TeO_2 with a discrimination
- Other isotopes - scintillating bolometers



Conclusions

- The detector crystals are inside the cryostat, the "coldest cubic meter in the known universe"
- CUORE has its first pulses, and is commissioning and calibrating
- CUORE is on track to achieve: $T_{1/2}$ (5 years, 90% C.L.) > 9.5×10^{25} y



cuore.lngs.infn.it

facebook.com/CUORECollaboration

CUORE Cryostat

"The coldest cubic meter in the known universe"

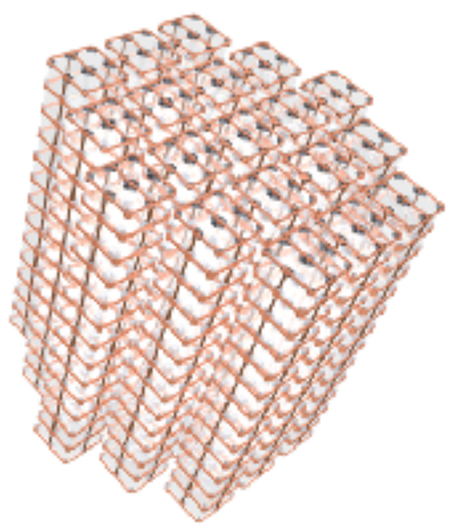
6.3mK base temperature

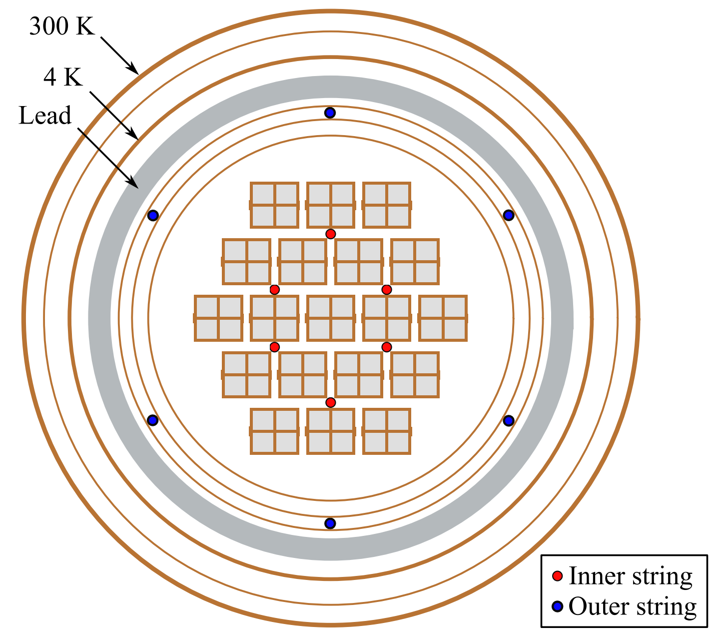
- 1m diameter inner volume
- ~3 weeks to cool

Compare to a more typical dilution refrigerator:

