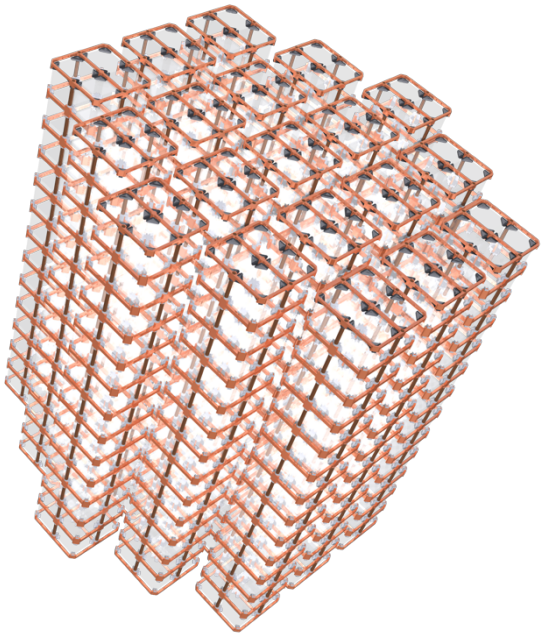
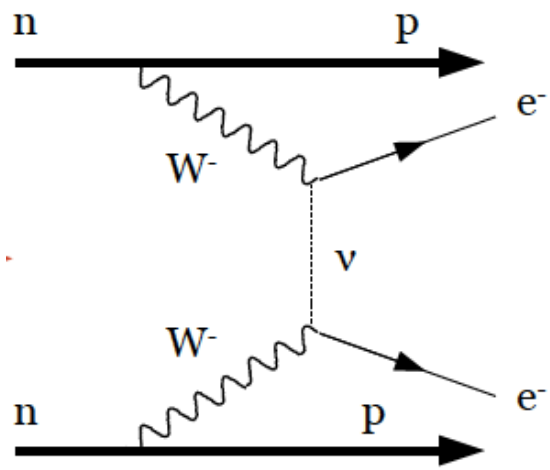
Status of the CUORE program in neutrinoless double beta decay

Tom Banks, on behalf of the CUORE Collaboration
(UC Berkeley, LBNL, LNGS)

EPS HEP 2013 conference
Stockholm, Sweden
July 20, 2013



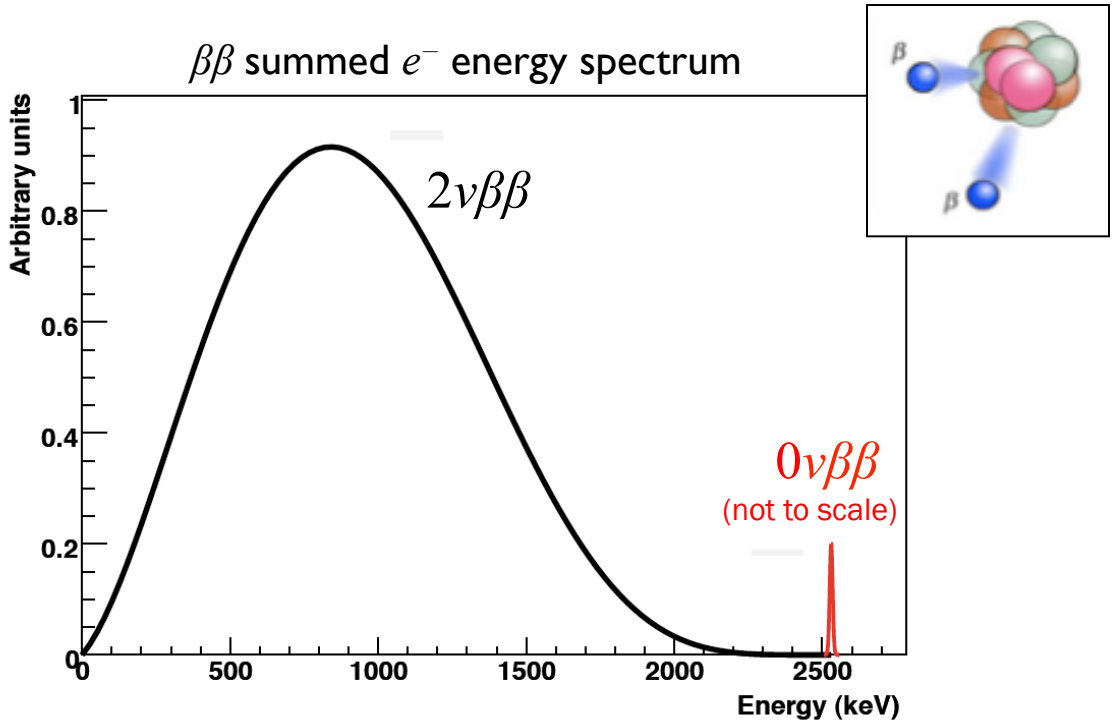
Physics motivation



If $0\nu\beta\beta$ decay is observed, it would

1. confirm neutrinos are Majorana particles (i.e., $\nu = \bar{\nu}$);
2. set constraints on the effective Majorana mass $\langle m_{\beta\beta} \rangle$, providing information about the absolute ν mass scale;
3. provide information about the mass hierarchy.

Detecting $0\nu\beta\beta$ decay

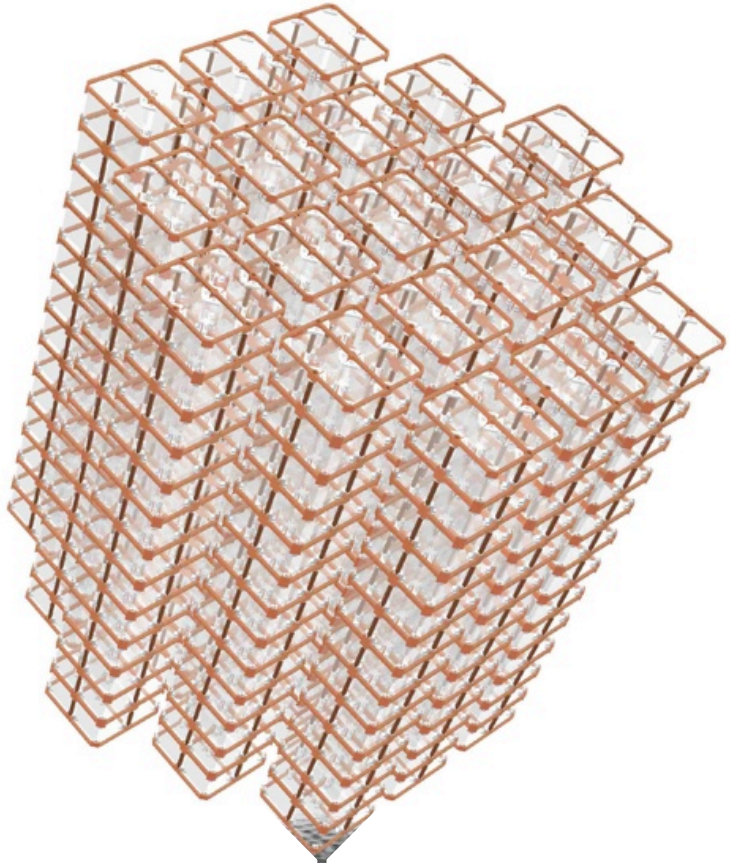


- **General approach:** Detect the two final-state electrons

- **Signature:** Two simultaneous electrons with summed energy $Q_{\beta\beta}$, the Q-value for $\beta\beta$ decay in the isotope under study

