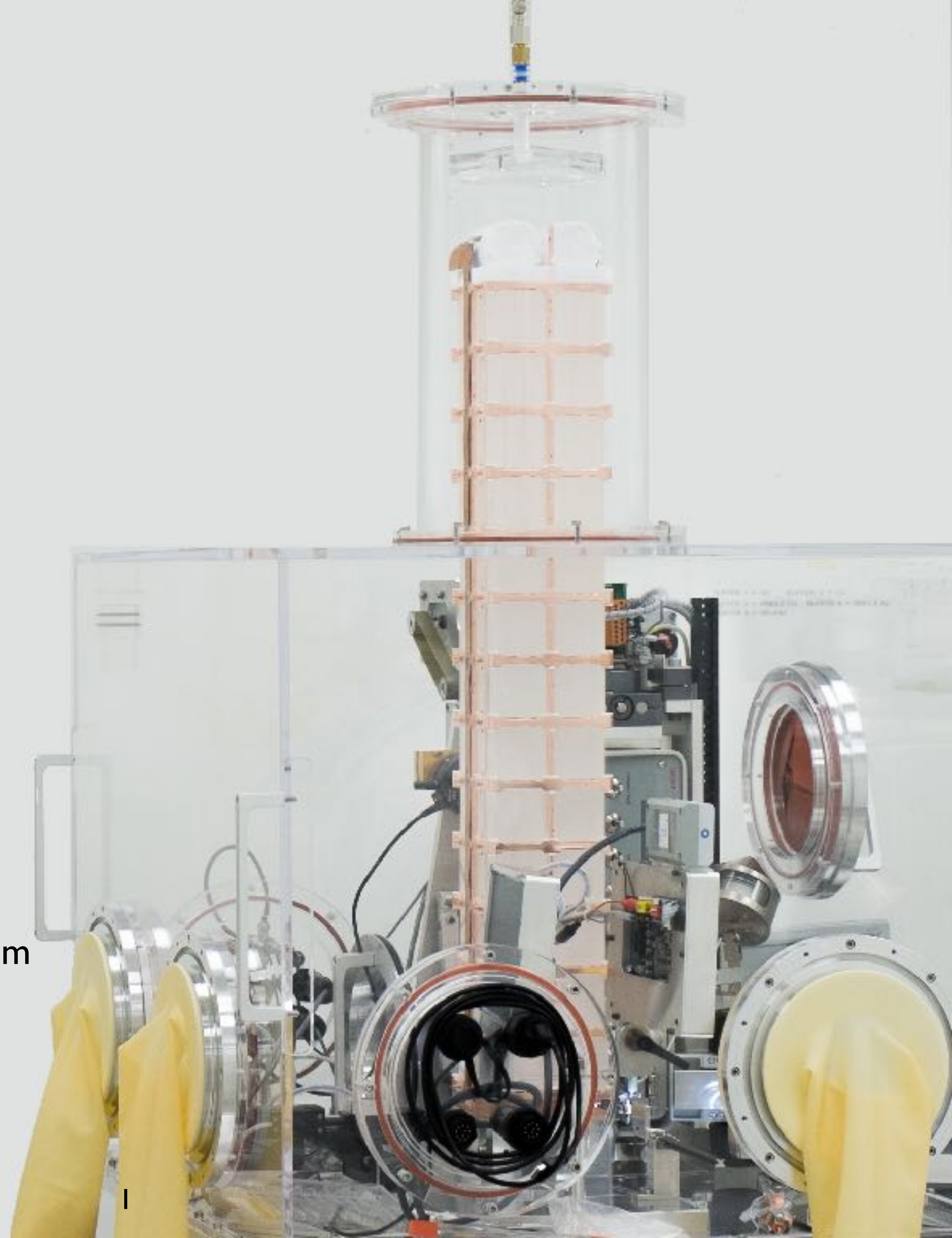
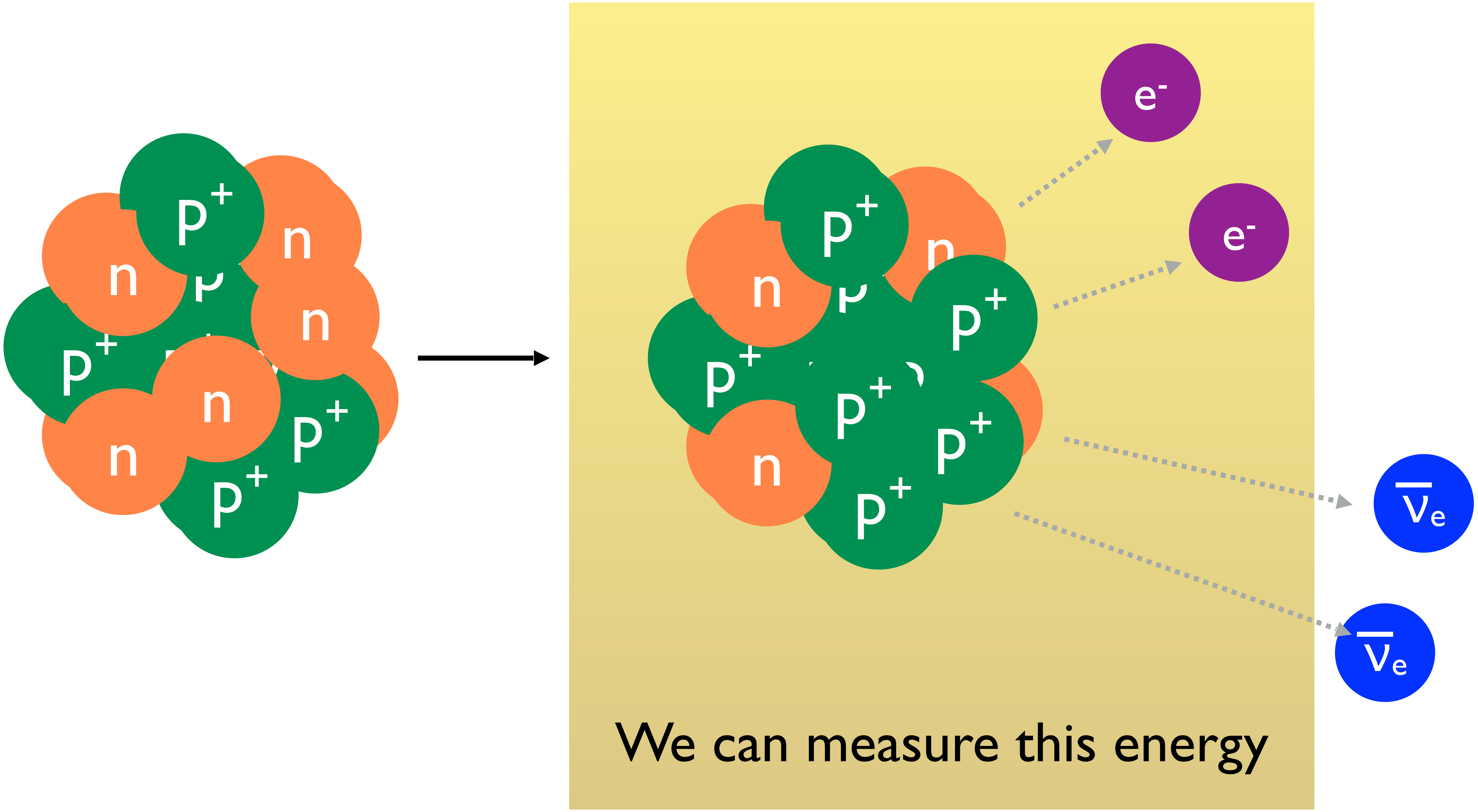
Status of CUORE



Dr. Laura Gladstone
MIT Laboratory for Nuclear Science

IceCube Particle Astrophysics Symposium
Madison, WI
May 2017

Double Beta Decay



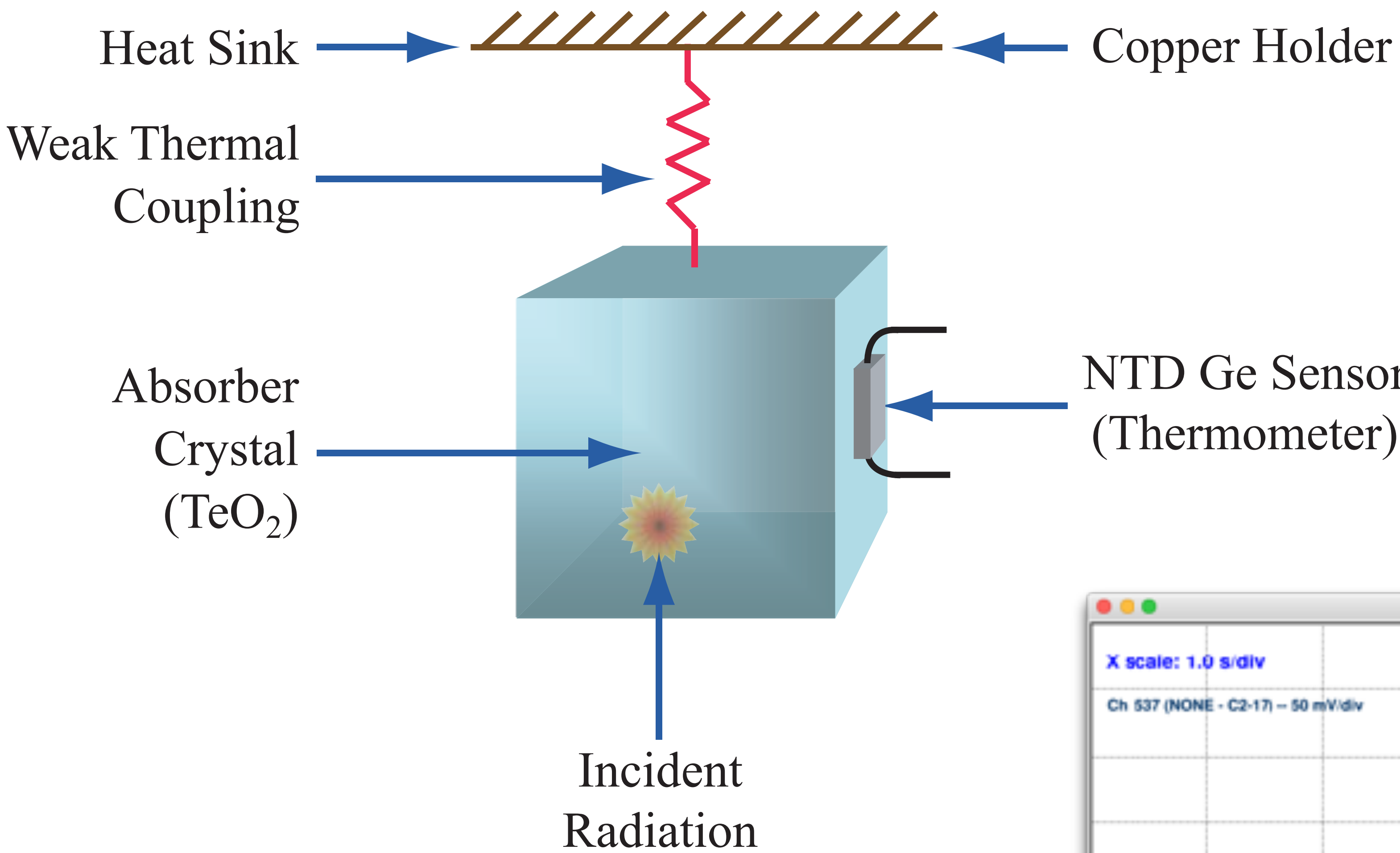
The Experimental Challenge

Long Time Scales:

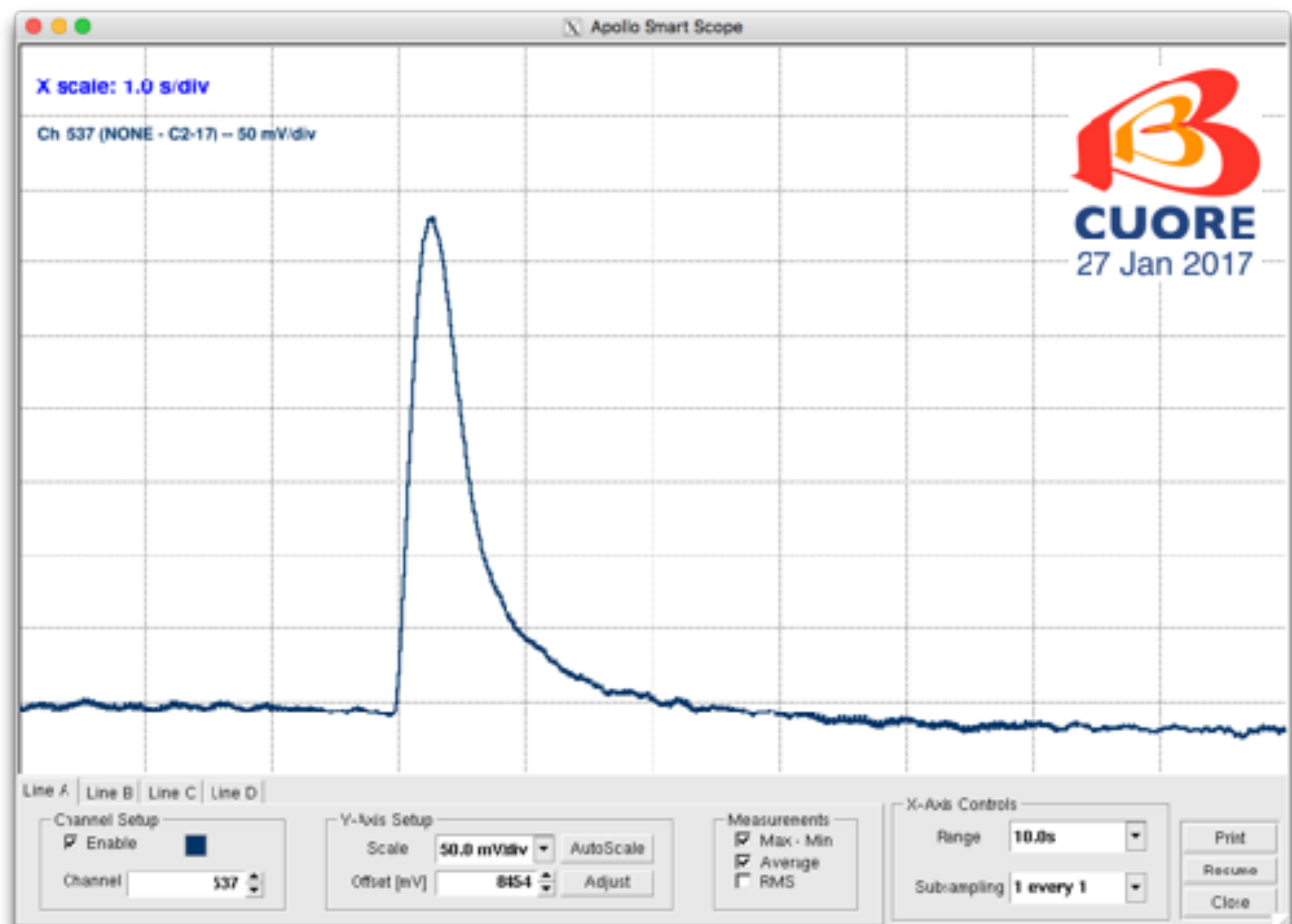
^{14}C	10^4 years
^{40}K	10^9 years
^{232}Th	10^{10} years
The Universe	10^{10} years
Two Neutrino Double Beta	10^{20} years ← background
Neutrinoless Double Beta	$>10^{26}$ years ← signal
Proton Decay	$>10^{34}$ years

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

Bolometers measure total heat



First pulse!