- 20cm diameter inner volume
- 24 hr to cool

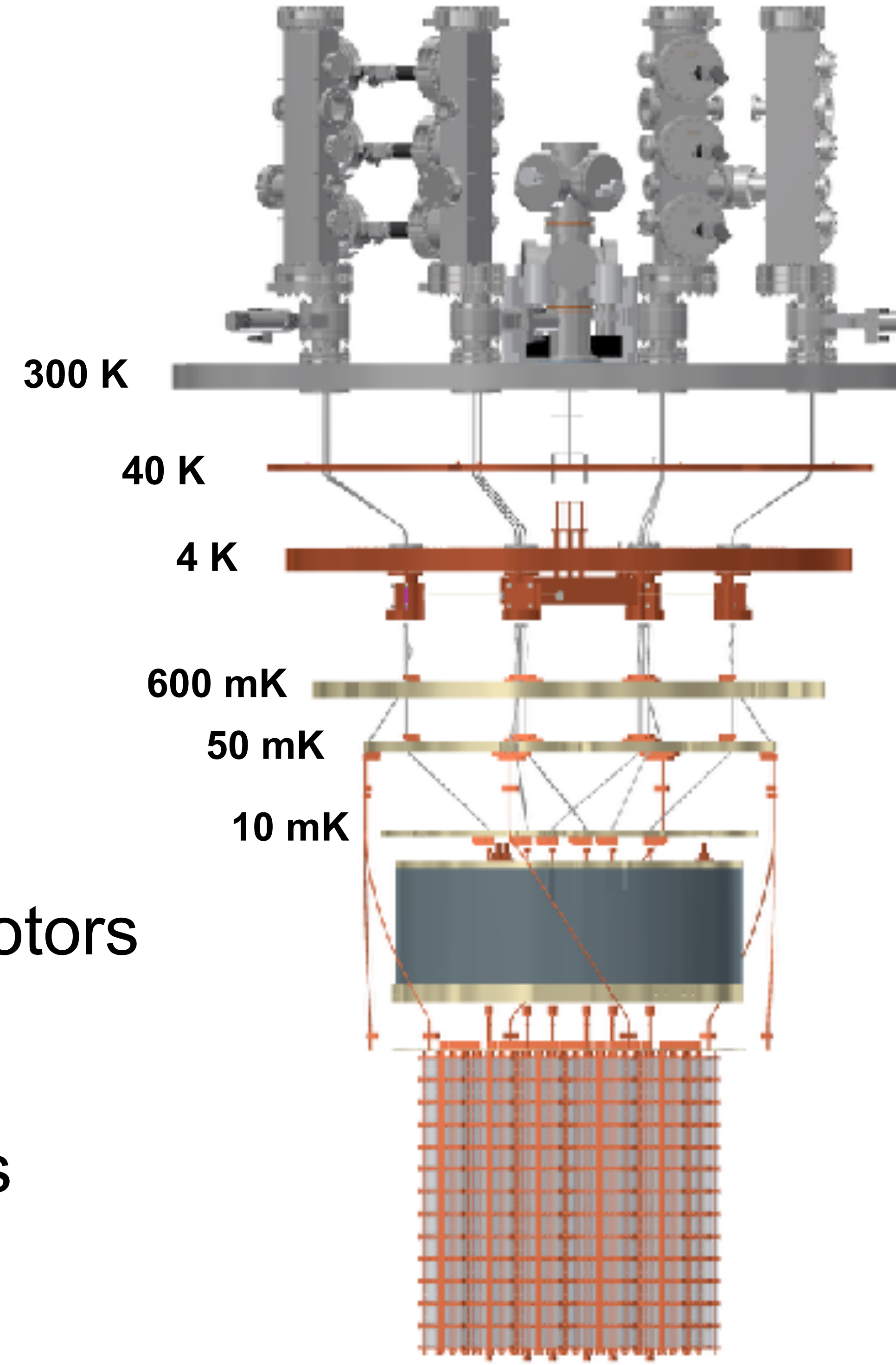
CUORE calibration system





Calibration system

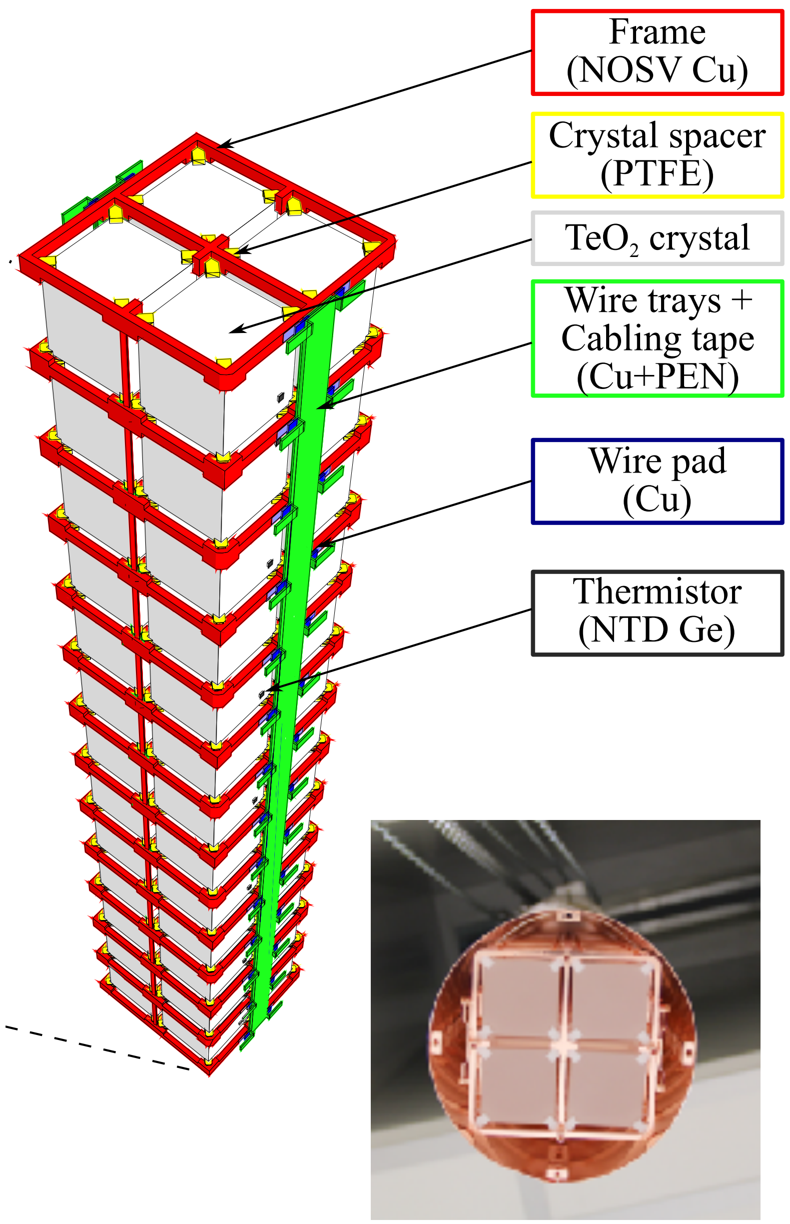
- ^{232}Th capsules on strings
- 6 internal strings (10 mK), 6 external strings (50 mK)
- Lowered in and out monthly with stepper motors
- 10 mm/min constant speed @ 10 mK stage
- ~1 day to supply
- 239 keV - 2615 keV (^{208}Tl) calibration peaks
  2615 keV close to Q_{bb} at 2527.5 keV