CUORE

Cryogenic Underground Observatory for Rare Events

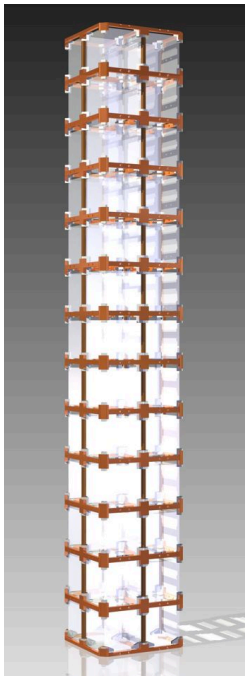


Primary objective is to search for $0\nu\beta\beta$ decay in ^{130}Te

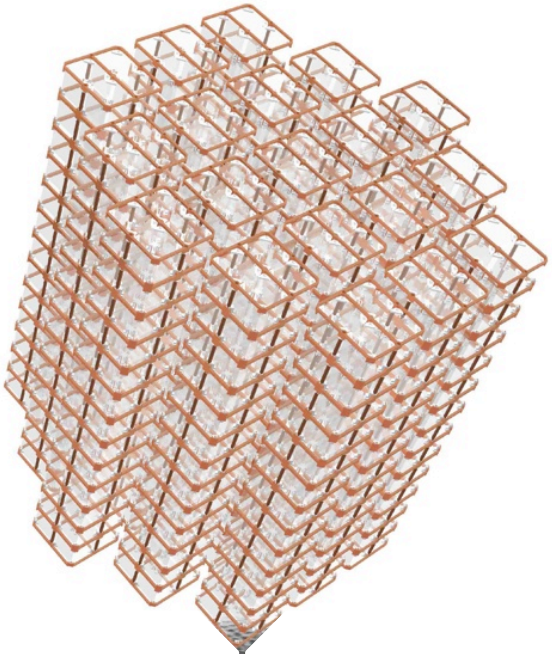
CUORE program

Cuoricino
2003–2008
11 kg ^{130}Te

COMPLETE



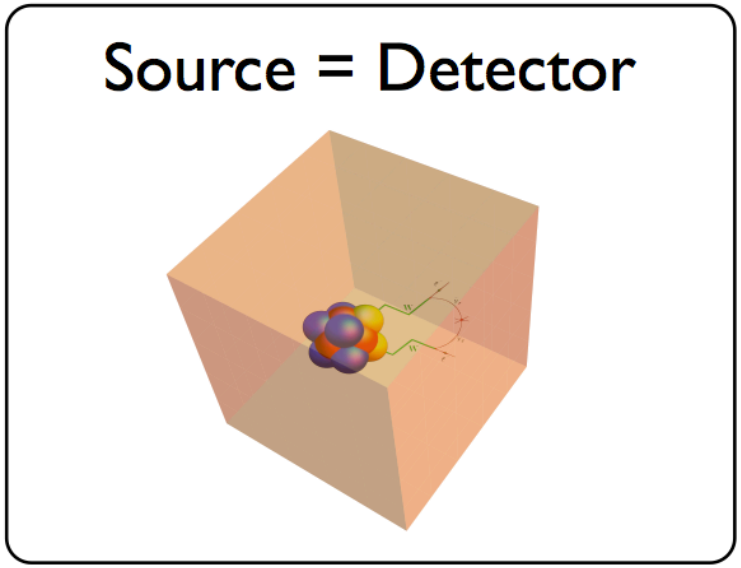
CUORE-0
2013–2015
11 kg ^{130}Te



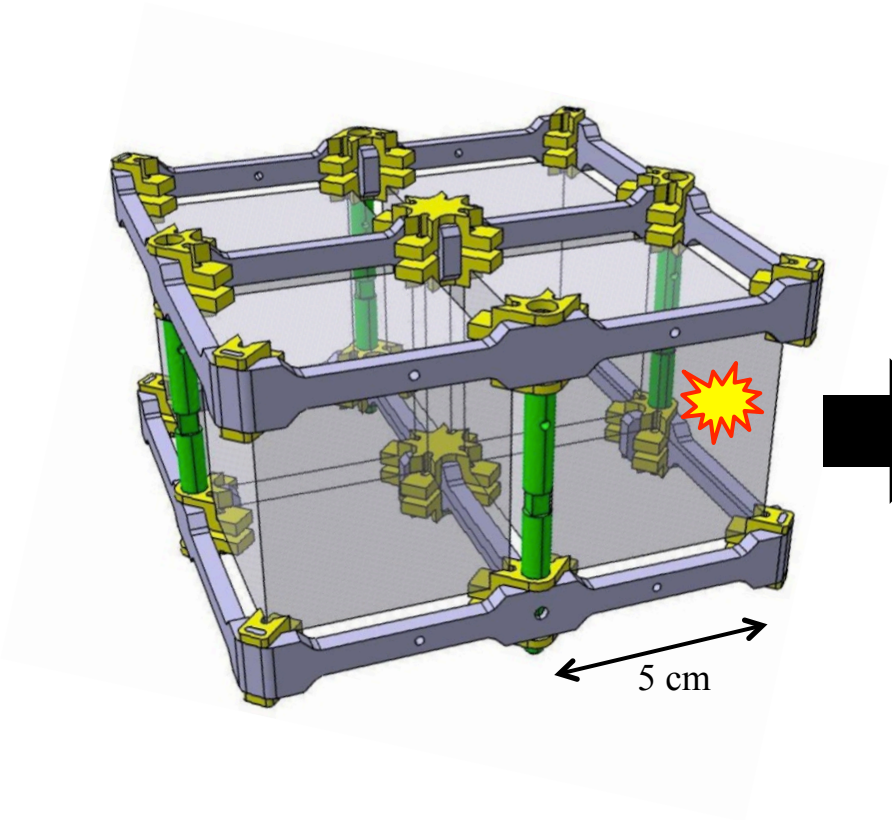
CUORE
2015–2020
206 kg ^{130}Te

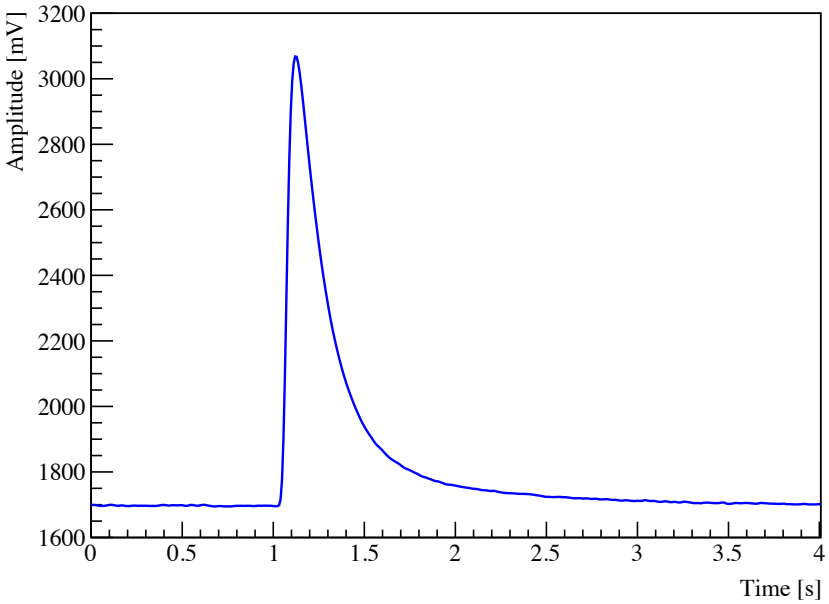
Cryogenic bolometers

Ultracold TeO_2 crystals function as highly sensitive calorimeters