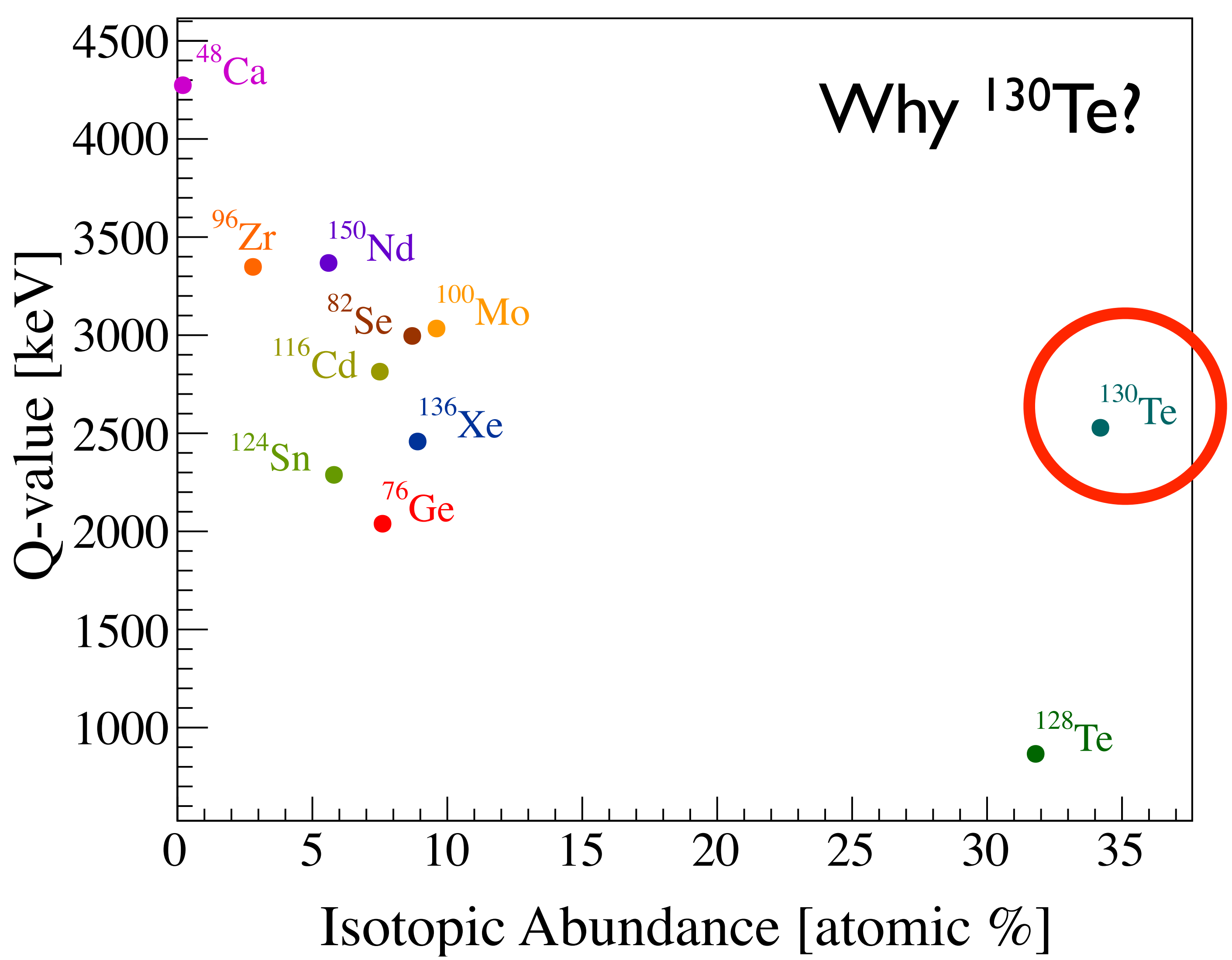


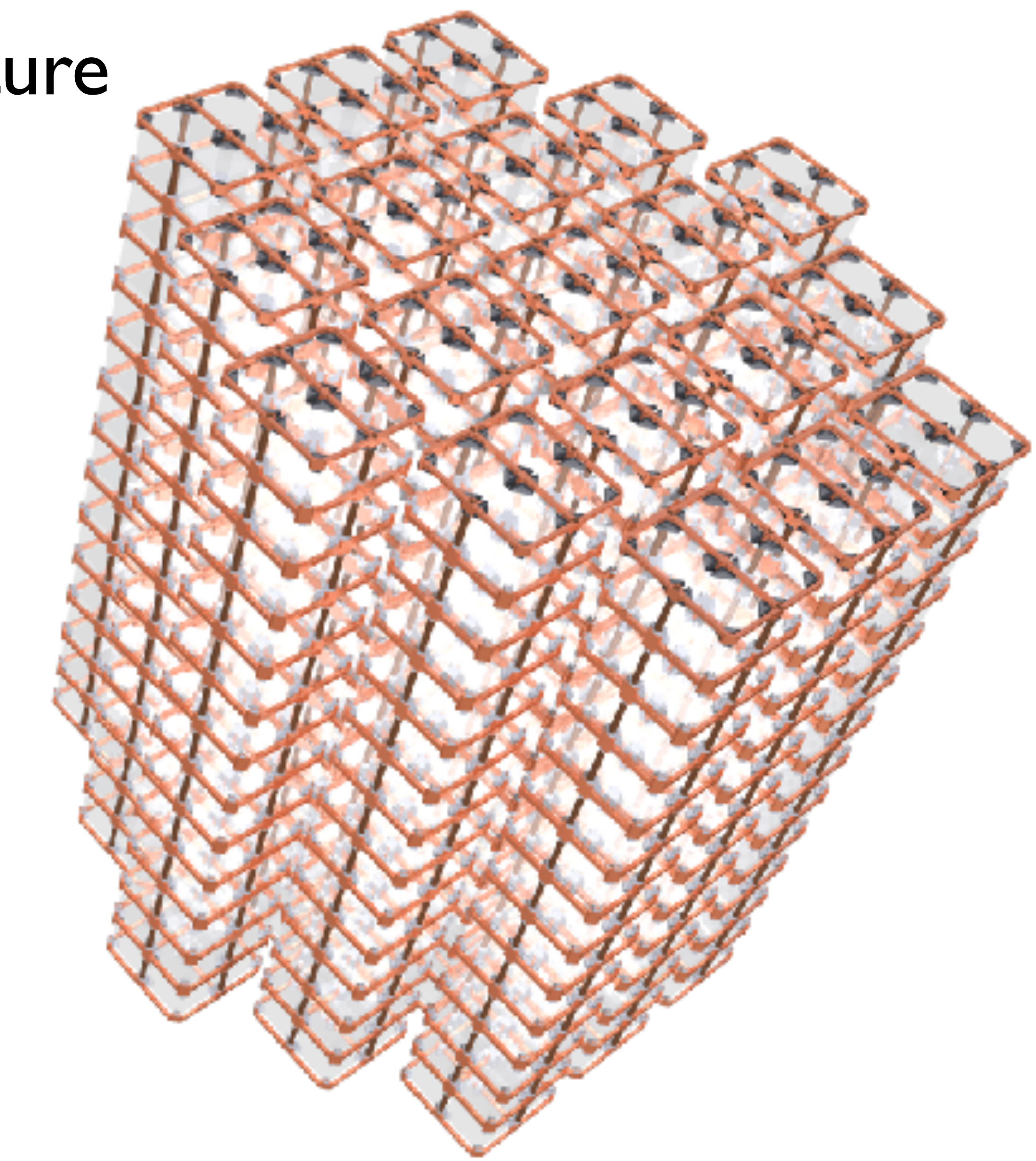
Need a cold environment for:

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

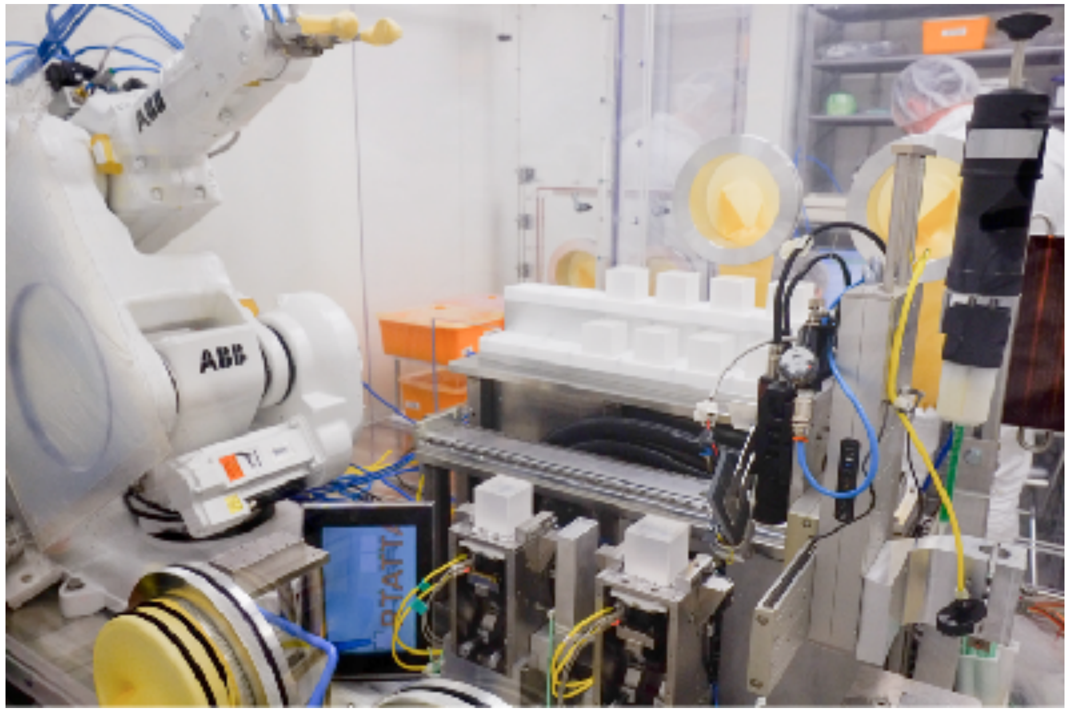
CUORE is an array of bolometers

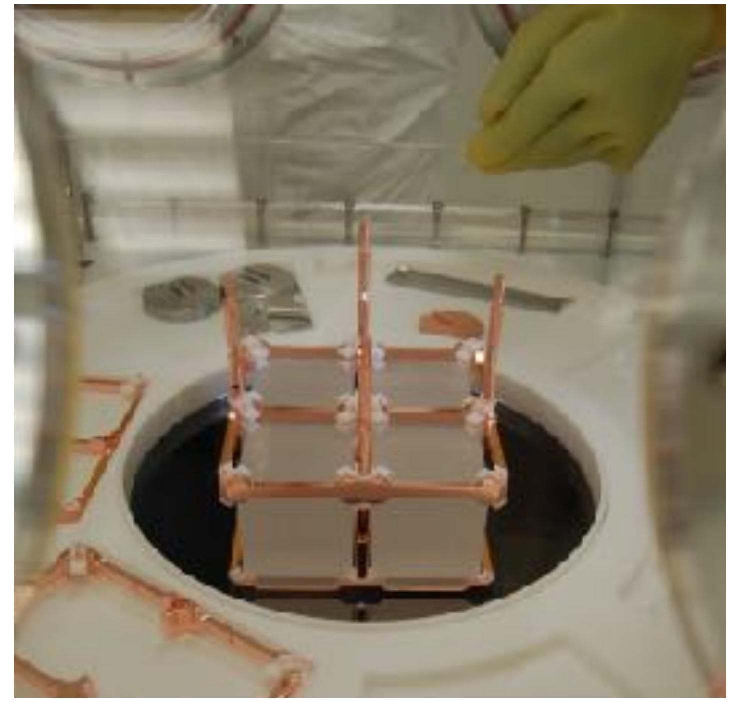
- “Cryogenic Underground Observatory for Rare Events”
- 988 TeO_2 crystals operated as bolometers
- 742kg TeO_2, 206 kg ^{130}Te
- Copper and PTFE (teflon) support structure