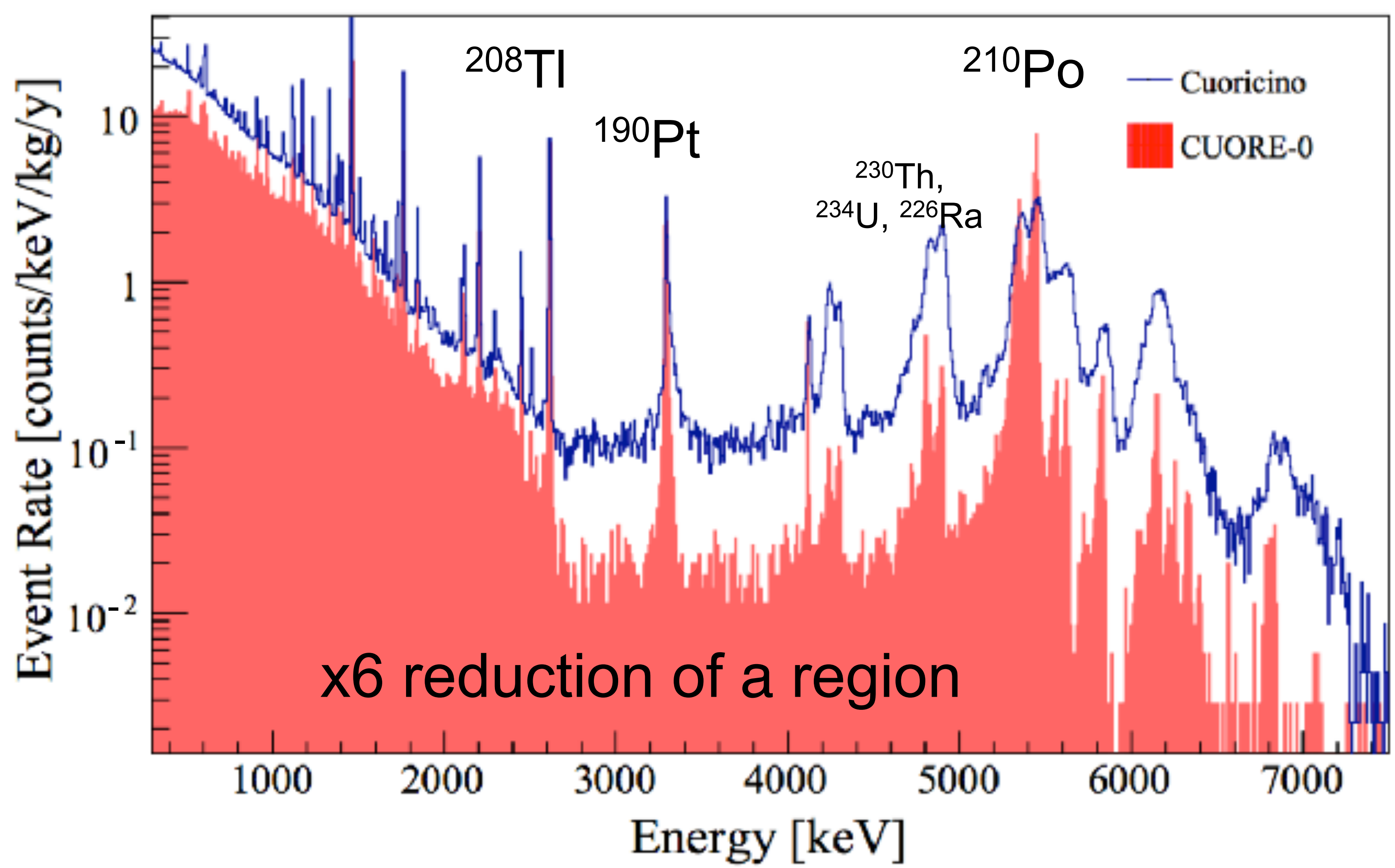
Online Monitoring

- Internal websites archives and displays all channels, plus cryostat environment data, with details in pop-up plots
- Display summaries of each run
- Tag bad intervals automatically or by hand
- System sends email and phone alarms
- Use mobile-friendly web libraries