Cryogenic bolometers

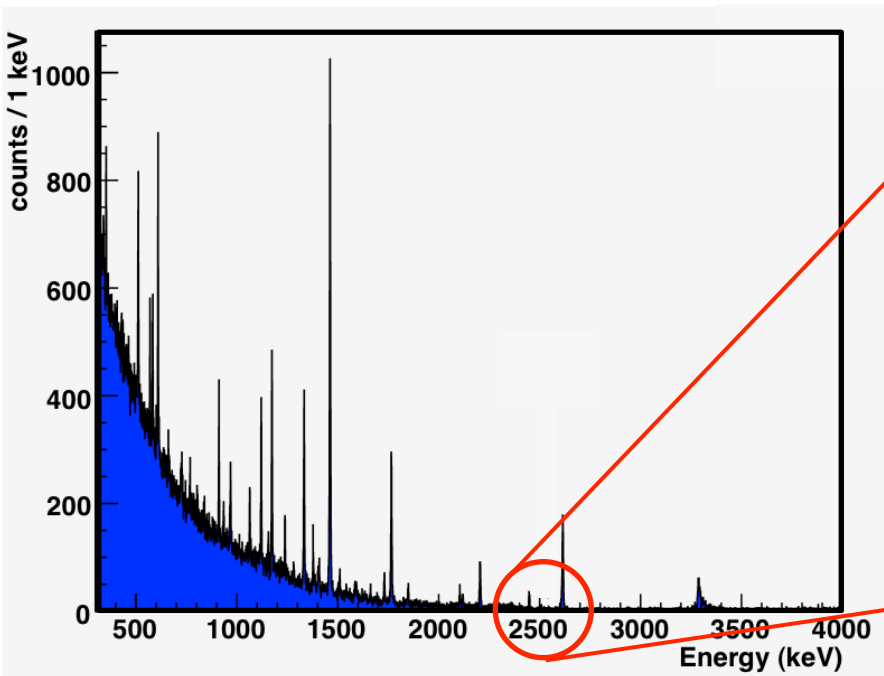


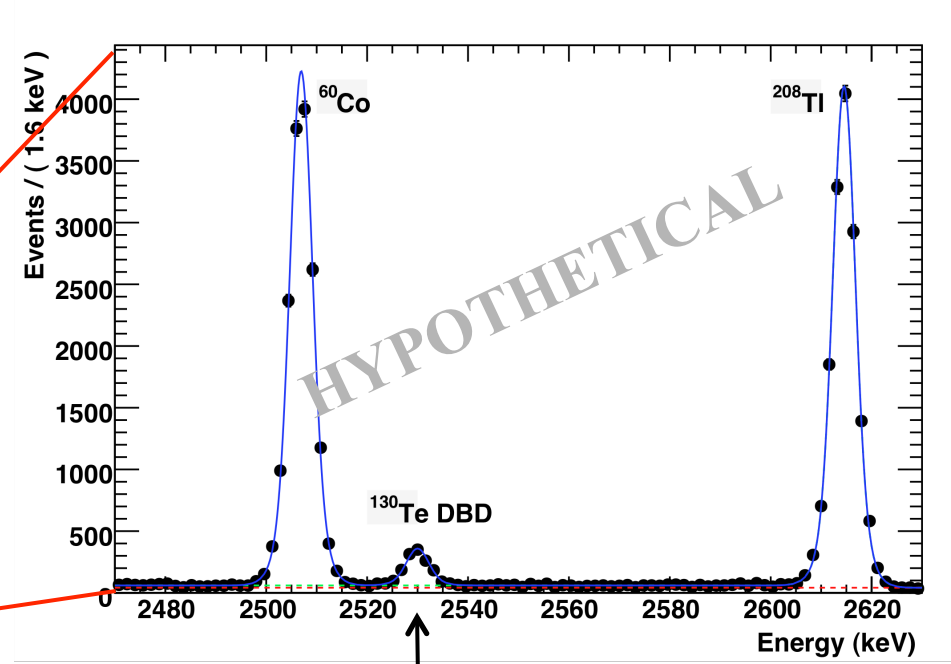


At T=10 mK, particle interactions inside TeO_2 crystal produce a measurable rise in its temperature

Amplitude of temperature pulse is proportional to deposited energy

Experimental method

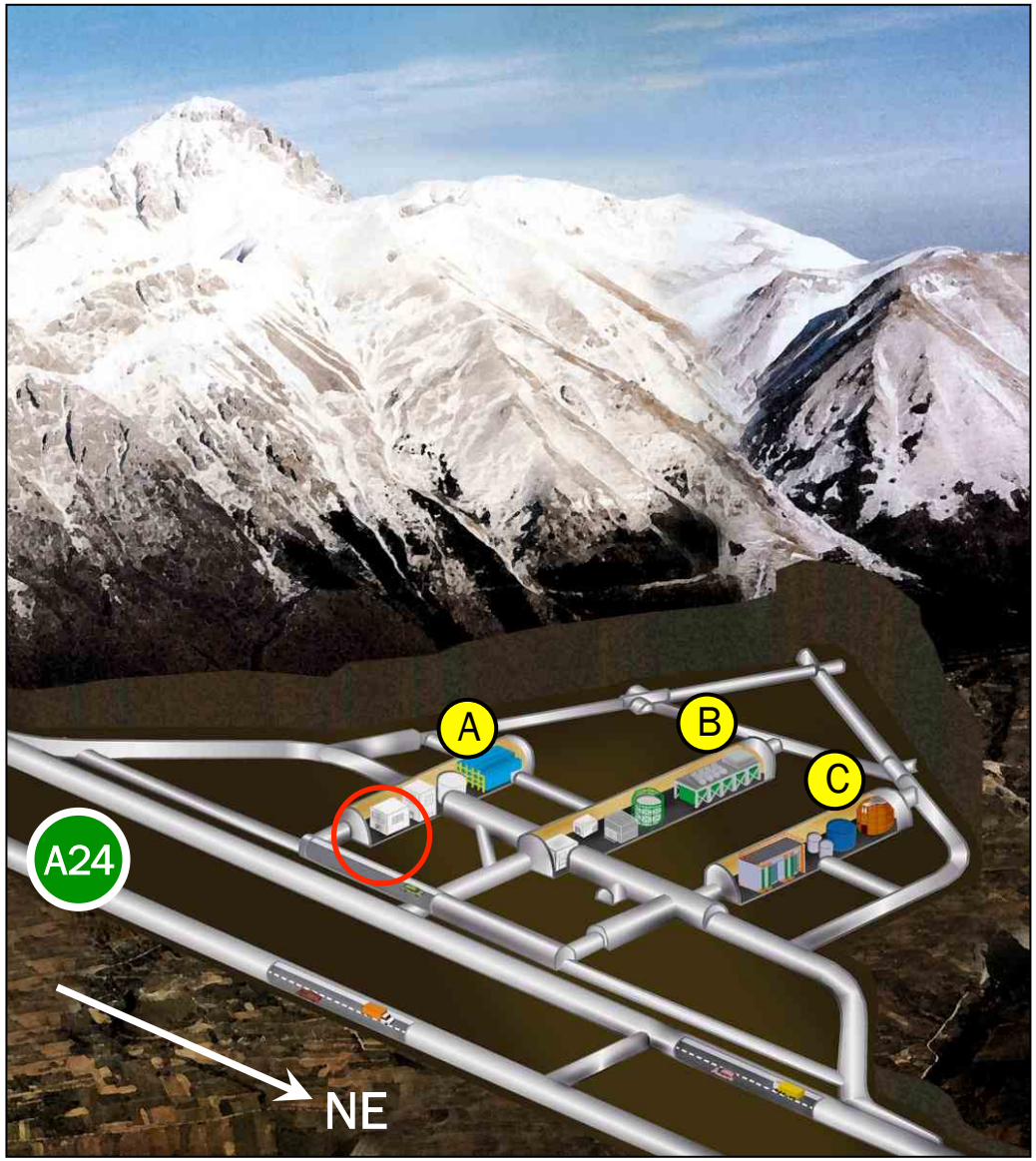




The energy spectrum of detected pulses is compiled...

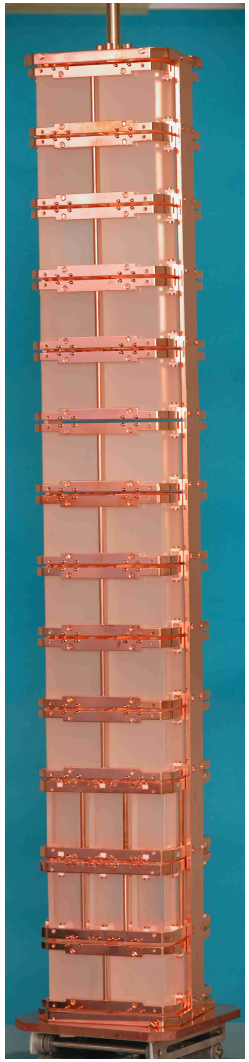
... and the signature of $0\nu\beta\beta$ in ^{130}Te would be a small peak at ~ 2527 keV.