Detector Construction



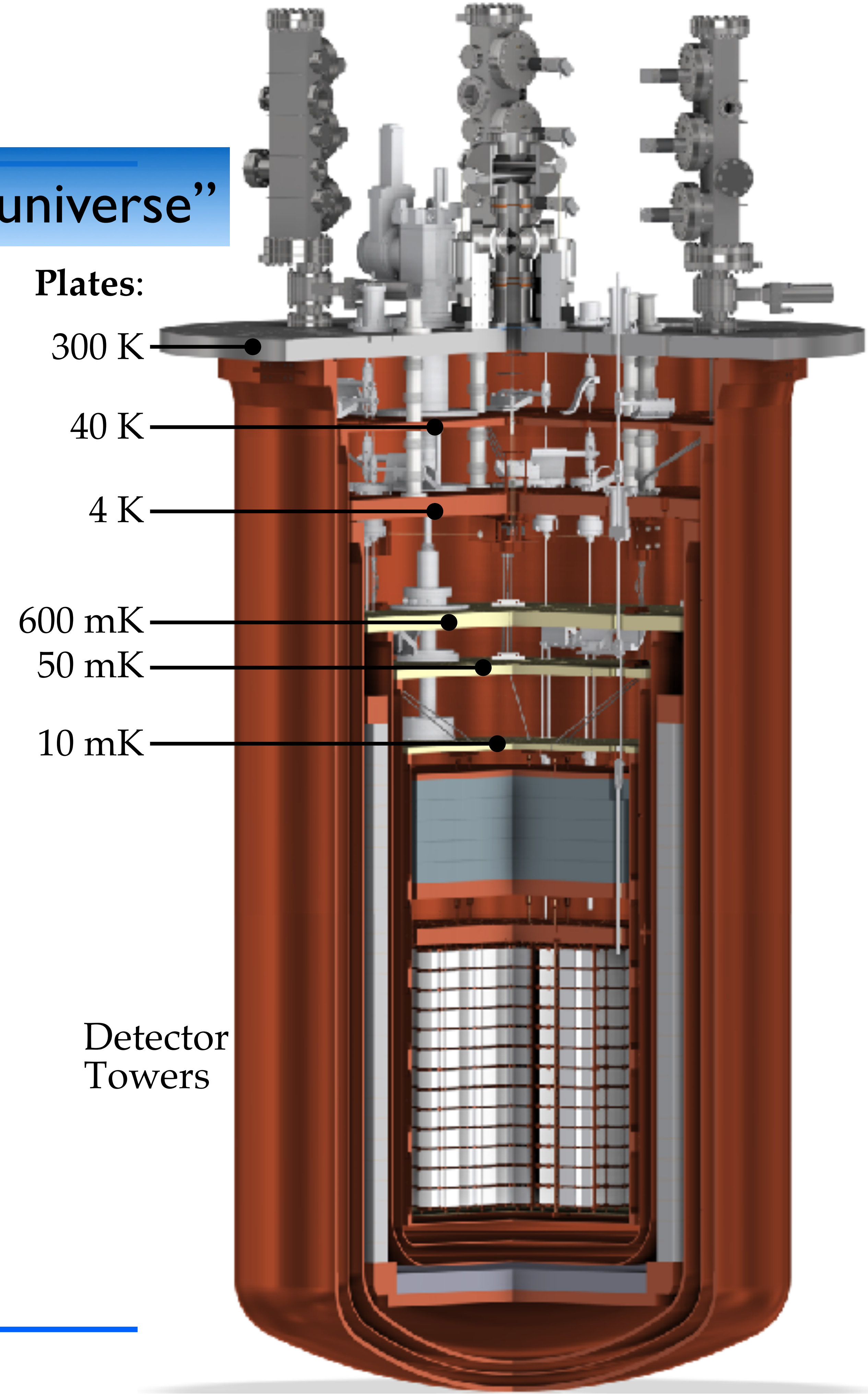


- Ultra-pure source materials
- Ship, don't fly, to Gran Sasso
- Apply sensors and heaters with a robotic arm to ensure consistency
- Only handle crystals in N_2 environment

CUORE Cryostat

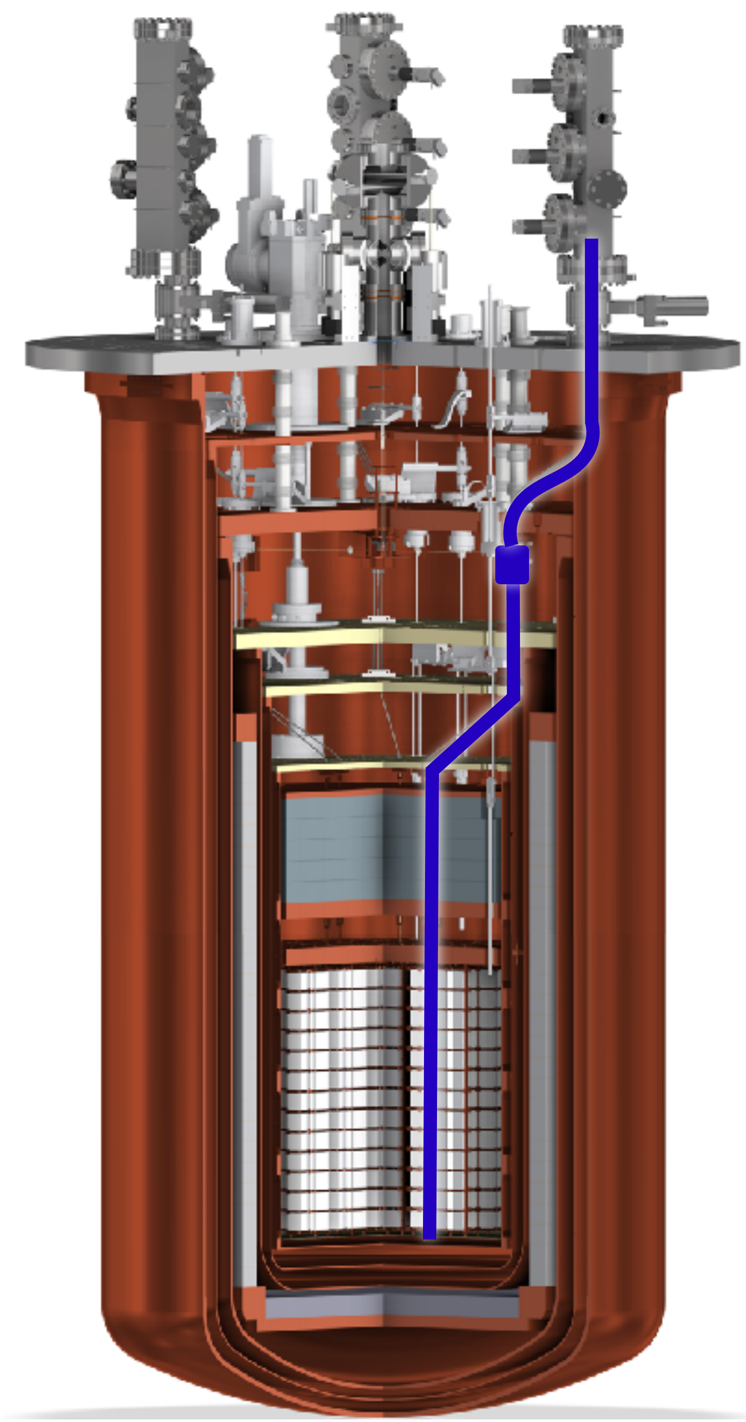
"The coldest cubic meter in the known universe"

- 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

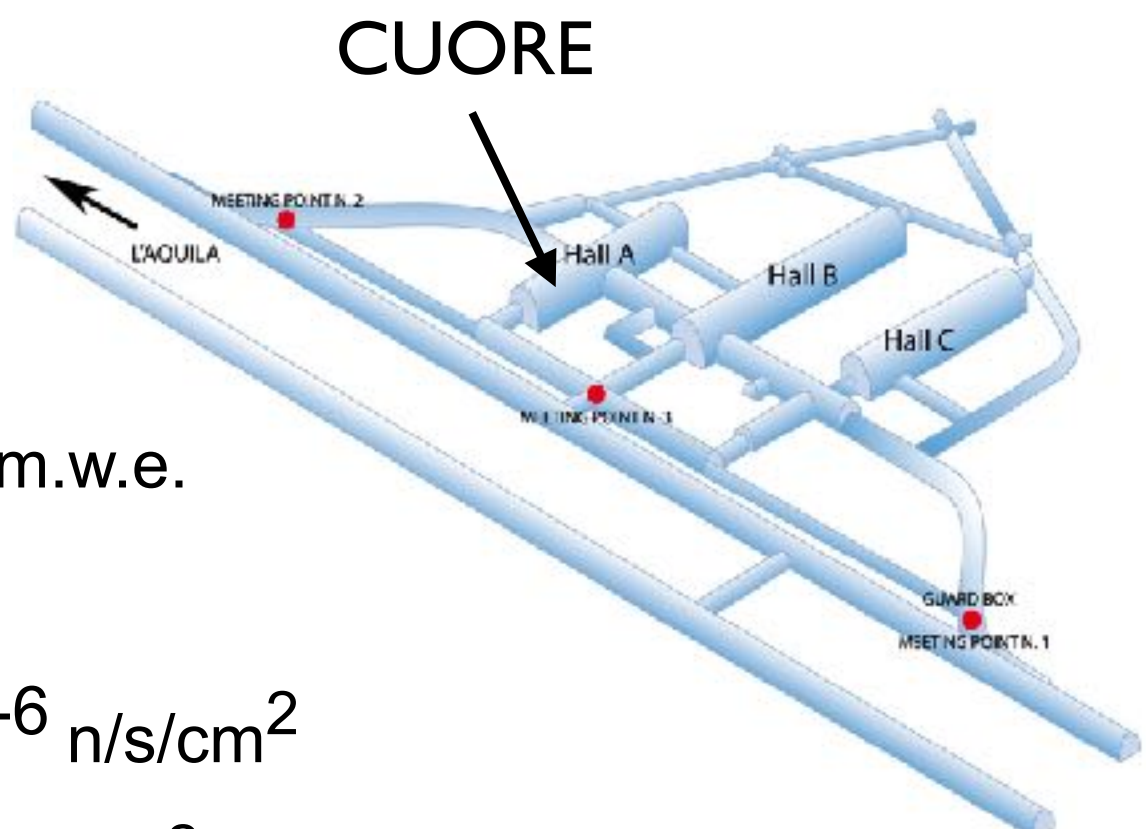
- For CUORE, we use:
  - Constant-energy pulsers to measure detector stability and correct for variations in detector gain
  - ^{232}Th γ-ray sources every ~month (239 keV to 2615 keV)
- Sources are outside cryostat during physics data-taking and lowered into cryostat and cooled to 10 mK for calibration
- 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

Gran Sasso National Lab

Backgrounds from cosmic rays are rare and easily removed from data



Average depth ~ 3600 m.w.e.