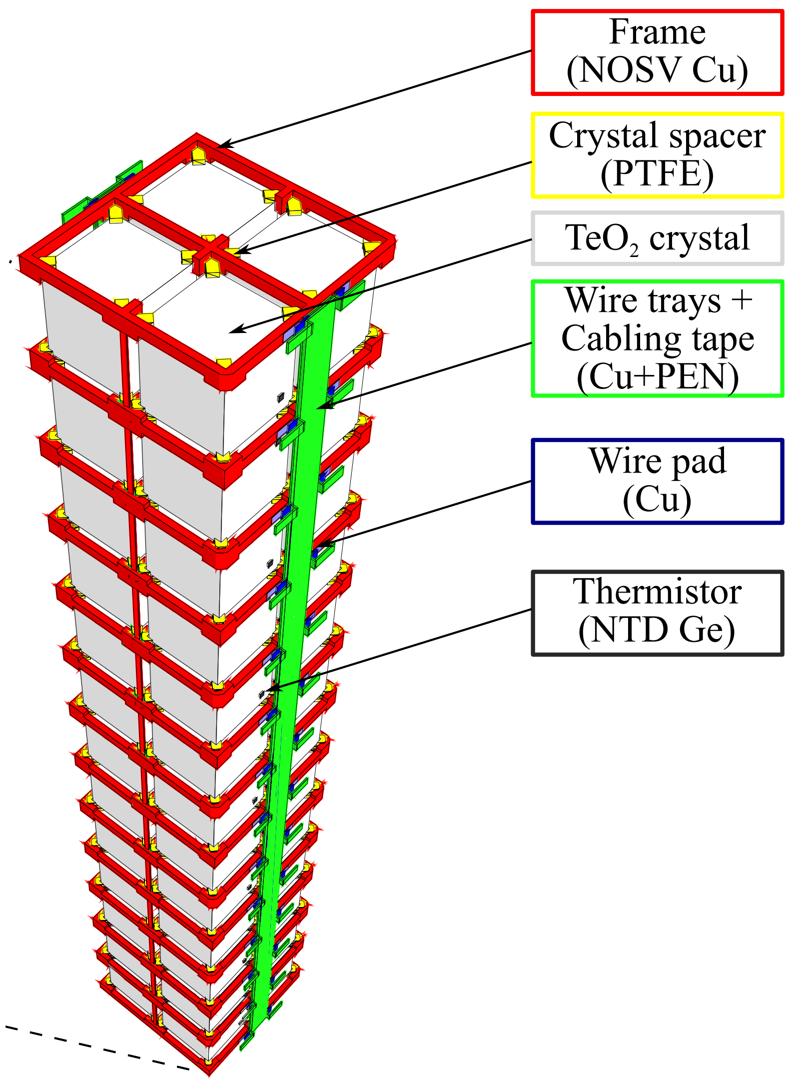
CUORE-0 backgrounds



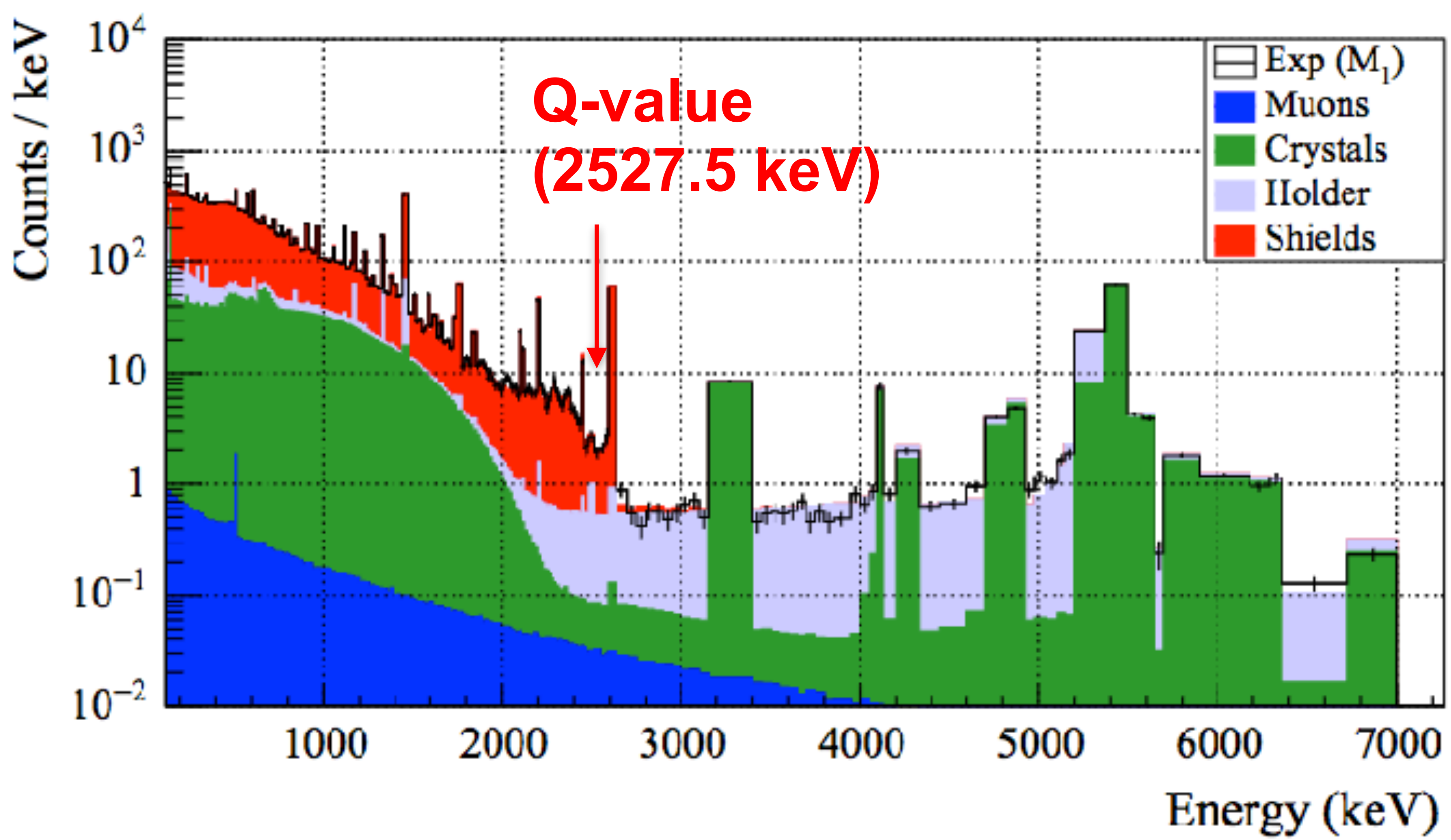
Result of surface cleaning procedures:
0.016±0.001 c/keV/kg/y versus
0.110±0.001 c/keV/kg/y with E in [2.7,3.9] MeV