LNGS underground lab

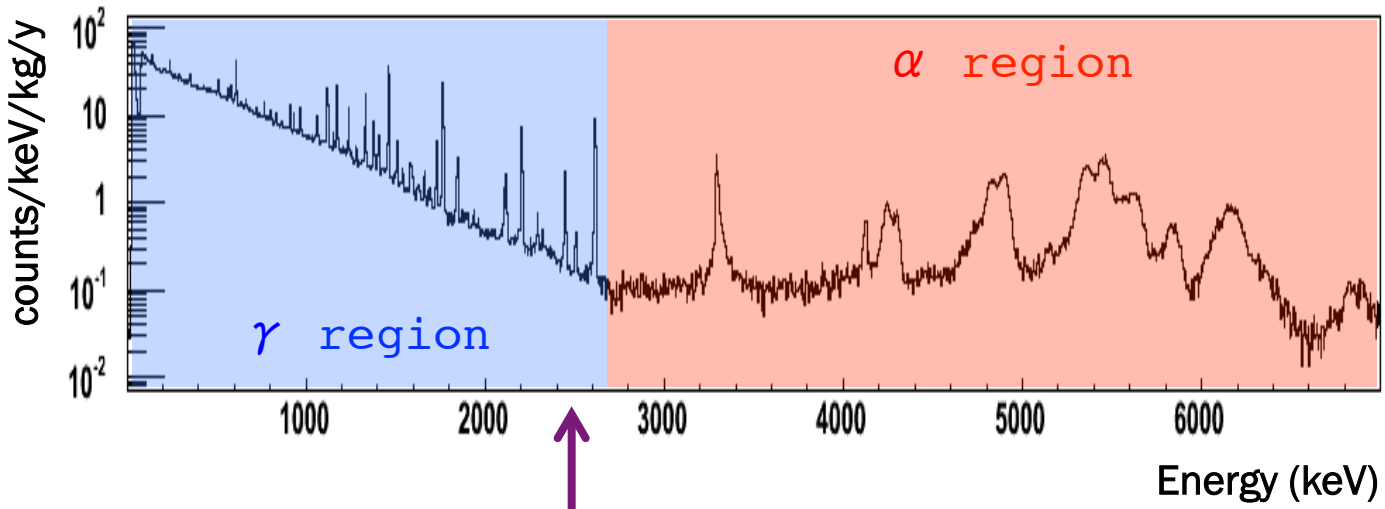


- Gran Sasso, Italy
- 1.4-km rock overburden

The past: Cuoricino

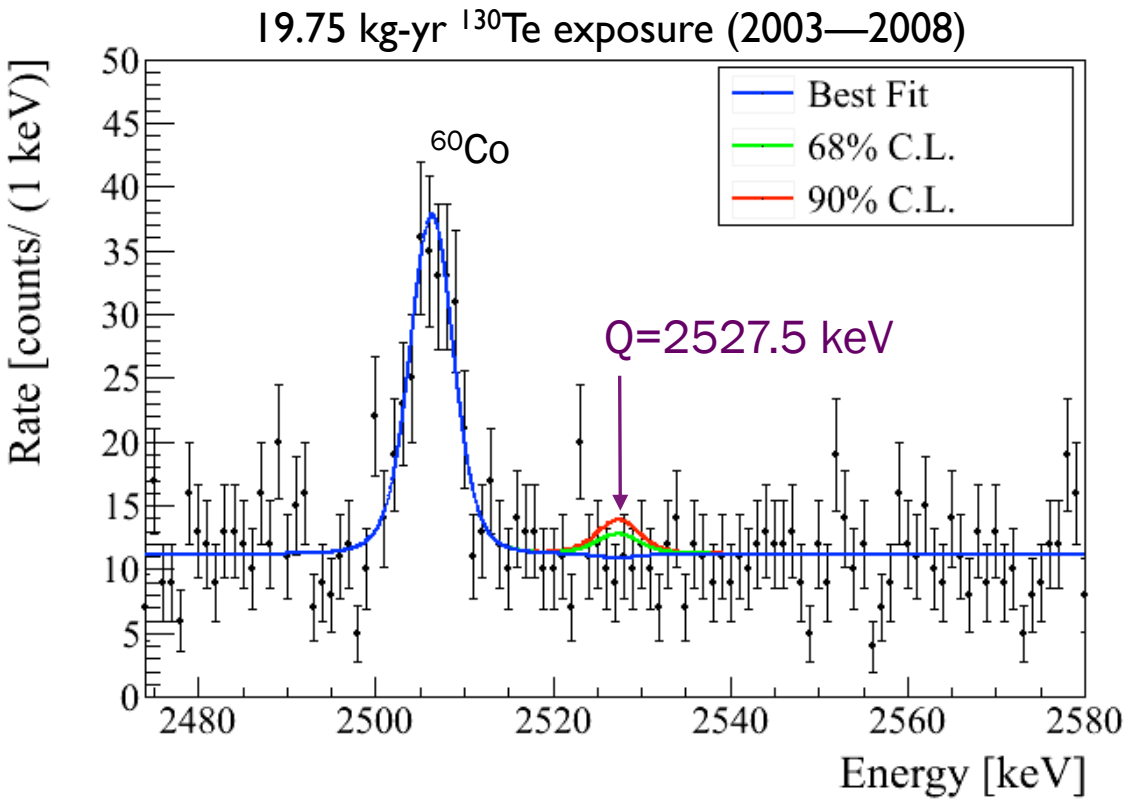


Energy spectrum



^{130}Te Q-value = 2527.5 keV

The past: Cuoricino



Background: 0.169 ± 0.006 counts/keV/kg/y (^{130}Te)

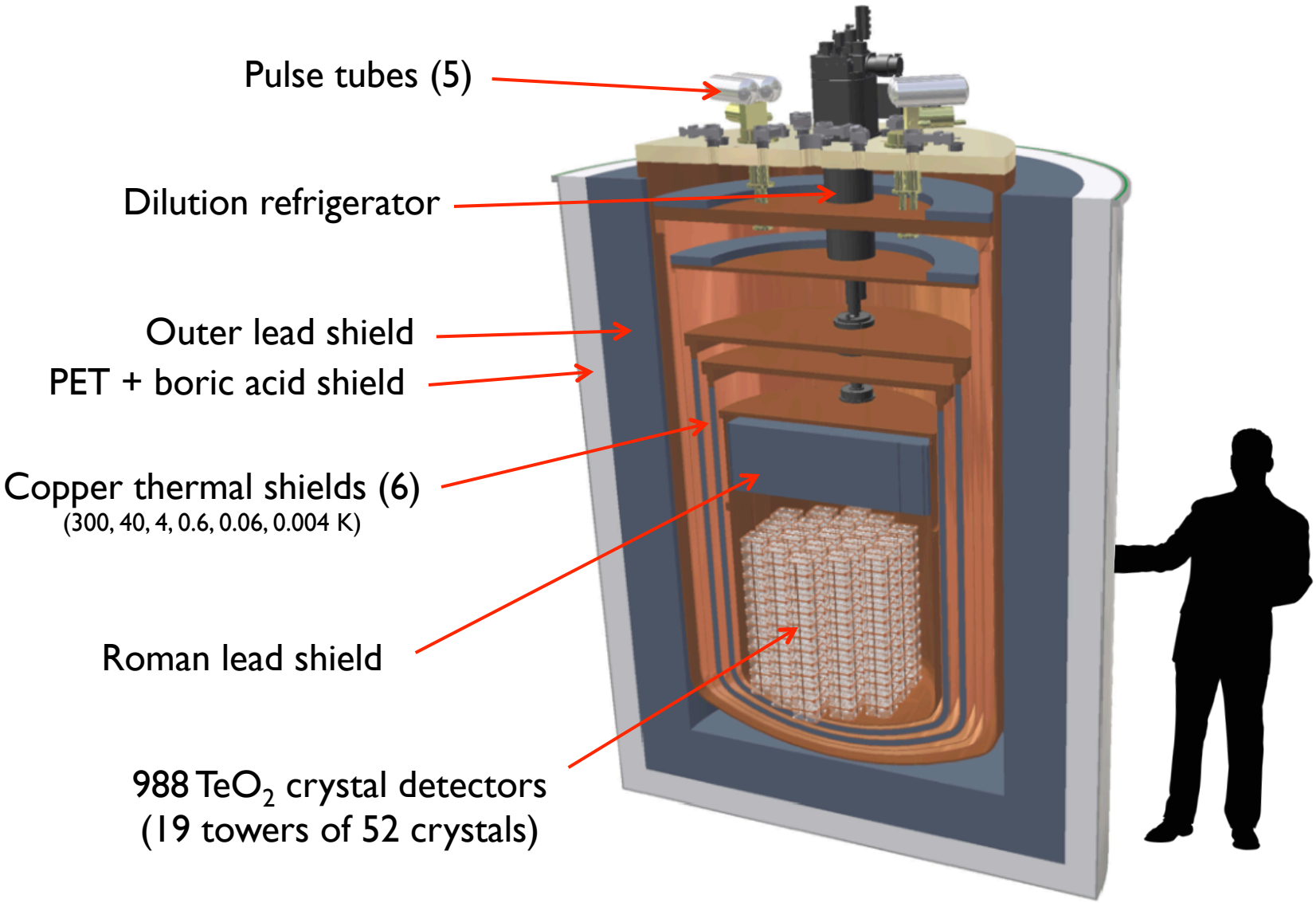
Lower limit, half-life: $T_{1/2}^{0\nu\beta\beta}(^{130}\mathrm{Te}) \geq 2.8 \times 10^{24}$ y (90% C.L.)