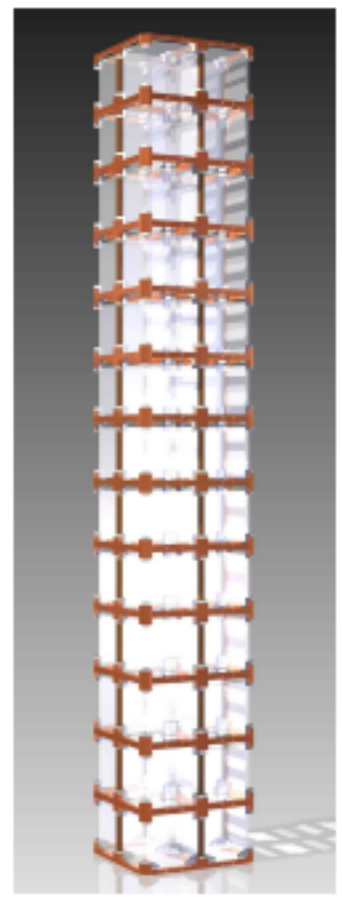
μ flux: ~3 $\cdot 10^{-8}$ μ/s/cm^2

n flux <10 MeV: < $4\cdot 10^{-6}$ n/s/cm^2

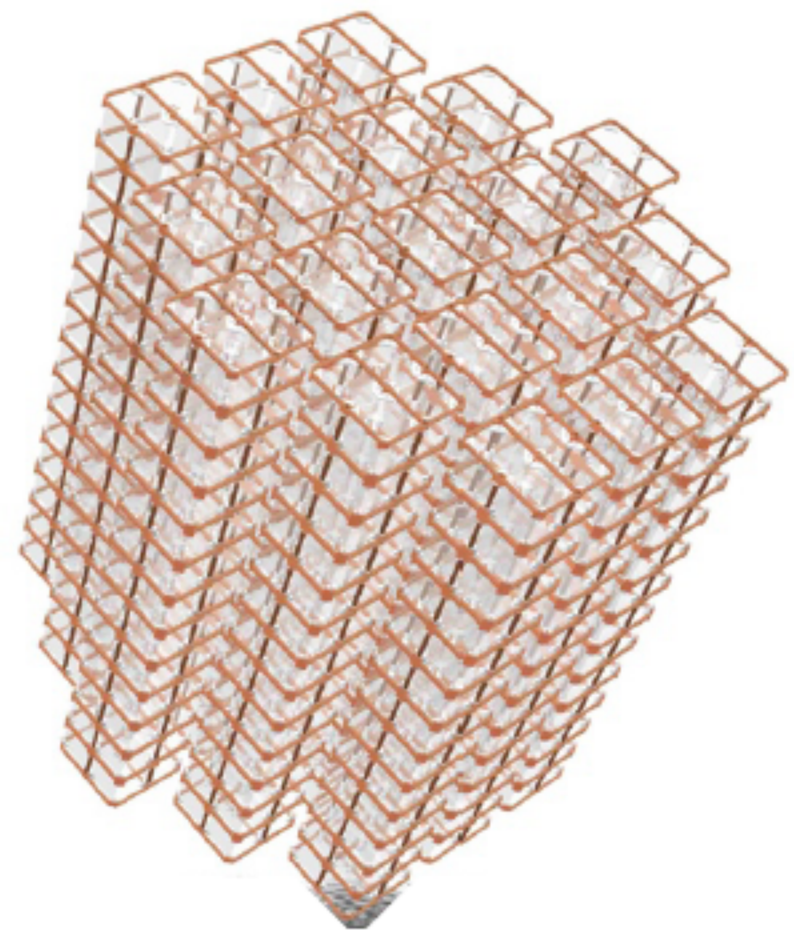
γ flux < 3 MeV: ~0.73 γ/s/cm^2

Generations of Bolometer Experiments

Cuoricino
2003 - 2008
11 kg ^{130}Te



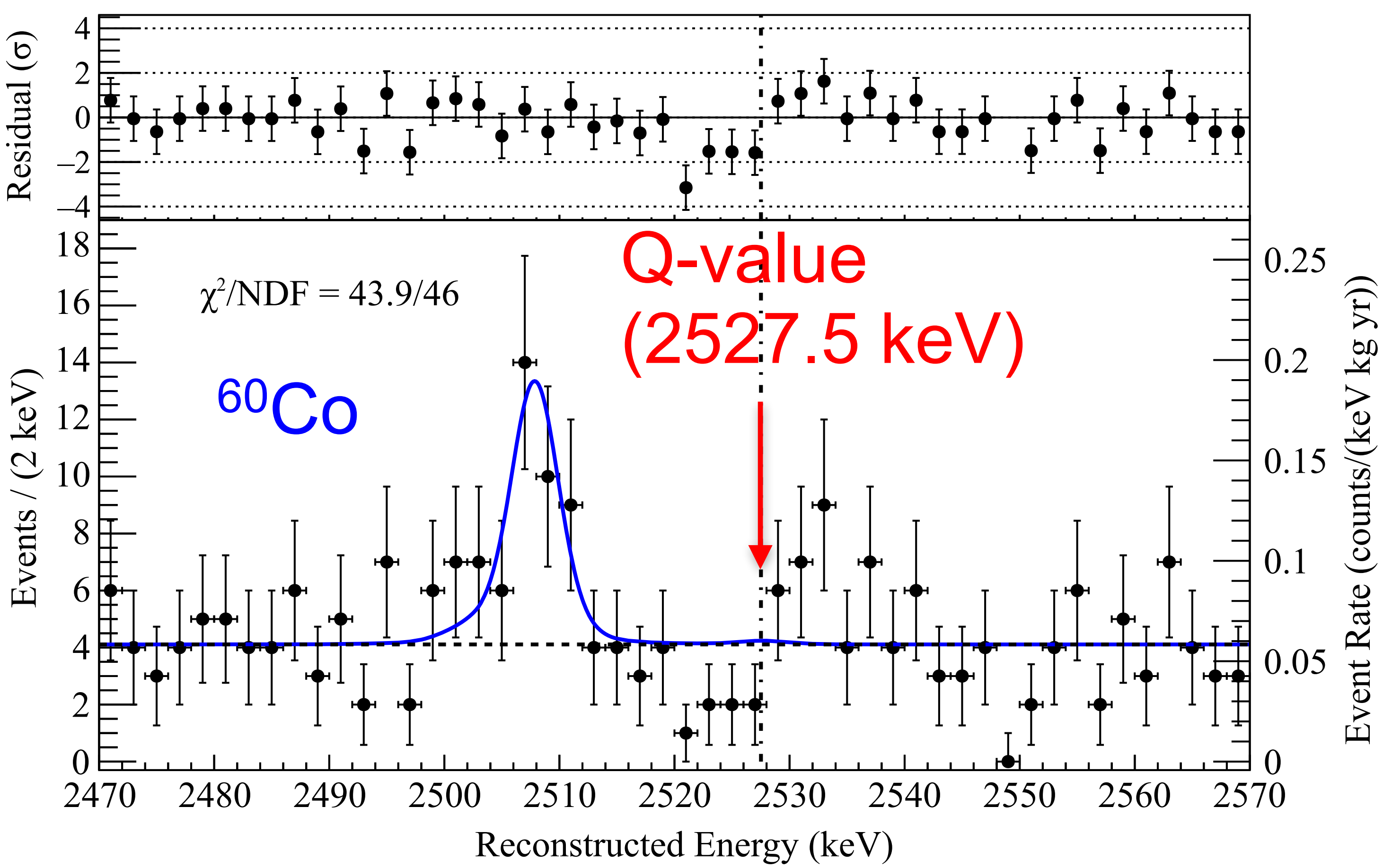
CUORE-0
2003 - 2015
11 kg ^{130}Te



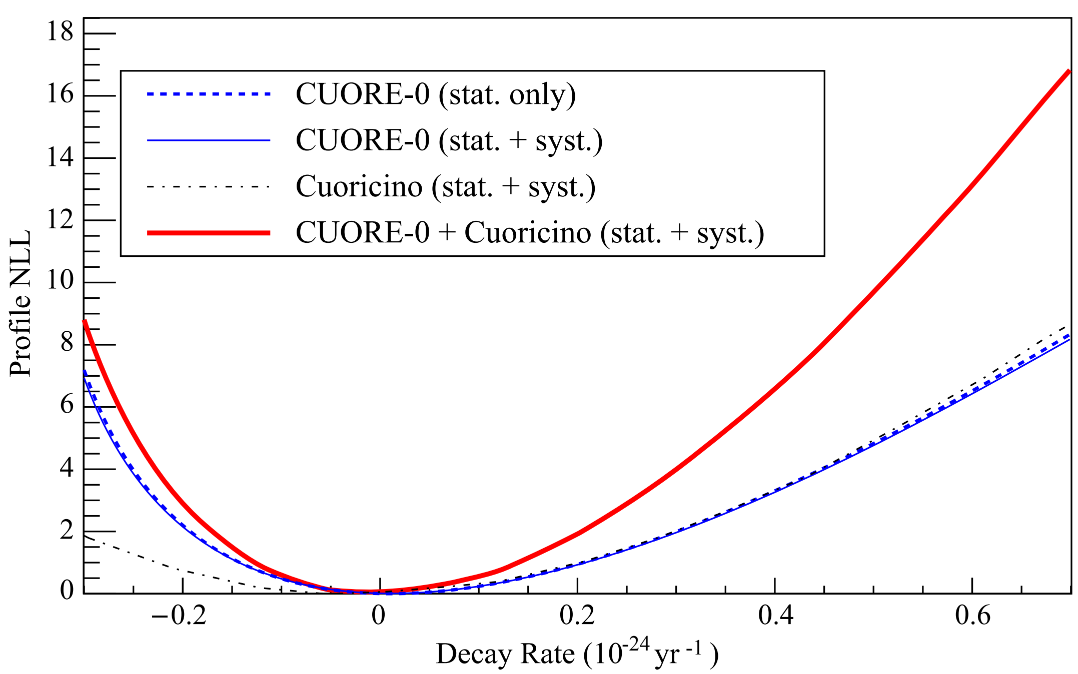
CUORE
2017 - 20??
206 kg ^{130}Te

CUORE-0: 0νββ decay results

- CUORE-0 regained the Cuoricino limit in 40% of the lifetime
- Combined with Cuoricino: **$T_{1/2}^{0\nu\beta\beta}$ (^{130}Te)> 4.0 × 10^{24} y (90% CL)**
- Effective Majorana Mass: **$m_{\beta\beta}$ <(270-650) meV**
- Validated data blinding for CUORE
- CUORE analysis testbed

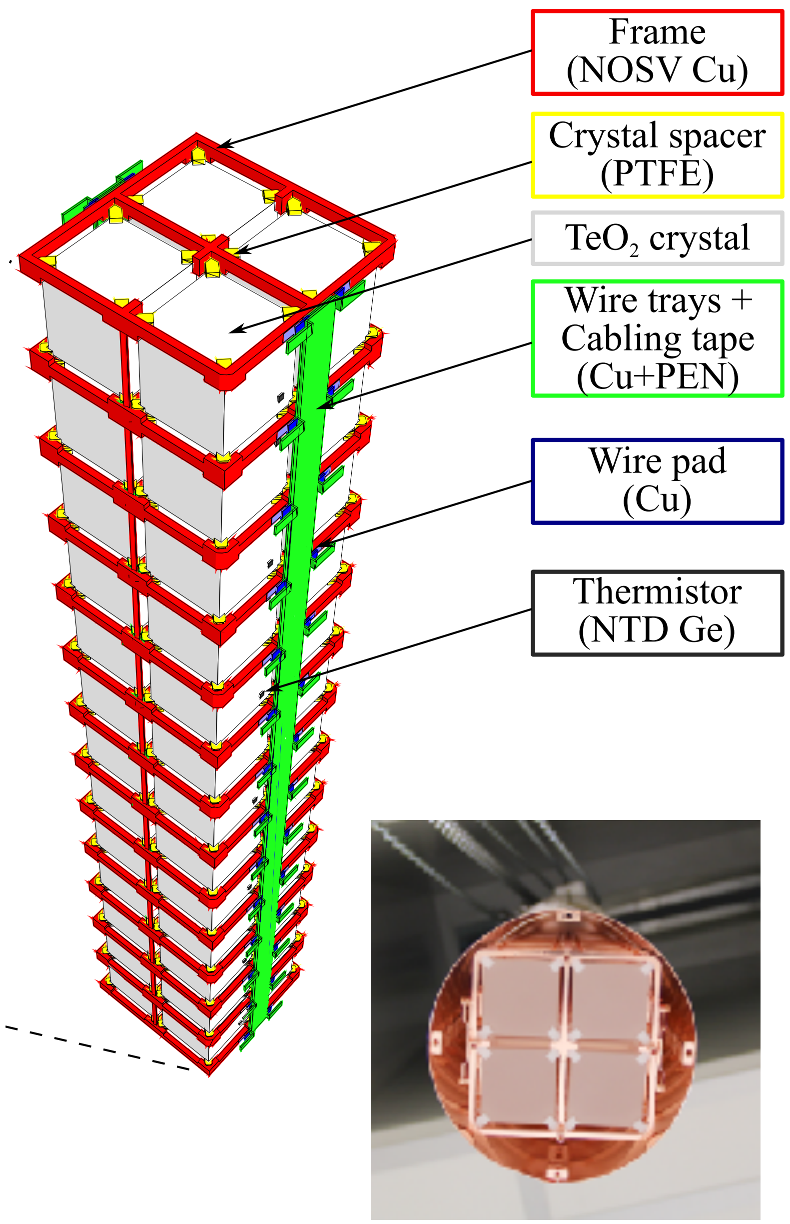


Phys. Rev. C 93, 045503 (2016)

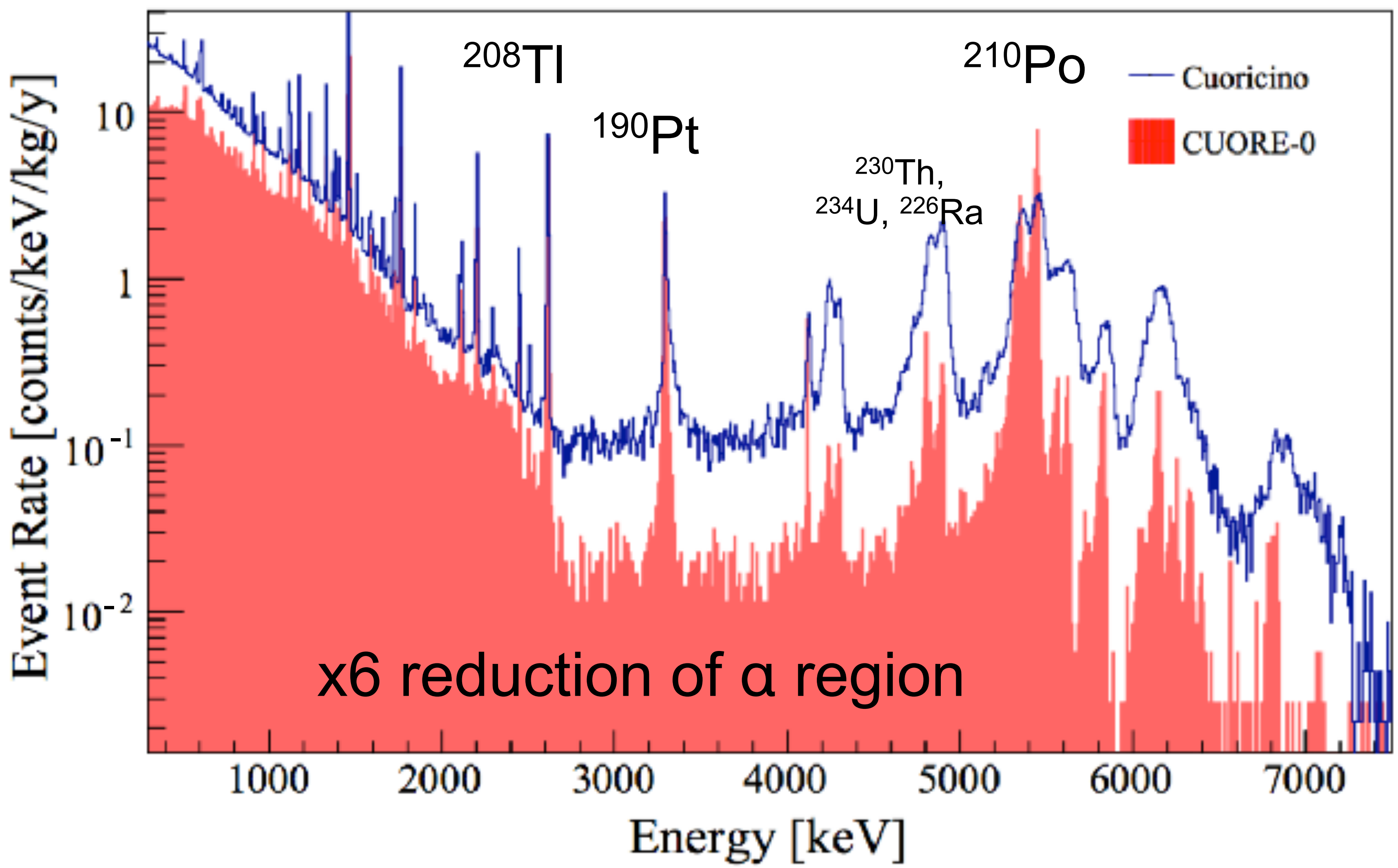


Phys. Rev. C 93, 045503 (2016)
Phys. Rev. Lett. 115, 102502 (2015)