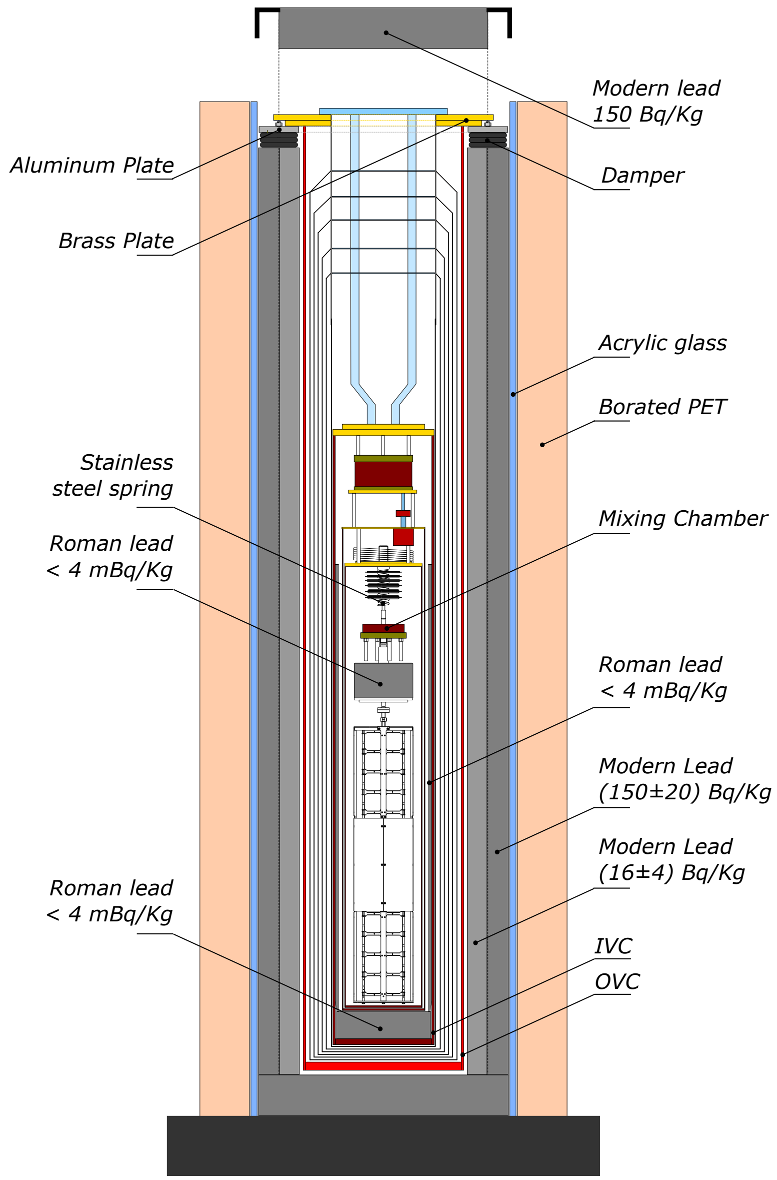
CUORE-0 backgrounds



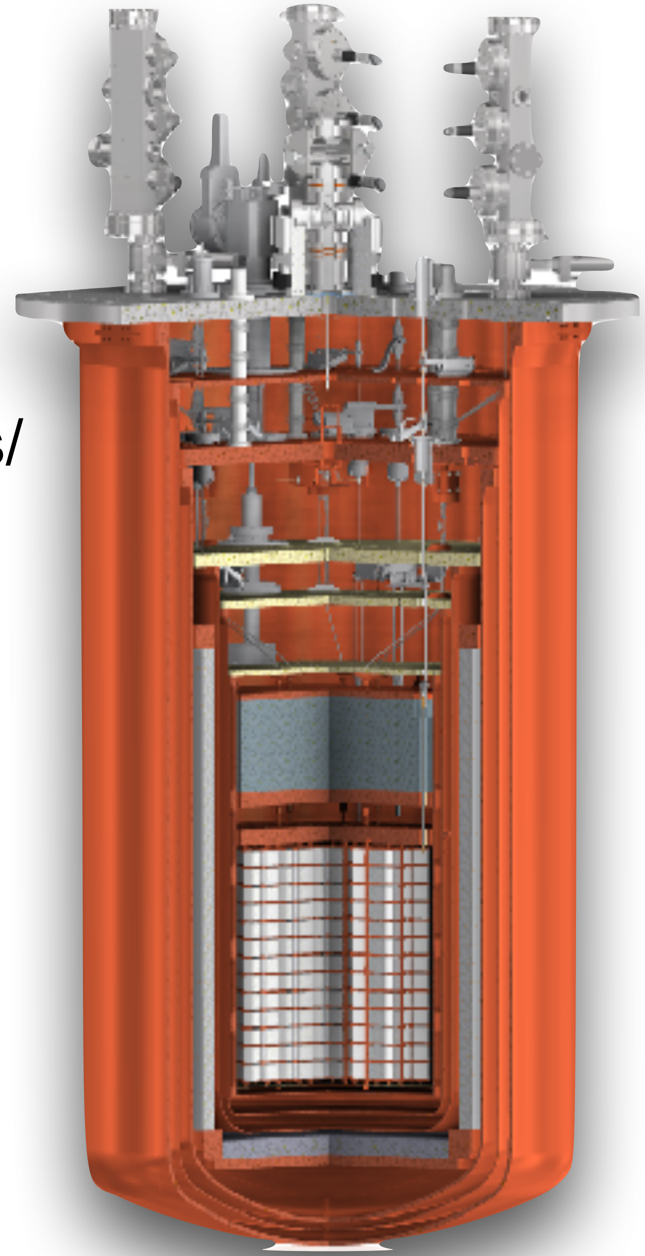
Backgrounds origins in the bayesian fit



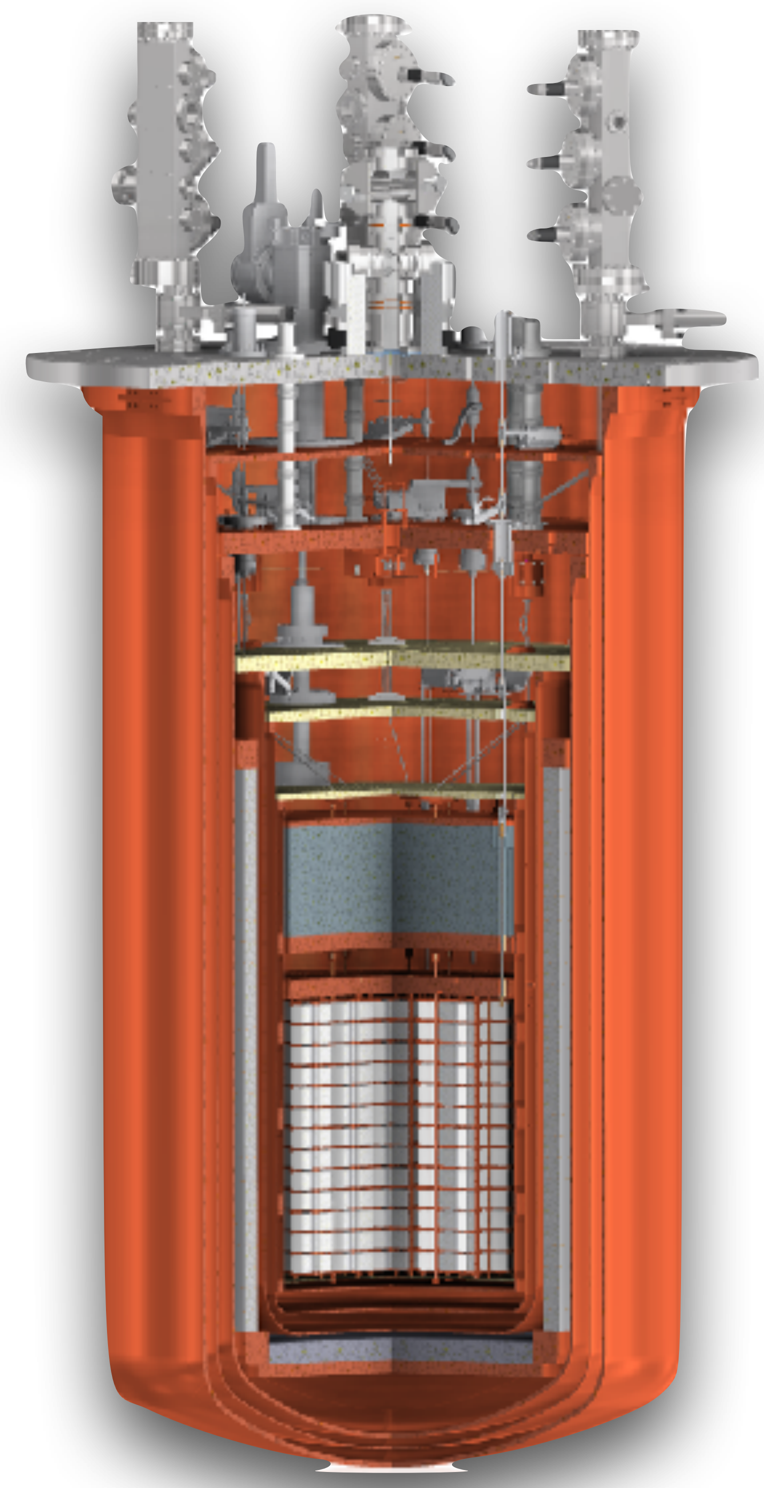
CUORE-0 to CUORE



- 741 kg of TeO2, **206 kg of ^{130}Te**
- new pulse tube cooled (dry) fridge continuous operation for many months/ years (better efficiency)
- better material screening, e.g. better and less copper
- CUORE-0 style cleaning procedures (surface etching, N_2 glove boxes)
- more shielding
- vibration dampening systems



CUPID



CUPID - **C**UORE **U**pgrade with **P**article **ID**entification

- Same cryostat
- Enriched TeO_2 (almost x3 improvement)
- with very low threshold bolometric light detectors to provide a/b discrimination
- TES, MMC, Neganov-Luke NTD type detector R&D started
- Surface optimizations - TeO_2 roughness, AR coating on bolometric light detector

Or

- Other isotopes - scintillating bolometers