Upper limit, Majorana ν mass: $\langle m_{\beta\beta} \rangle < 300 - 710$ meV

E. Andreotti et al. (CUORICINO Collaboration), Astropart. Phys. 34: 822–831 (2011) [arXiv:nucl-ex/1012.3266].

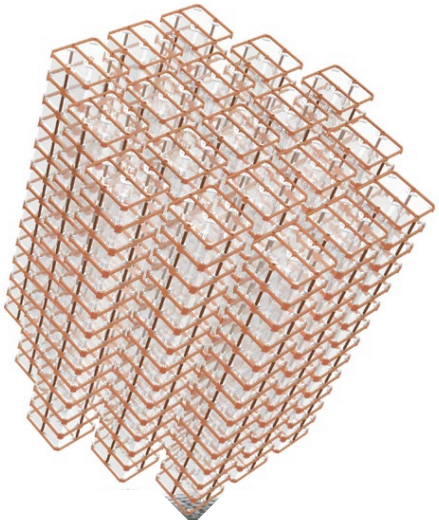
The present: CUORE

CUORE


Pulse tubes (5)
Dilution refrigerator
Outer lead shield
PET + boric acid shield
Copper thermal shields (6)
(300, 40, 4, 0.6, 0.06, 0.004 K)
Roman lead shield
988 TeO_2 crystal detectors
(19 towers of 52 crystals)

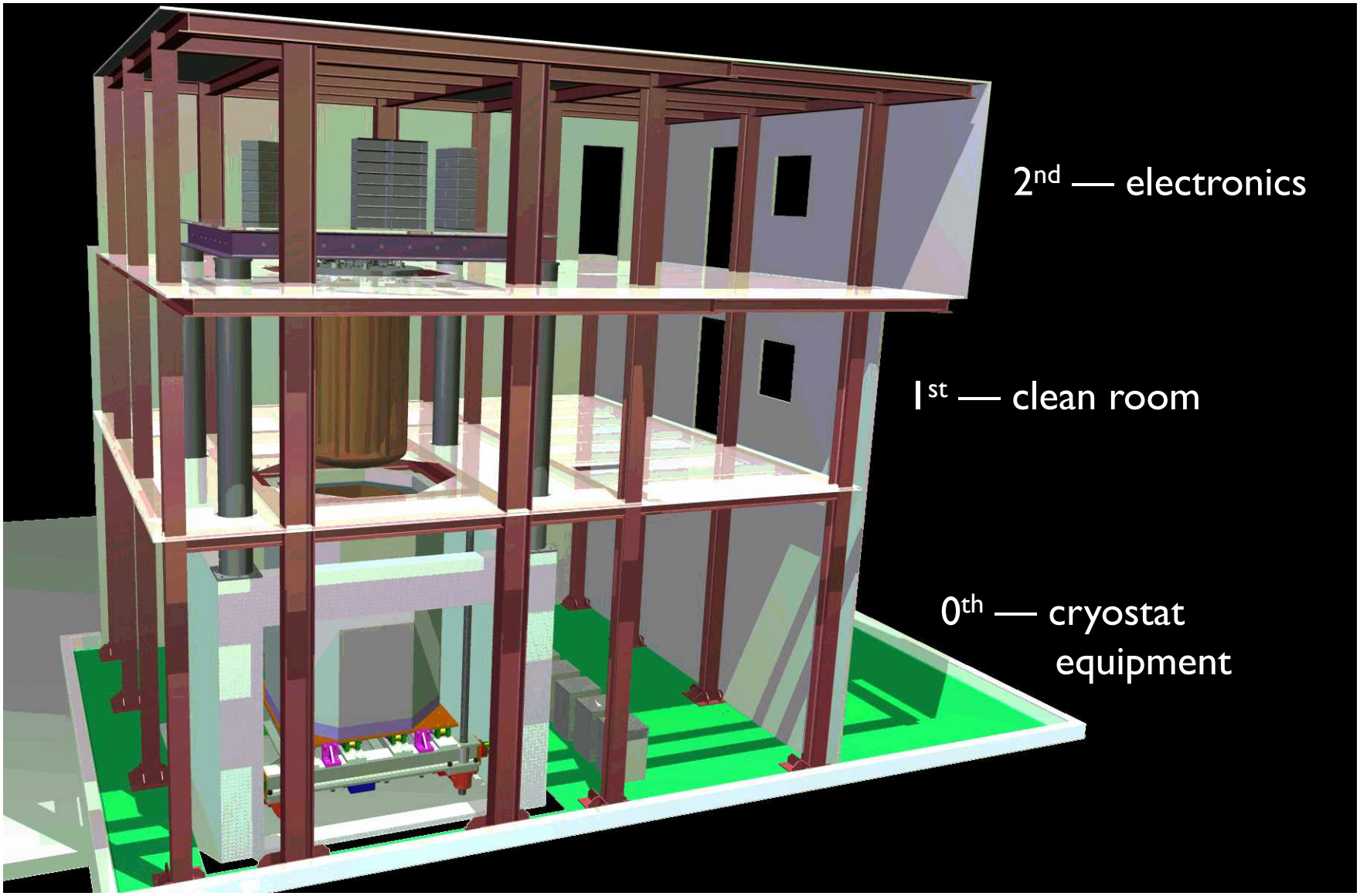
Detector improvements

- Cleaner crystals
- Cleaner copper, and less of it
- Cleaner assembly environment
- Less vibration in copper frames
- Better self-shielding & anticoincidence coverage