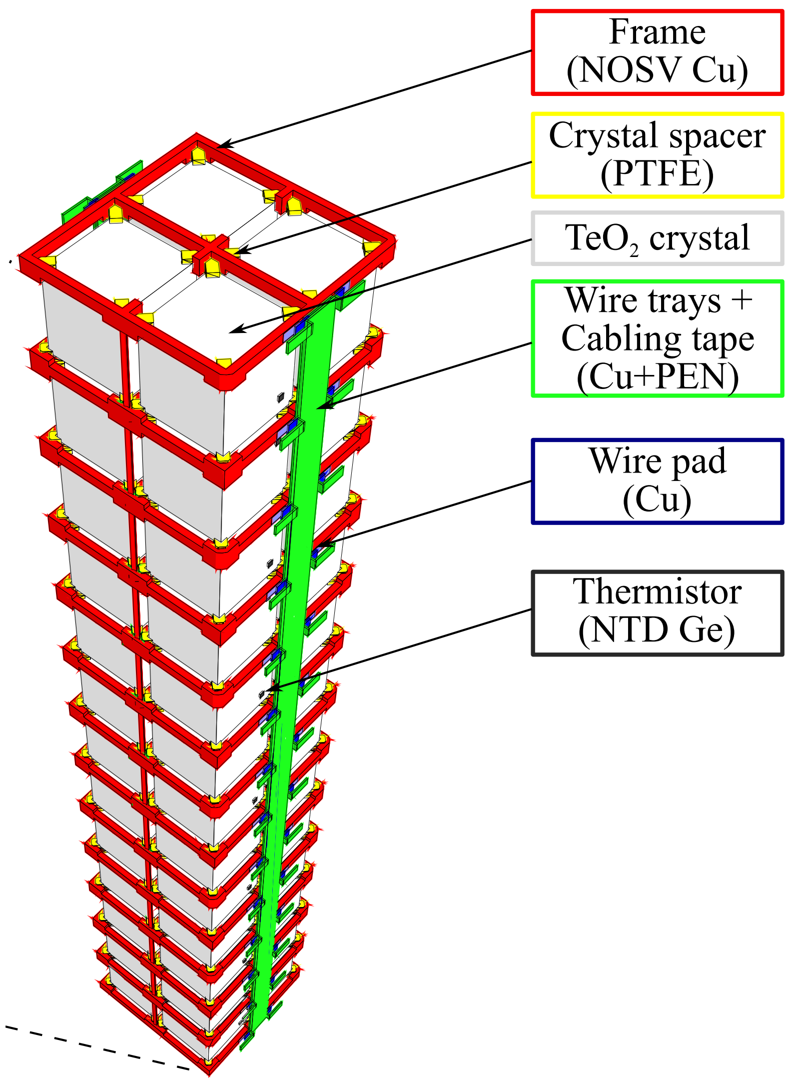
CUORE-0 backgrounds



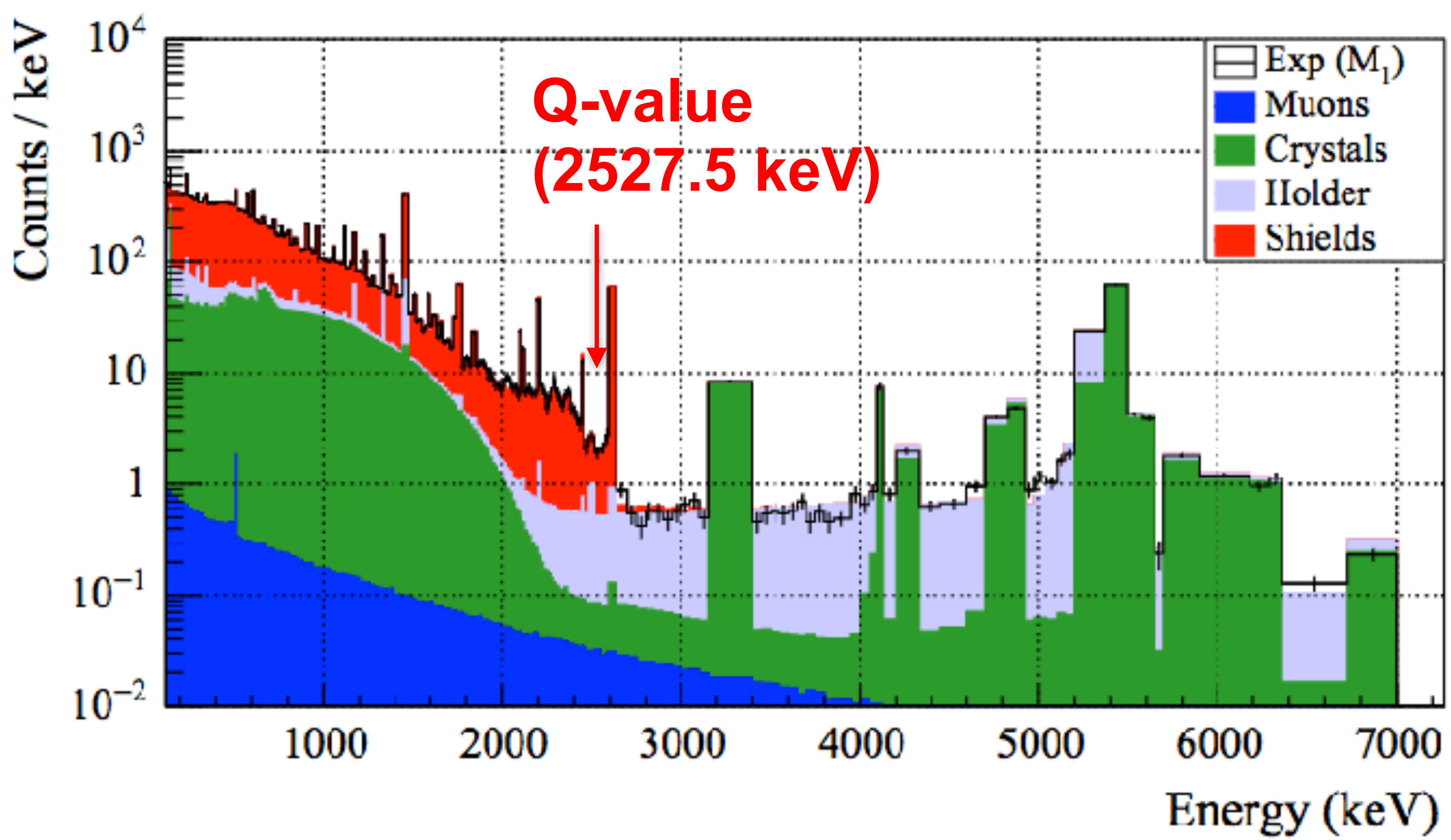
Result of surface cleaning procedures:
0.016±0.001 c/keV/kg/y versus
0.110±0.001 c/keV/kg/y with E in [2.7,3.9] MeV



CUORE-0 backgrounds

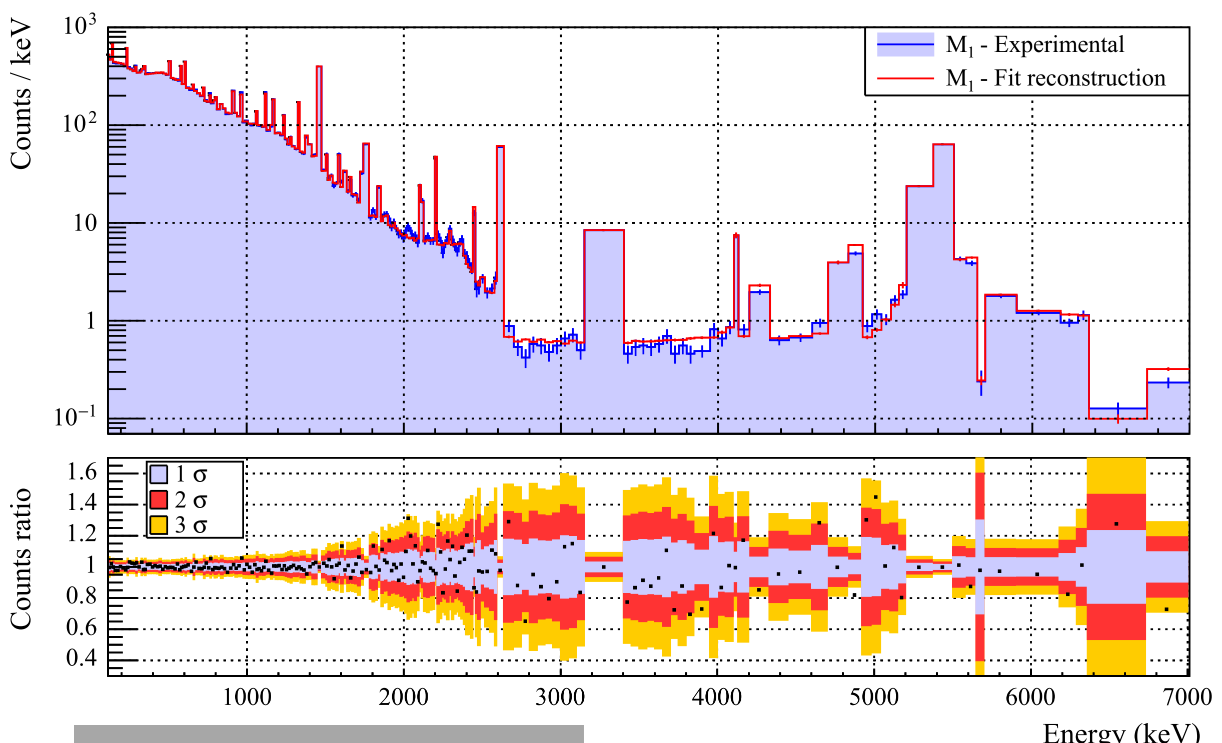


Backgrounds origins in the bayesian fit

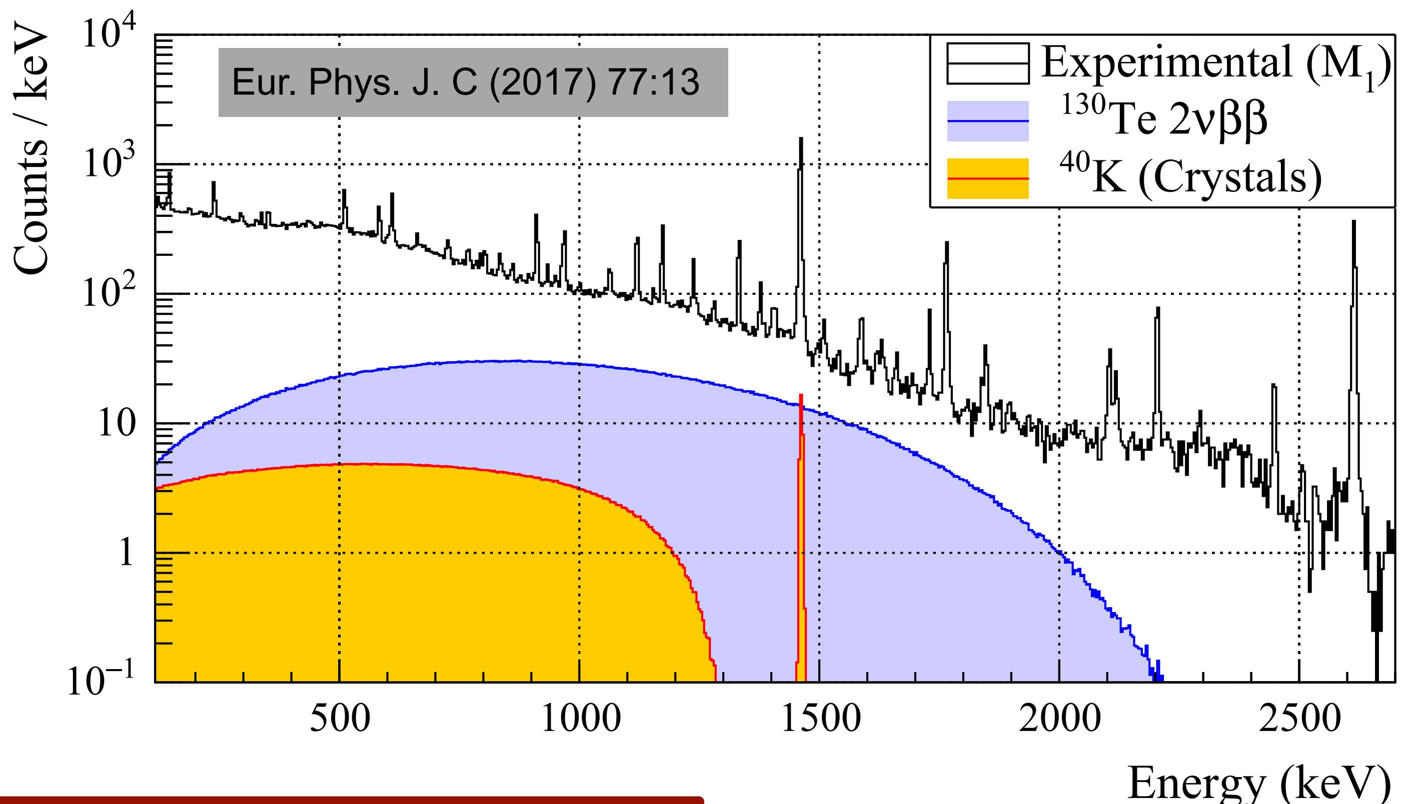


CUORE-0 backgrounds and 2vbb

- 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



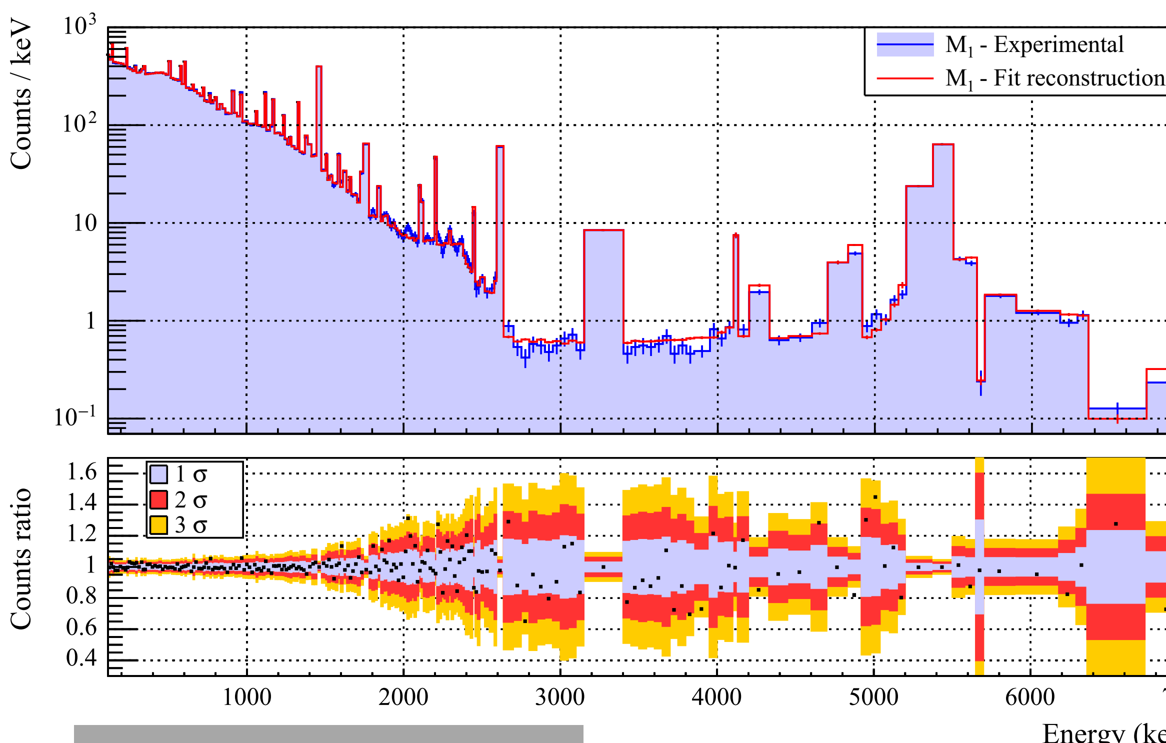
Eur. Phys. J. C (2017) 77:13



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

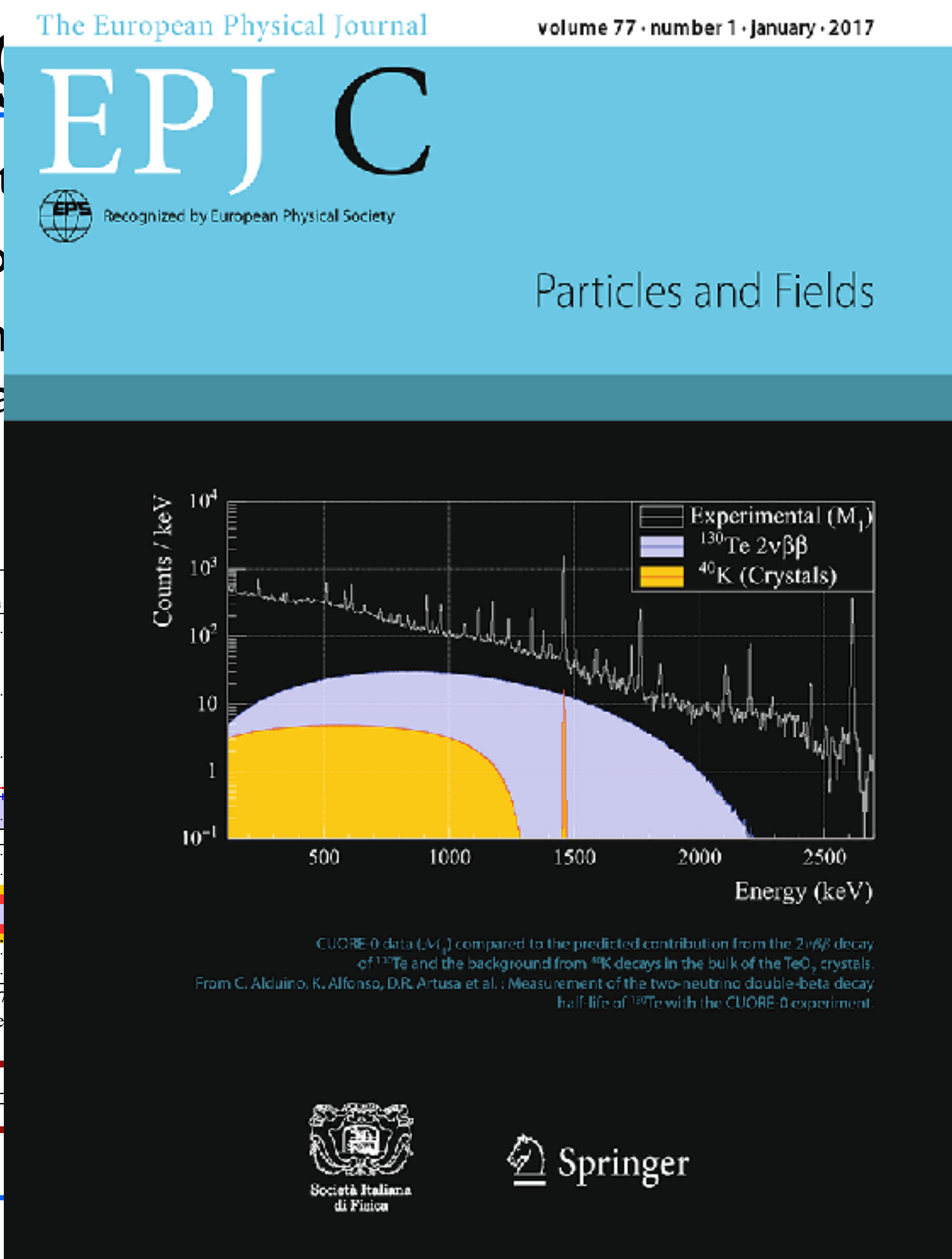
CUORE-0 backg

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



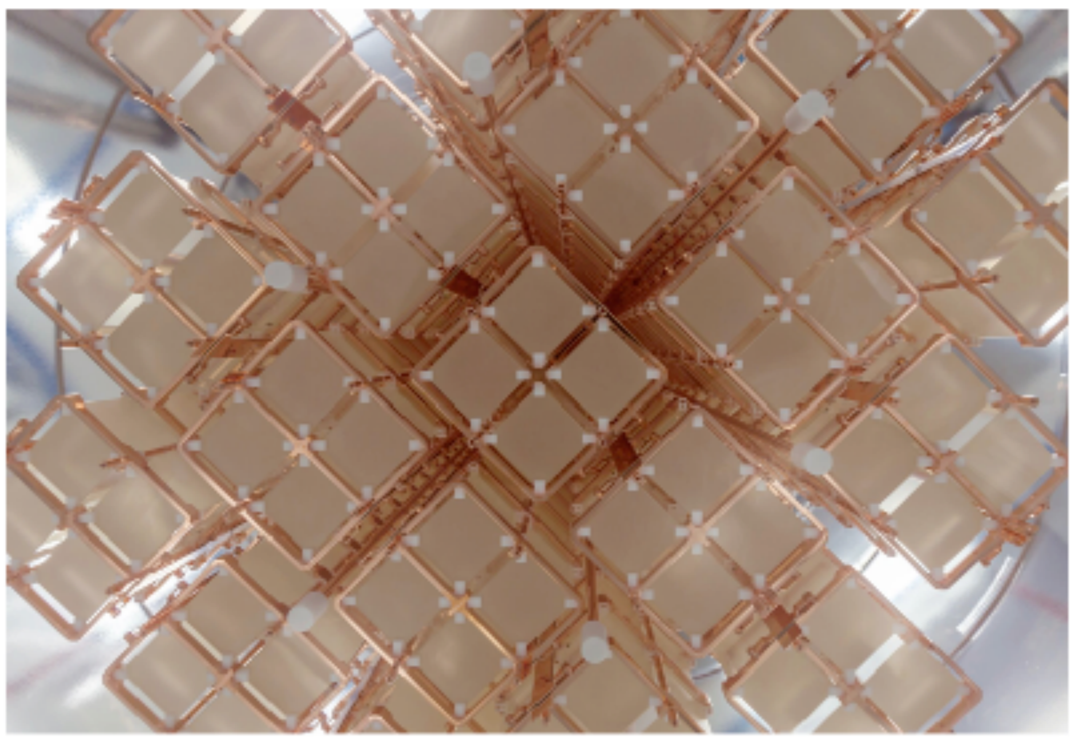
Eur. Phys. J. C (2017) 77:13

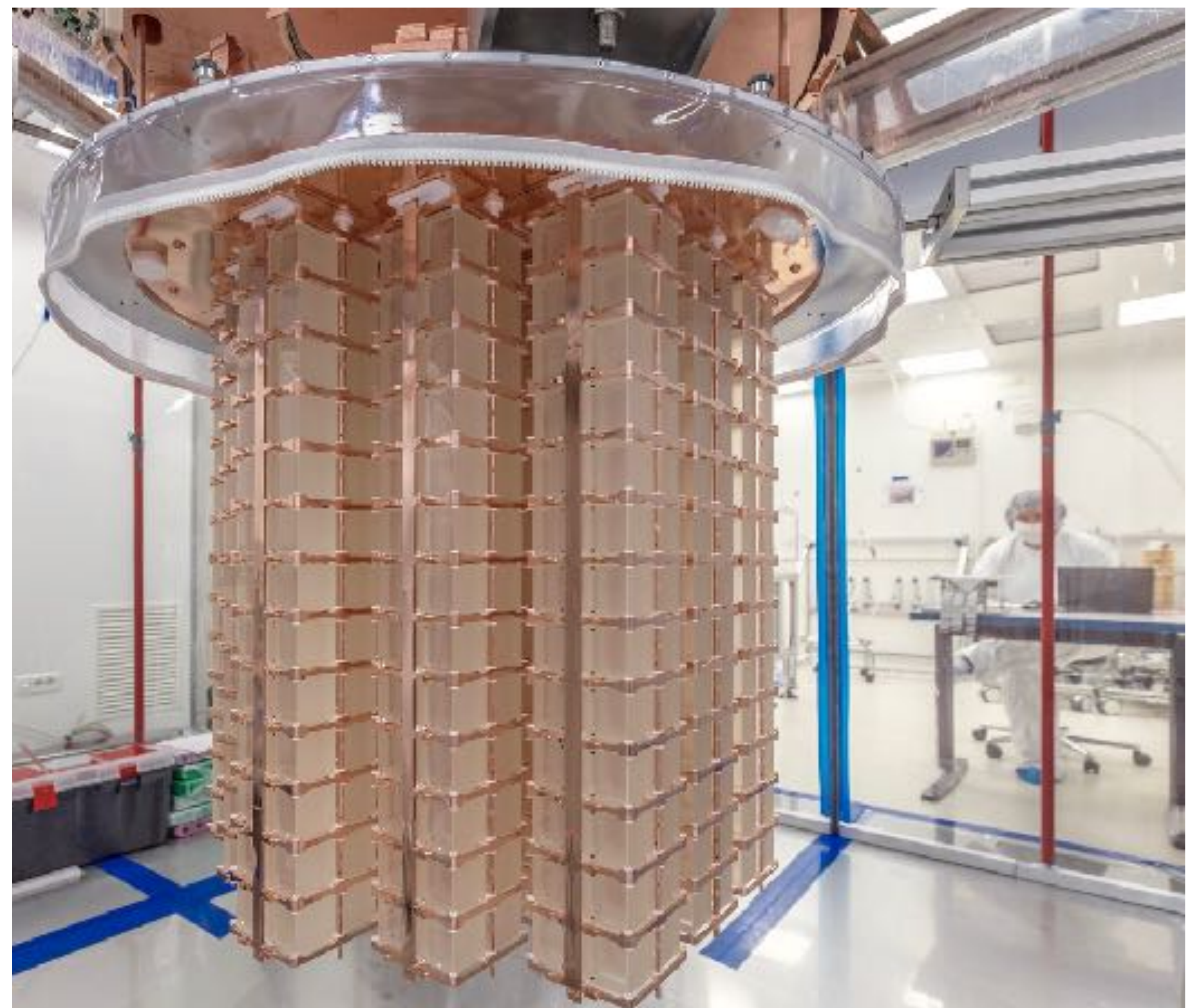
$$T_{1/2}^{2\nu\beta\beta} = [8.2$$



Detector Installation, Aug 2016

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





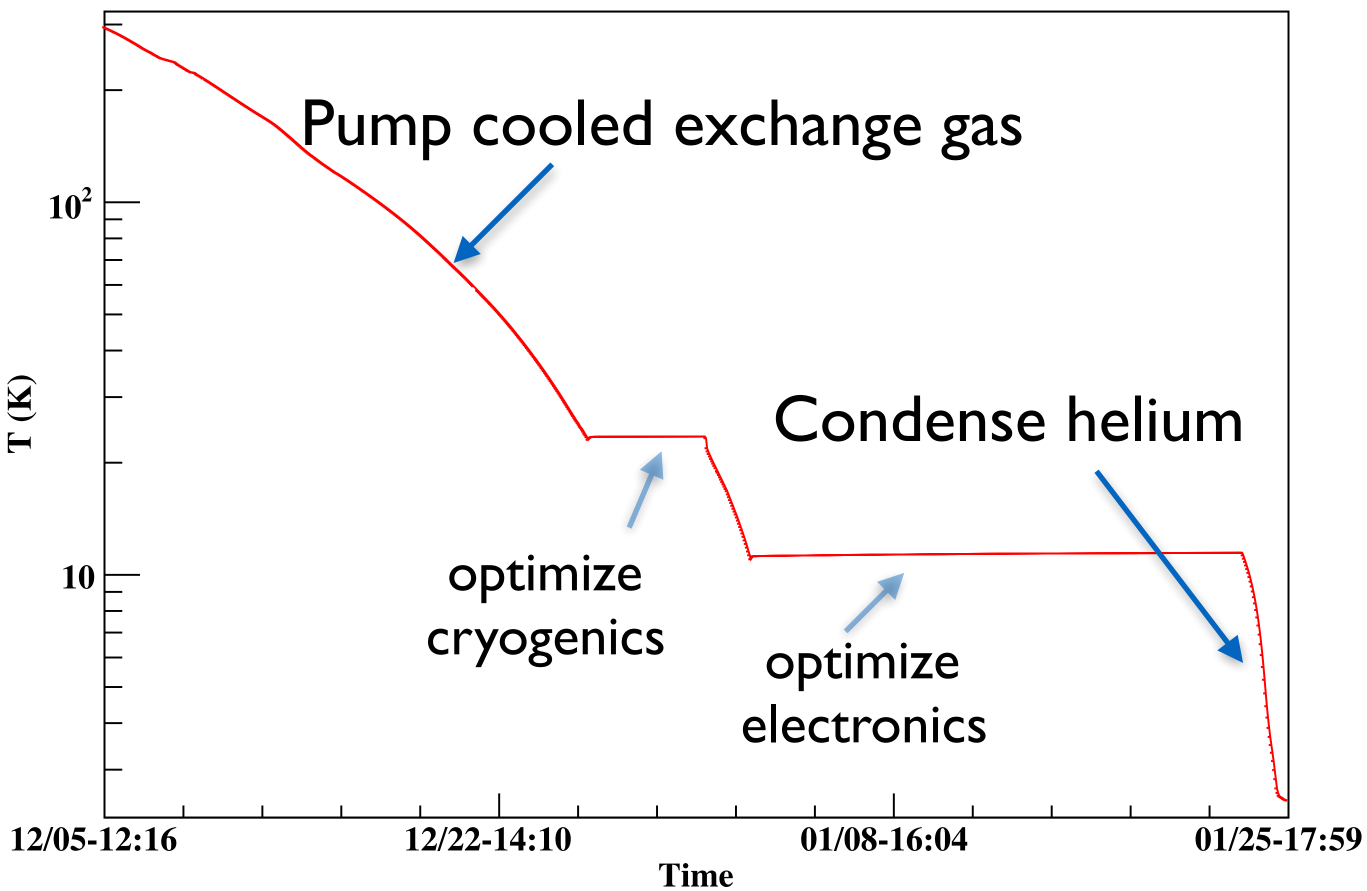
Cooling and commissioning

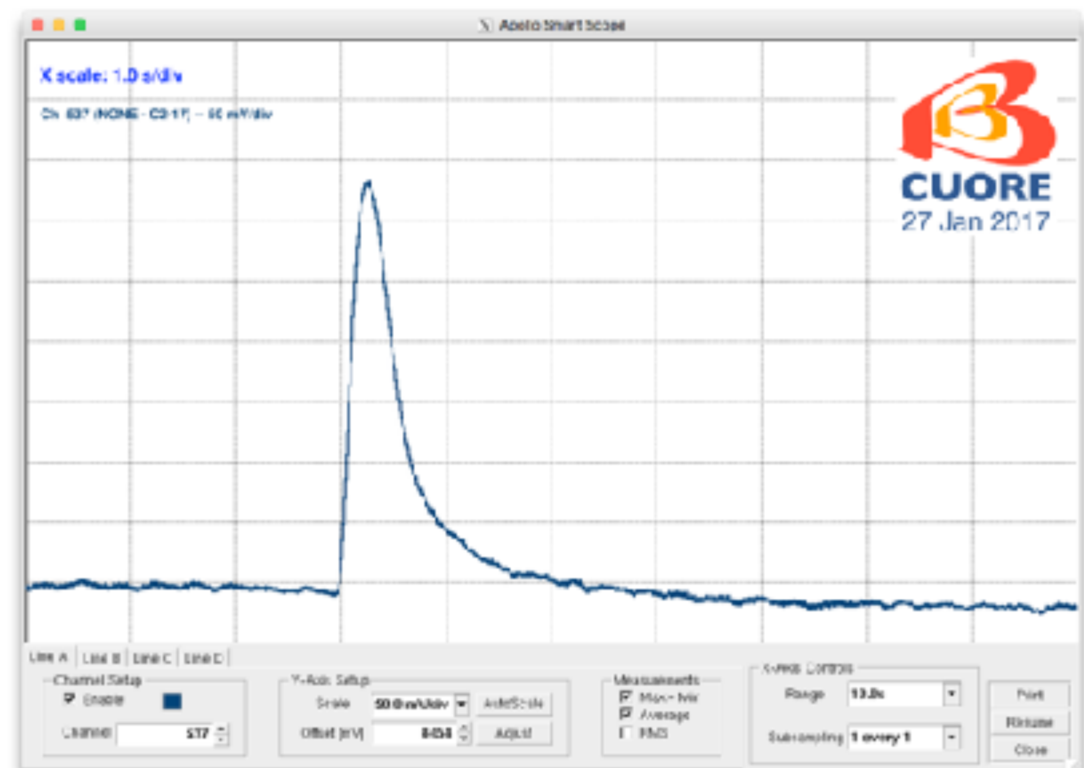
Start Dec 5

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