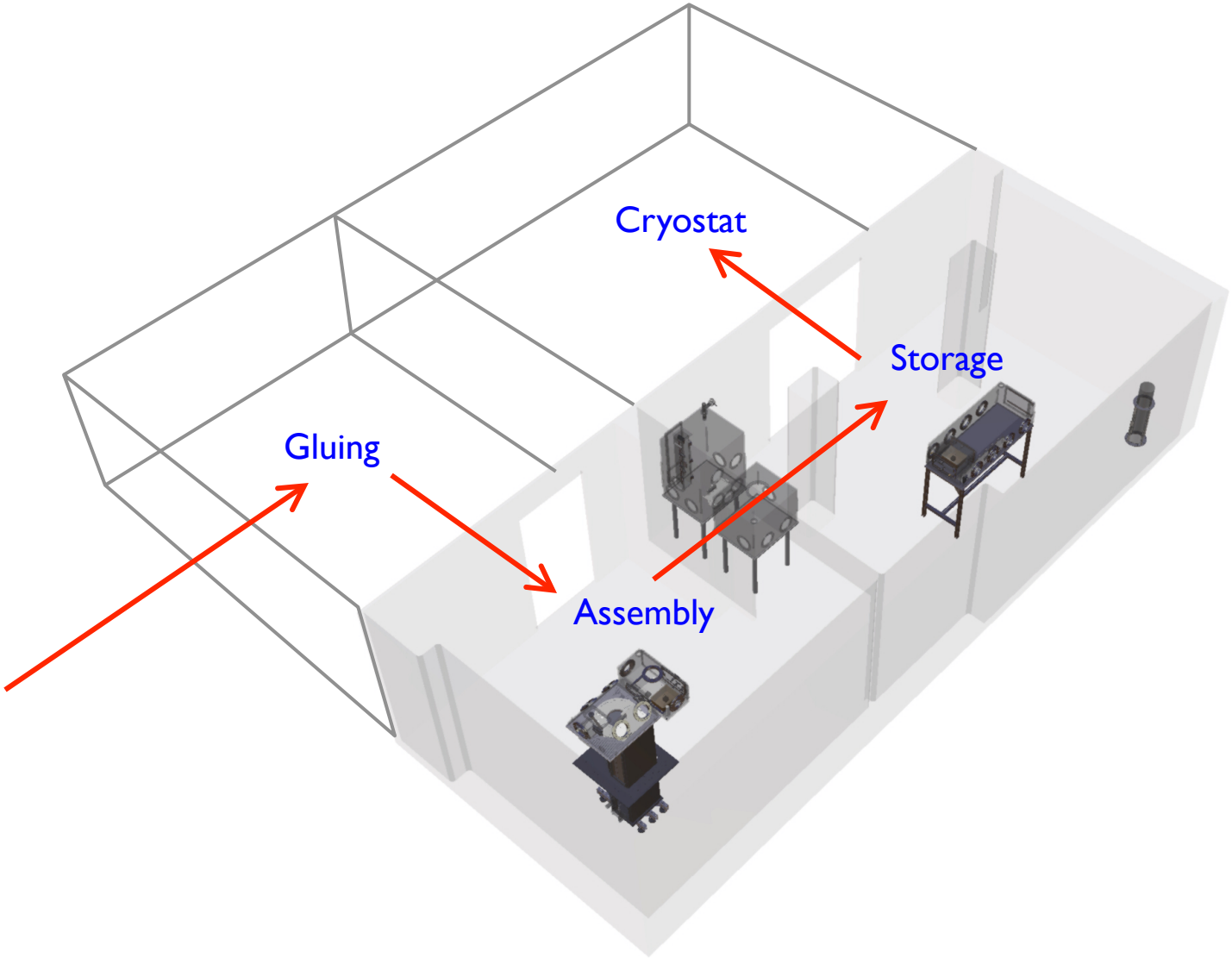


	Cuoricino	CUORE-0	CUORE
^{130}Te mass (kg)	11	11	206
Background (c/keV/kg/y) @ 2527.5 keV	0.17	0.05	0.01
E resolution (keV) FWHM @ 2615 keV	~ 6	5–6	5
$\langle m_{\beta\beta} \rangle$ (meV) @ 90% C.L.	300–710	204–533	51–133

Hut



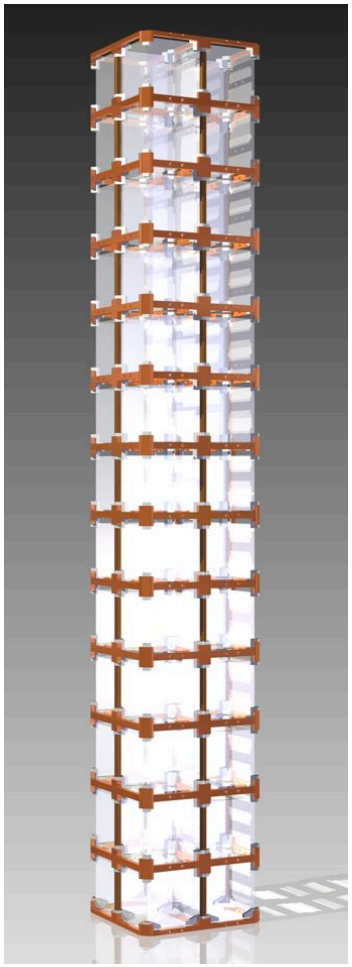
Detector assembly



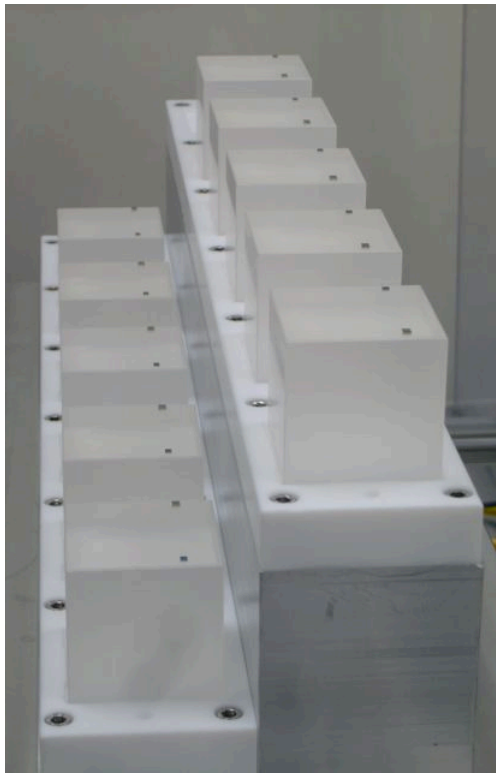
Crystals are prepared & assembled into towers inside N_2-filled glove boxes in clean room

CUORE-0

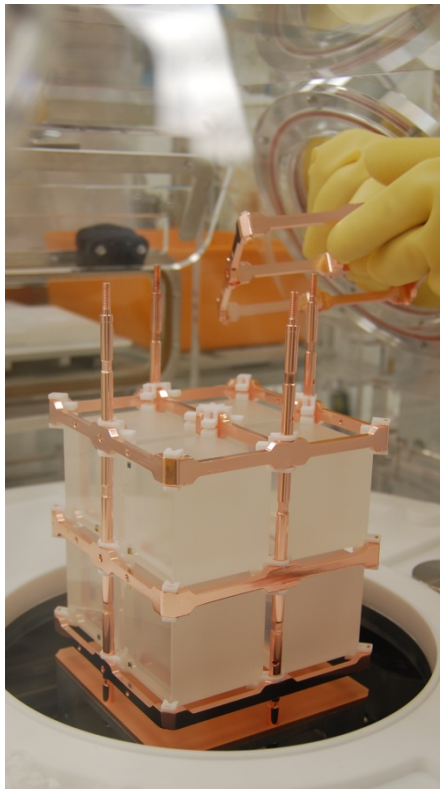
- First tower from CUORE assembly line
- Purpose:
  1. Test CUORE assembly line
  2. Surpass Cuoricino while CUORE is being assembled
- Assembled in Apr 2012
- Operating in former Cuoricino cryostat since Mar 2013



CUORE-0 assembly



Gluing

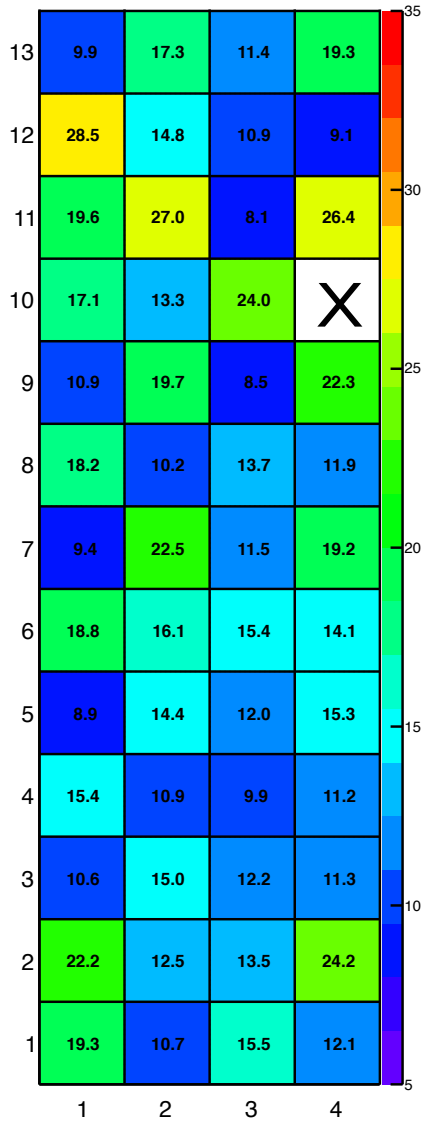


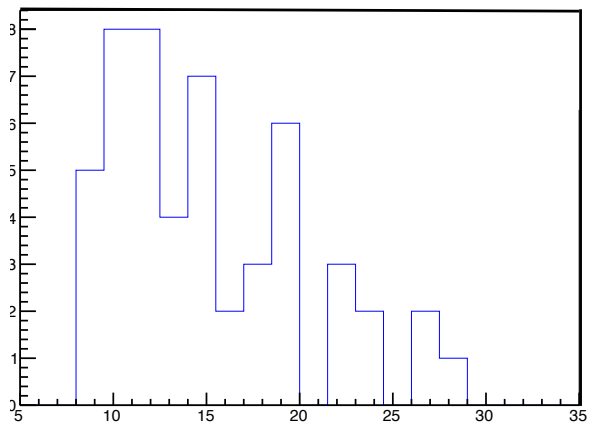
Assembly

Installation

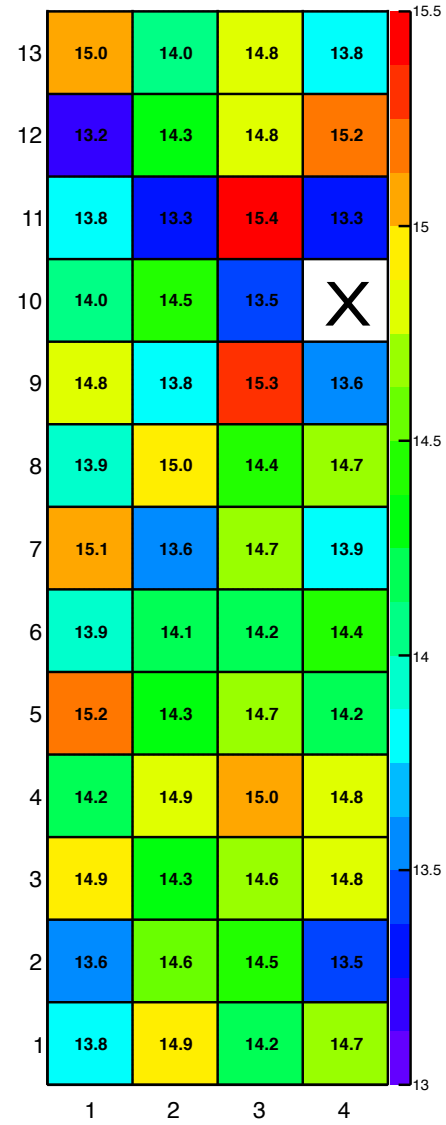
CUORE-0 working points

Resistance (MOhm)



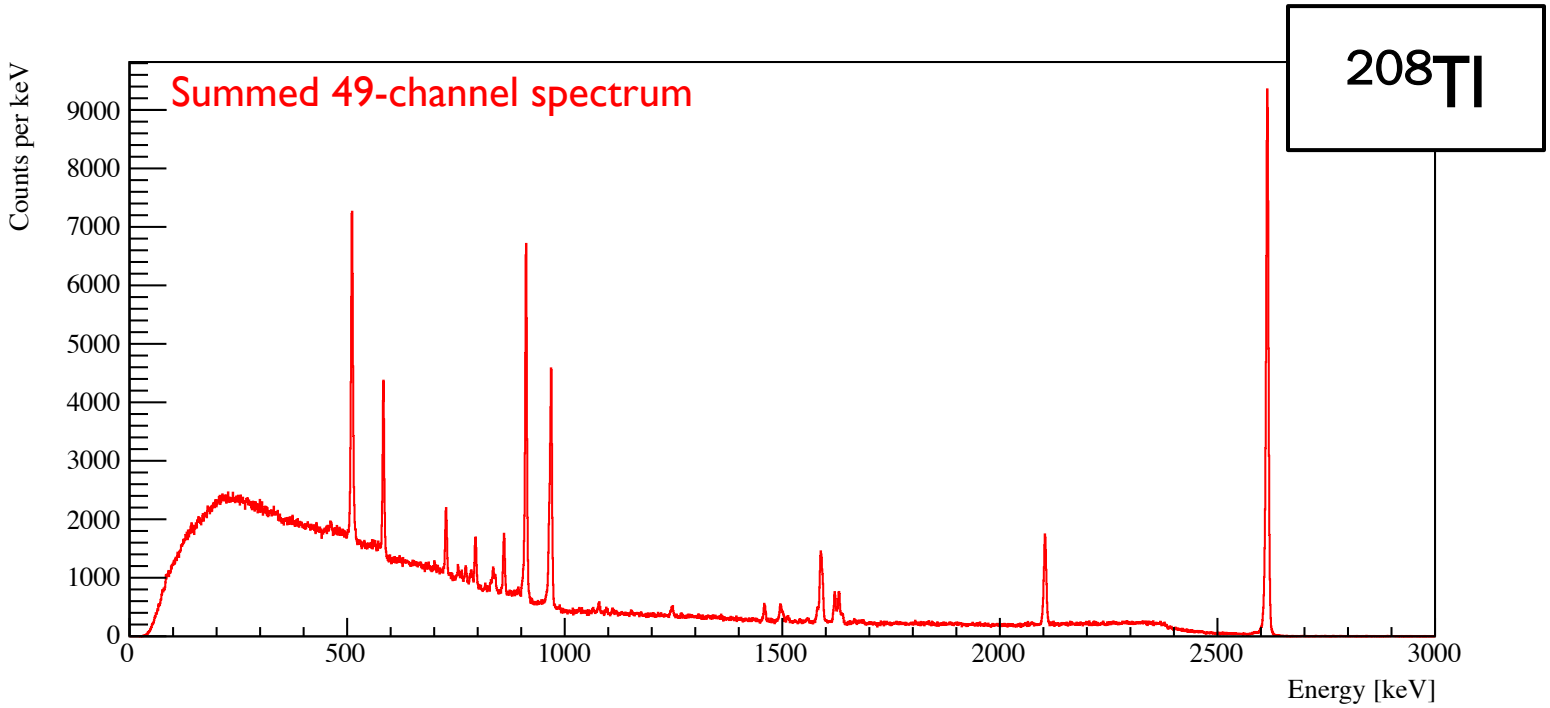


Temperature (mK)



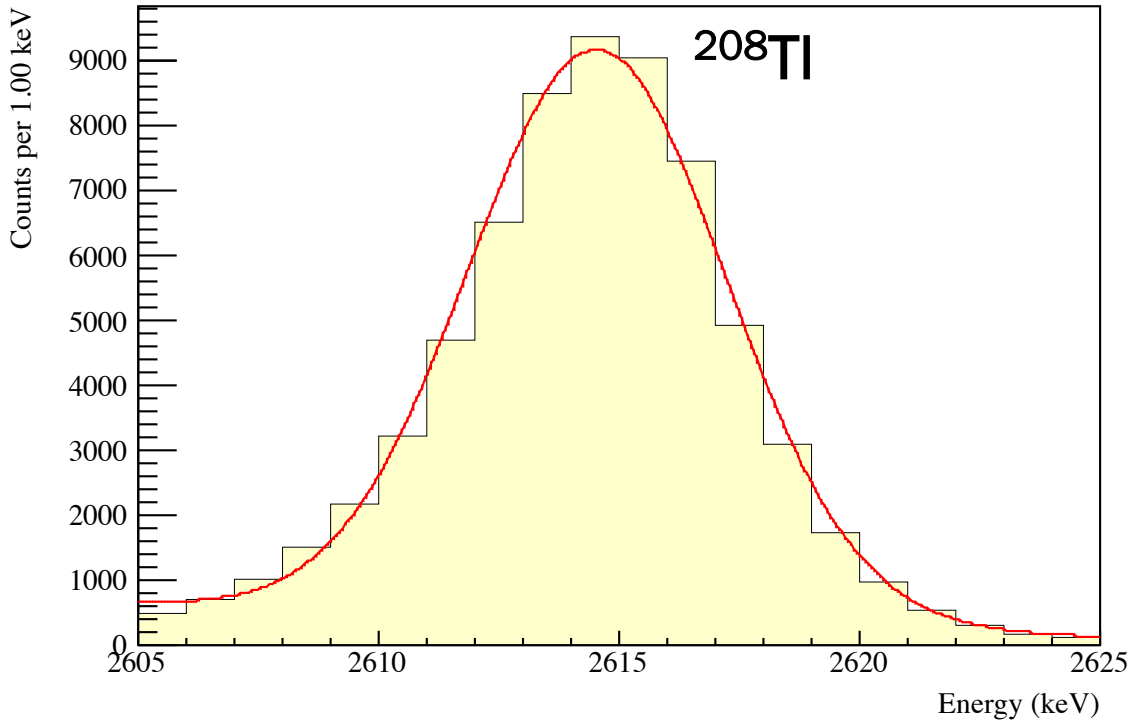
- 51 crystals were instrumented with thermistors; all survived cooldown
- 49/52 crystals have active thermistor and heater

CUORE-0 calibration



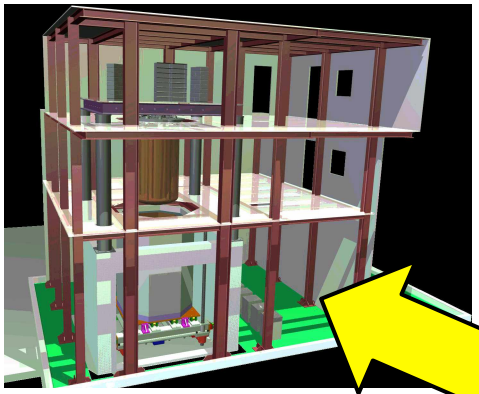
From ^{232}Th source strings lowered along outside of cryostat

CUORE-0 energy resolution



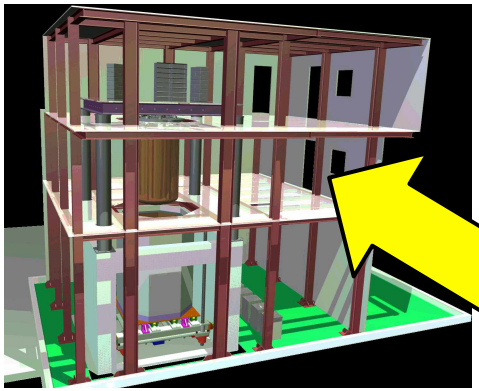
- Preliminary FWHM (@ 2615 keV) = 6.3 keV
- But not yet optimized with pulse-shape cuts!