First pulses: Jan 27

Diode thermometer at 10mK plate





Commissioning:

- Set the thermistor working points
- Tuned the PID temperature stabilization system
- Analyzed and optimized the noise spectrum

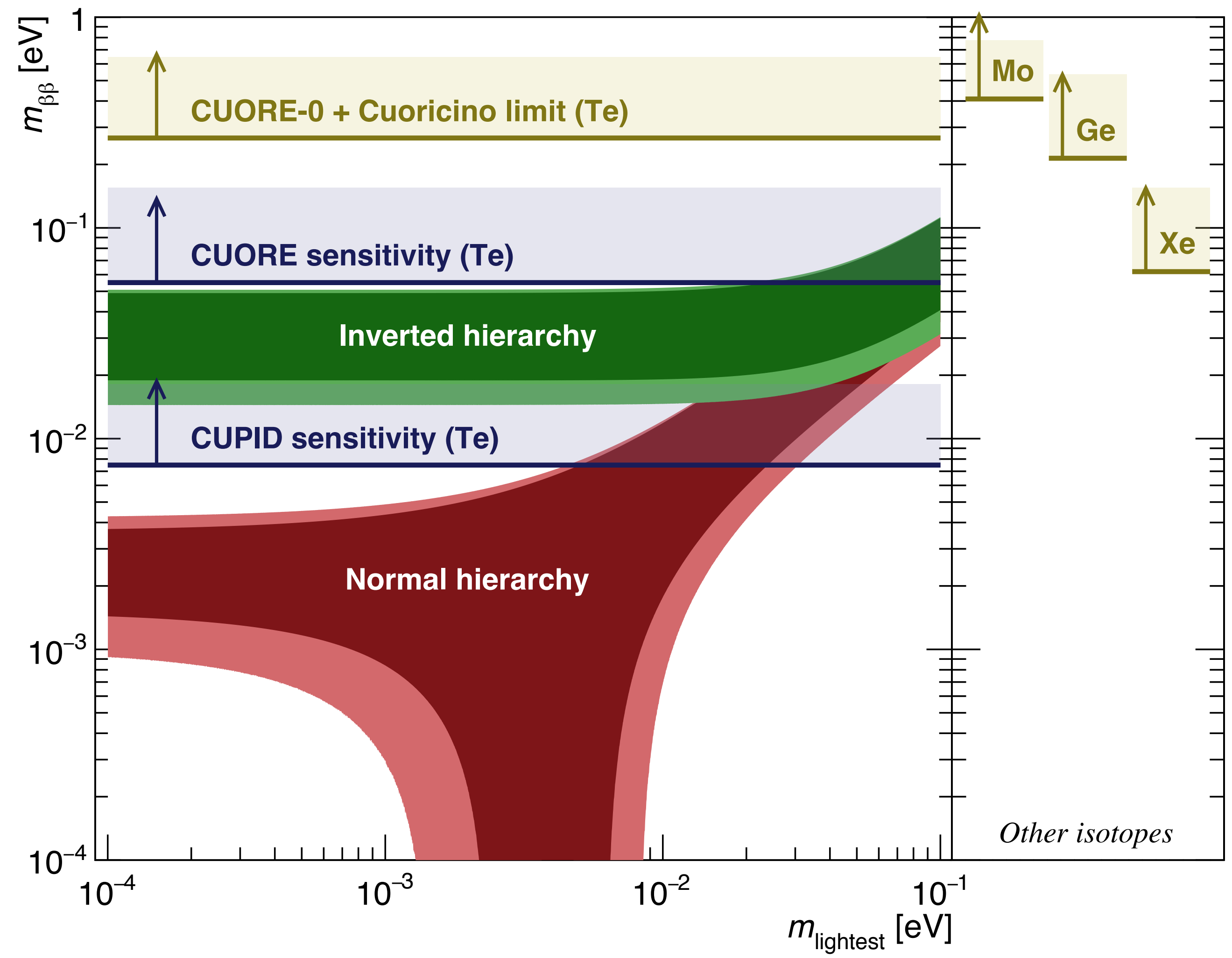
Projected Sensitivity

CUORE Goal:

- $\triangle E_{FWHM} \leq 5$ 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.

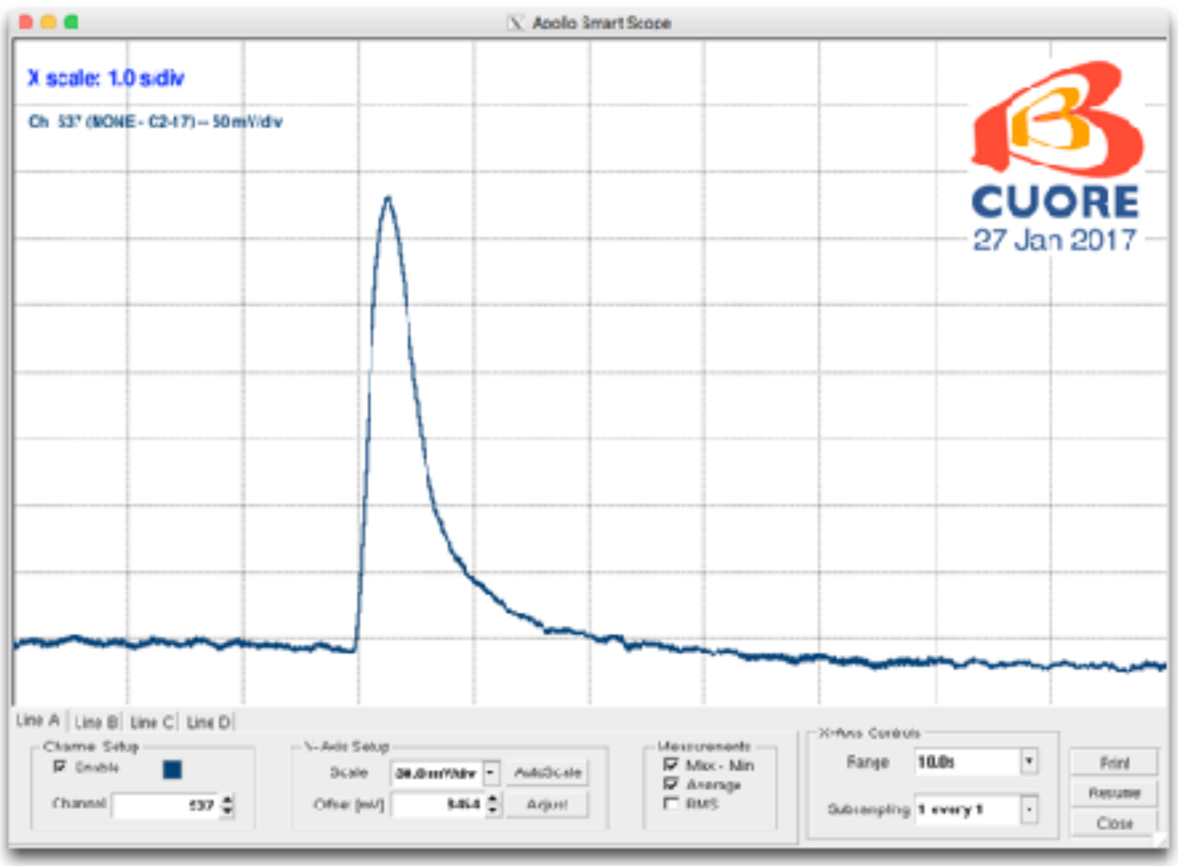
CUPID to cover the Inverted hierarchy

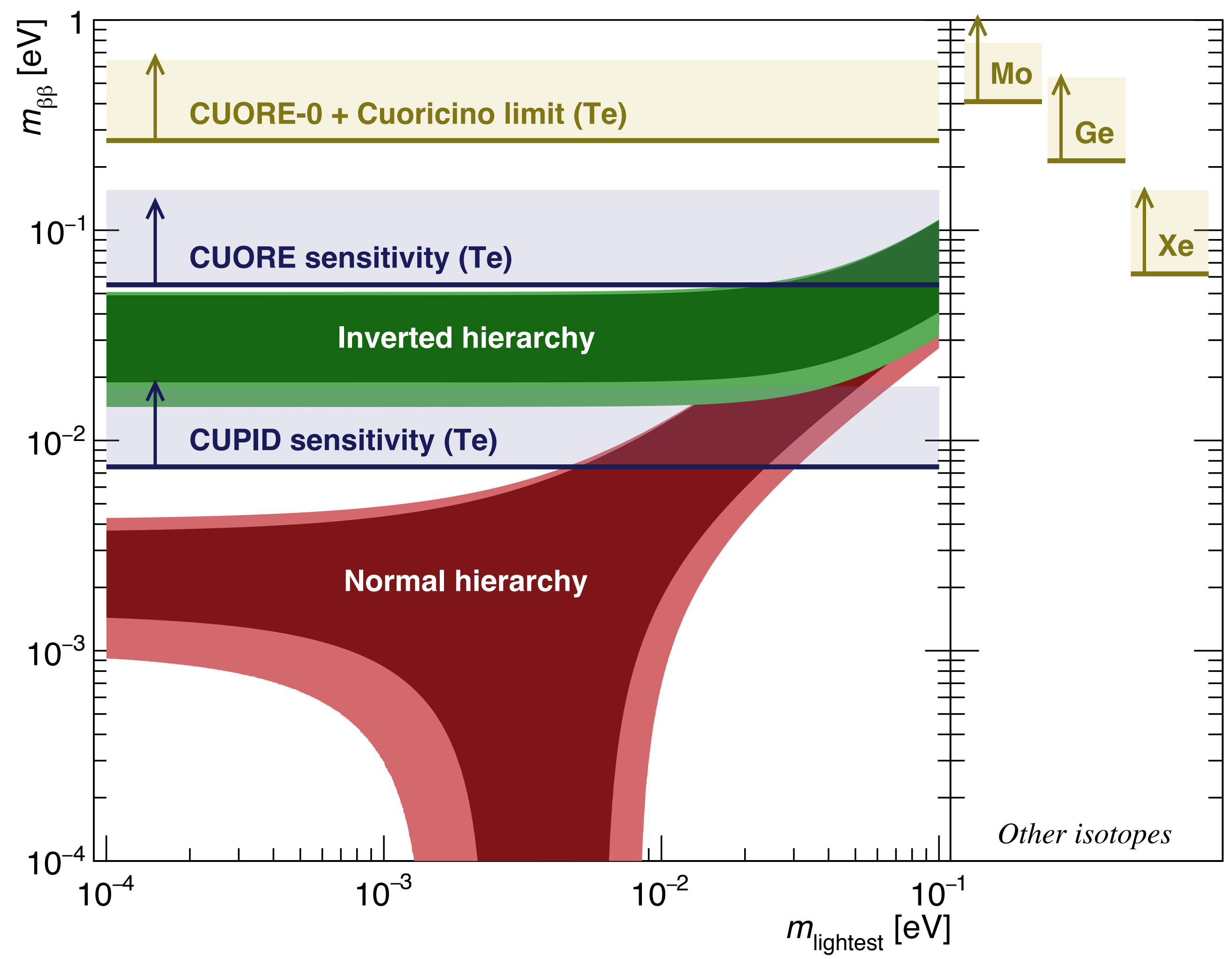
- Enriched TeO_2 with α discrimination
- Other isotopes - scintillating bolometers



Conclusions

- The detector crystals are in the cryostat, the “coldest cubic meter in the known universe”
- CUORE’s first pulse was recorded 27 Jan 2017
- The commissioning of the CUORE experiment was completed in April 2017 and CUORE is now taking data
- CUORE is on track to achieve: $T_{1/2}$ (5 years, 90% C.L.) > 9.5 x 10^{25} y





CUORE Collaboration

cuore.lngs.infn.it
facebook.com/CUORECollaboration

CSNSM

Yale

INFN Istituto Nazionale di Fisica Nucleare

Berkeley Lab

Cal Poly San Luis Obispo

Alma Mater Studiorum Università di Bologna

Università degli Studi di Cassino e del Lazio Meridionale

UCLA

SINAP

University of South Carolina

Massachusetts Institute of Technology

VirginiaTech Invent the Future®

Lawrence Livermore National Laboratory

Sapienza Università di Roma

Università degli Studi di Milano Bicocca

Shanghai Jiao Tong University

CUORE

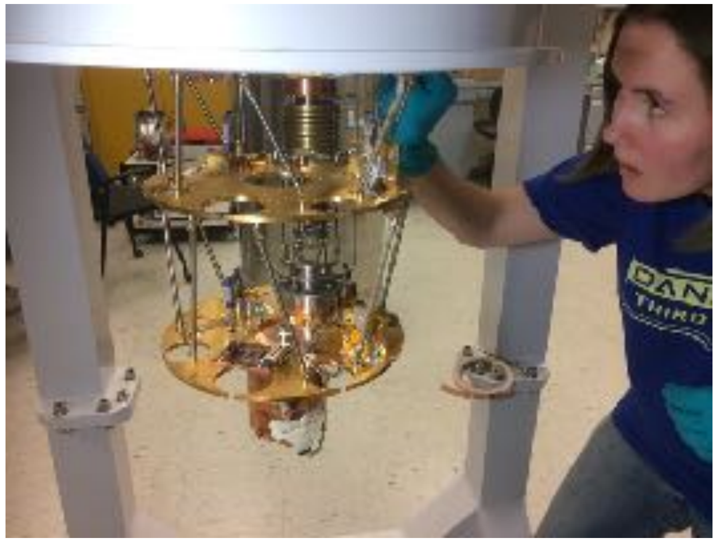
CUORE Cryostat

"The coldest cubic meter in the known universe"

6.3mK base temperature

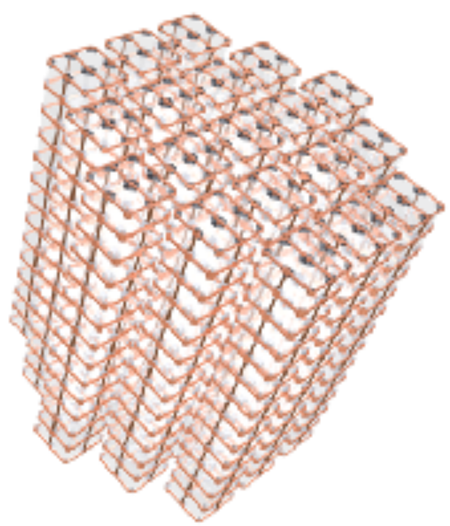
- 1m diameter inner volume
- ~3 weeks to cool

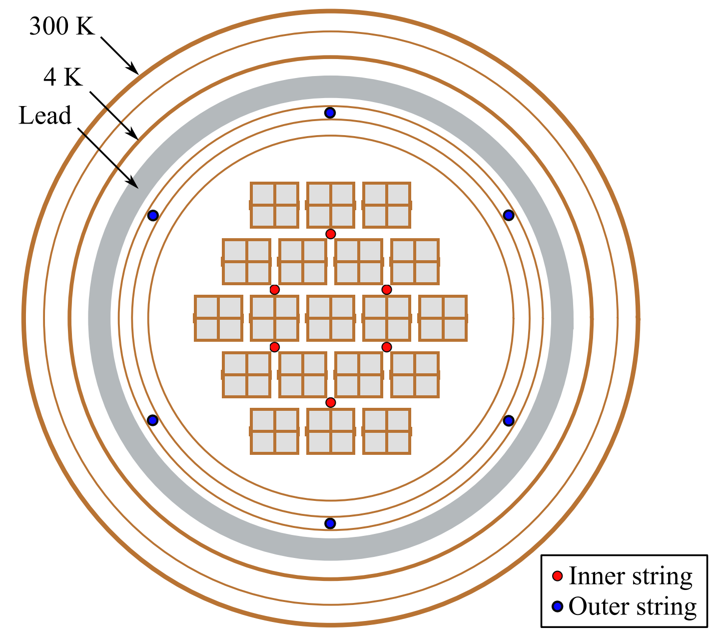
Compare to a more typical dilution refrigerator:



- 20cm diameter inner volume
- 24 hr to cool

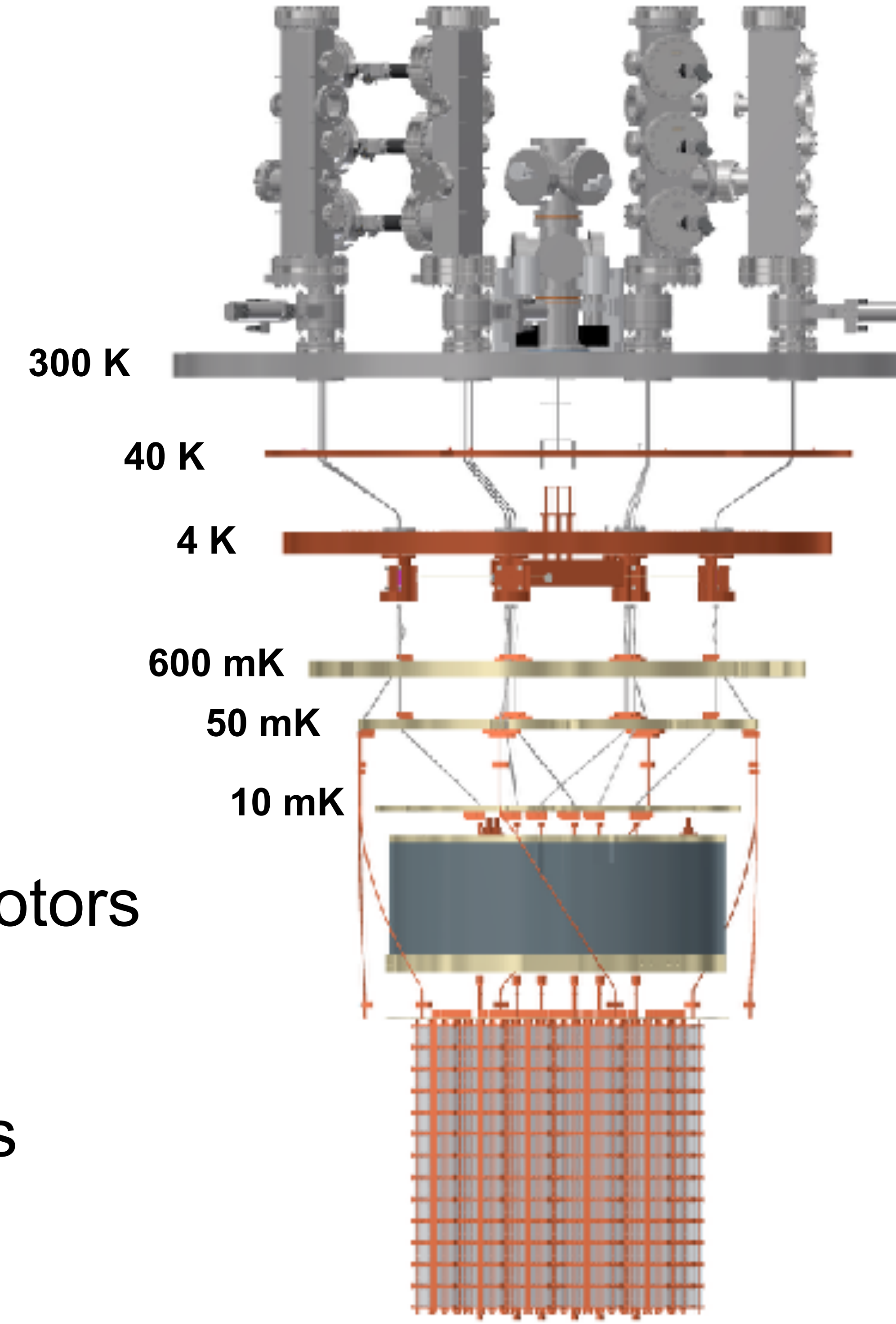
CUORE calibration system





Calibration system

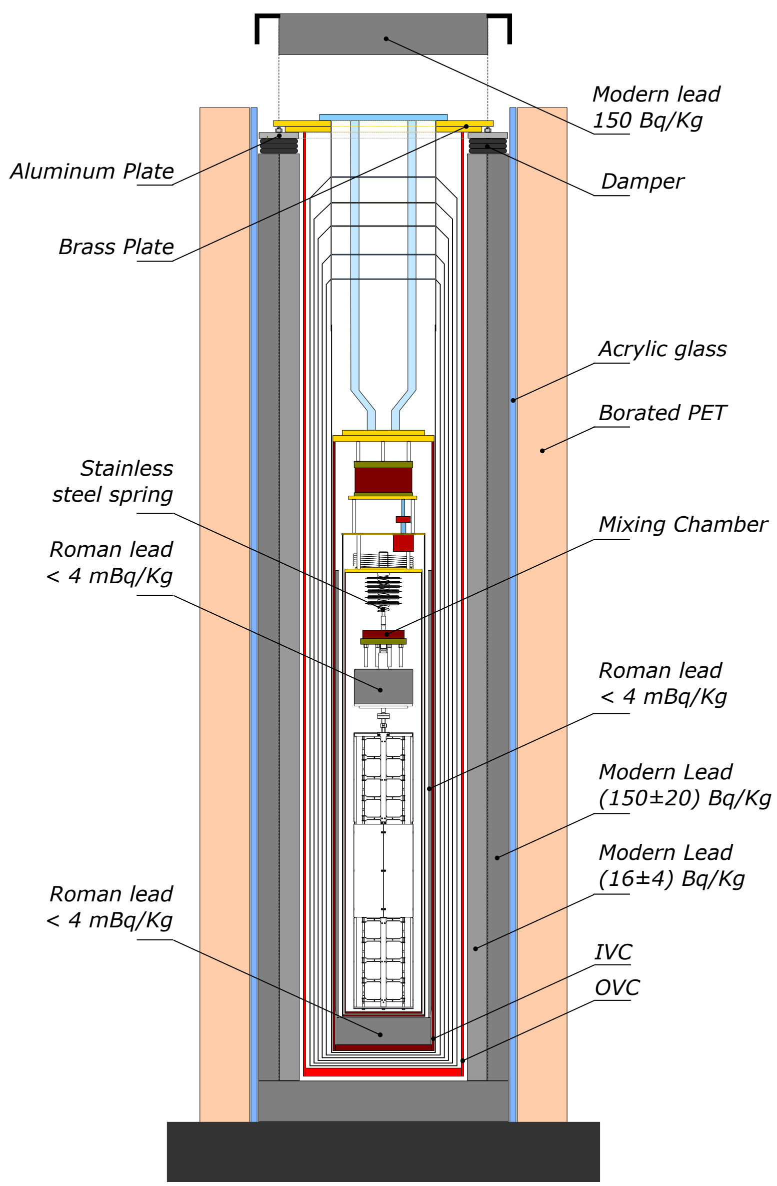
- ^{232}Th capsules on strings
- 6 internal strings (10 mK),
  6 external strings (50 mK)
- Lowered in and out monthly with stepper motors
- 10 mm/min constant speed @ 10 mK stage
- ~1 day to supply
- 239 keV - 2615 keV (^{208}Tl) calibration peaks
  2615 keV close to Q_{bb} at 2527.5 keV



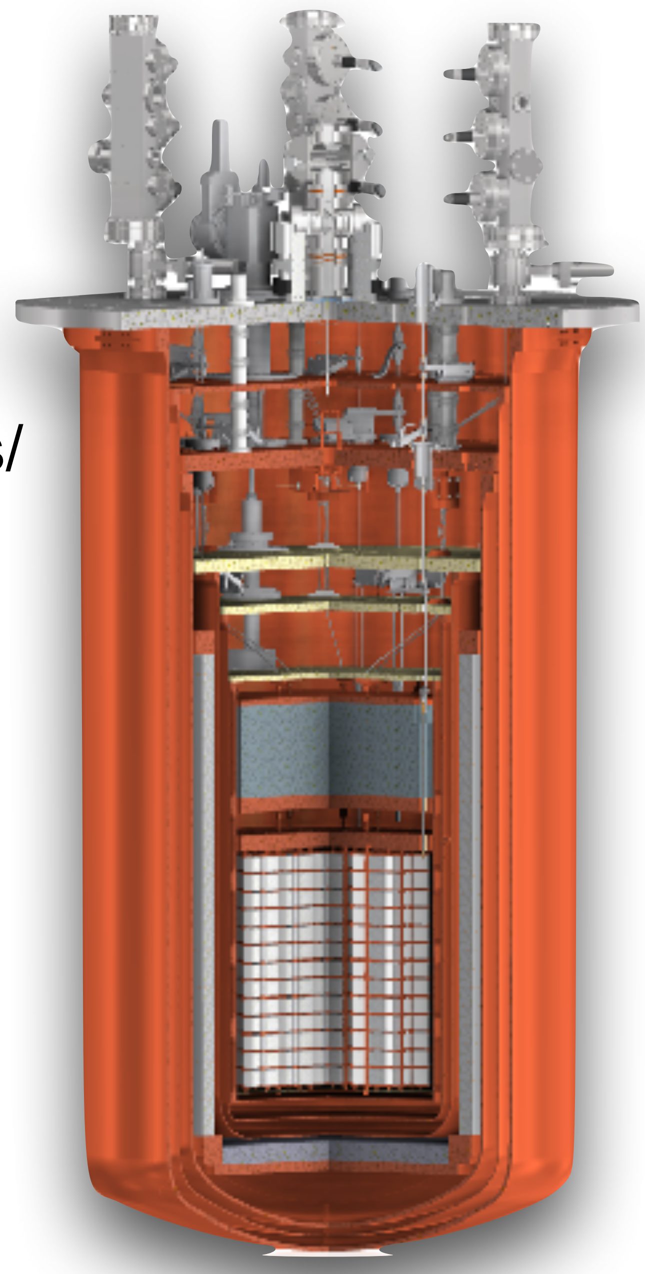
Online Monitoring

- 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 to CUORE



- 742 kg of TeO^2, **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 α/β discrimination
- TES, MMC, Neganov-Luke NTD type detector R&D started
- Surface optimizations - TeO_2 roughness, anti-reflective coating on bolometric light detector

Or

- Other isotopes - scintillating bolometers