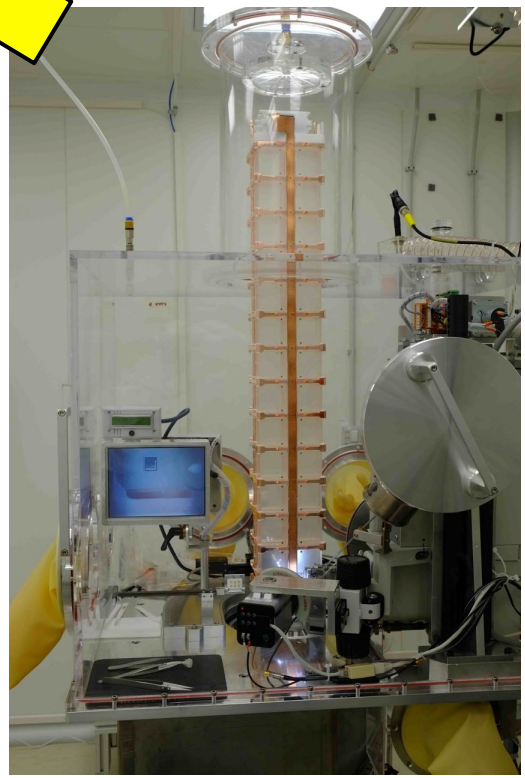
CUORE activities in progress

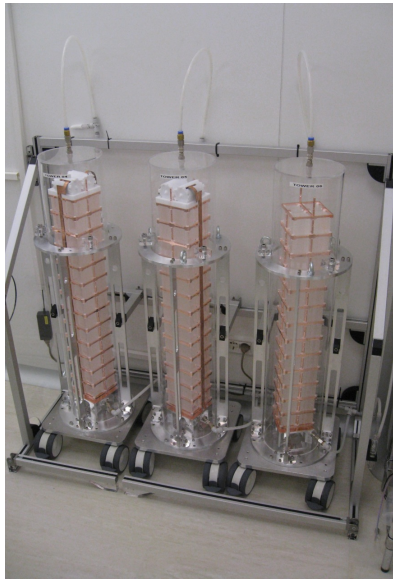


Commissioning & characterization of custom dilution refrigerator

CUORE activities in progress

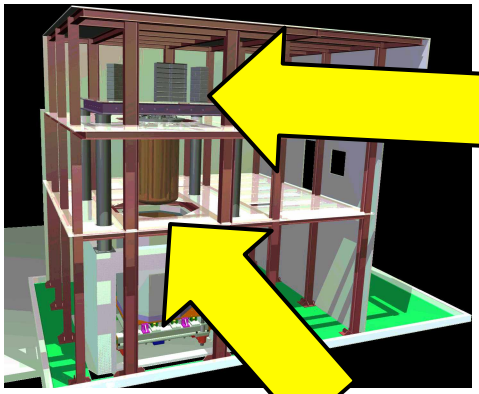


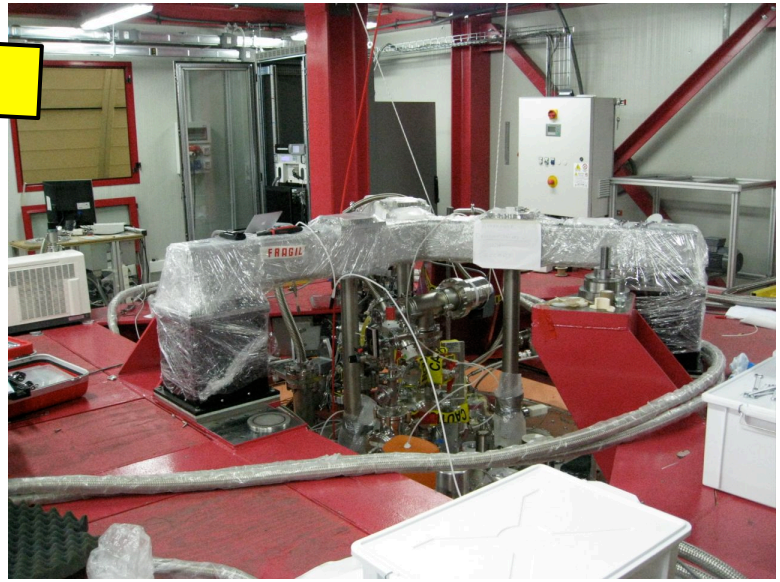




Tower assembly: 6 built to date, 2 of them finished

CUORE activities in progress





4K cold test of partial cryostat & calibration setups

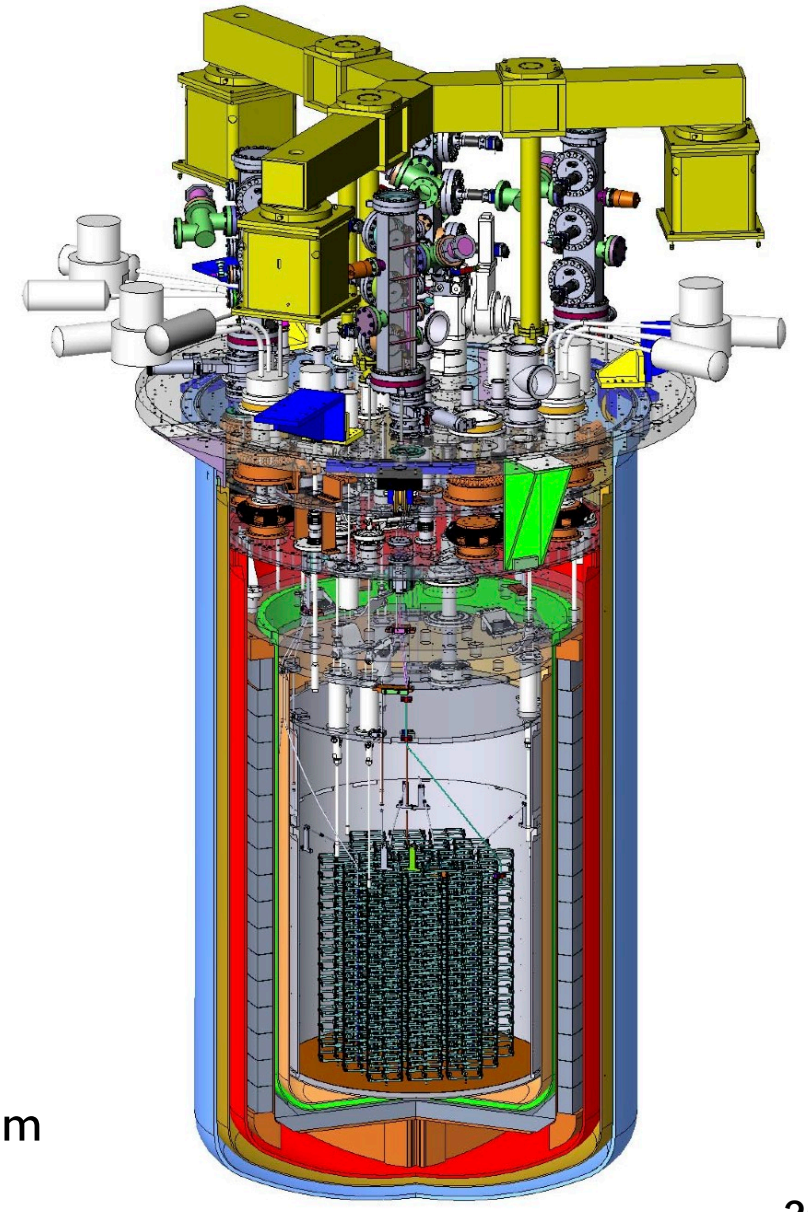
CUORE status

COMPLETED

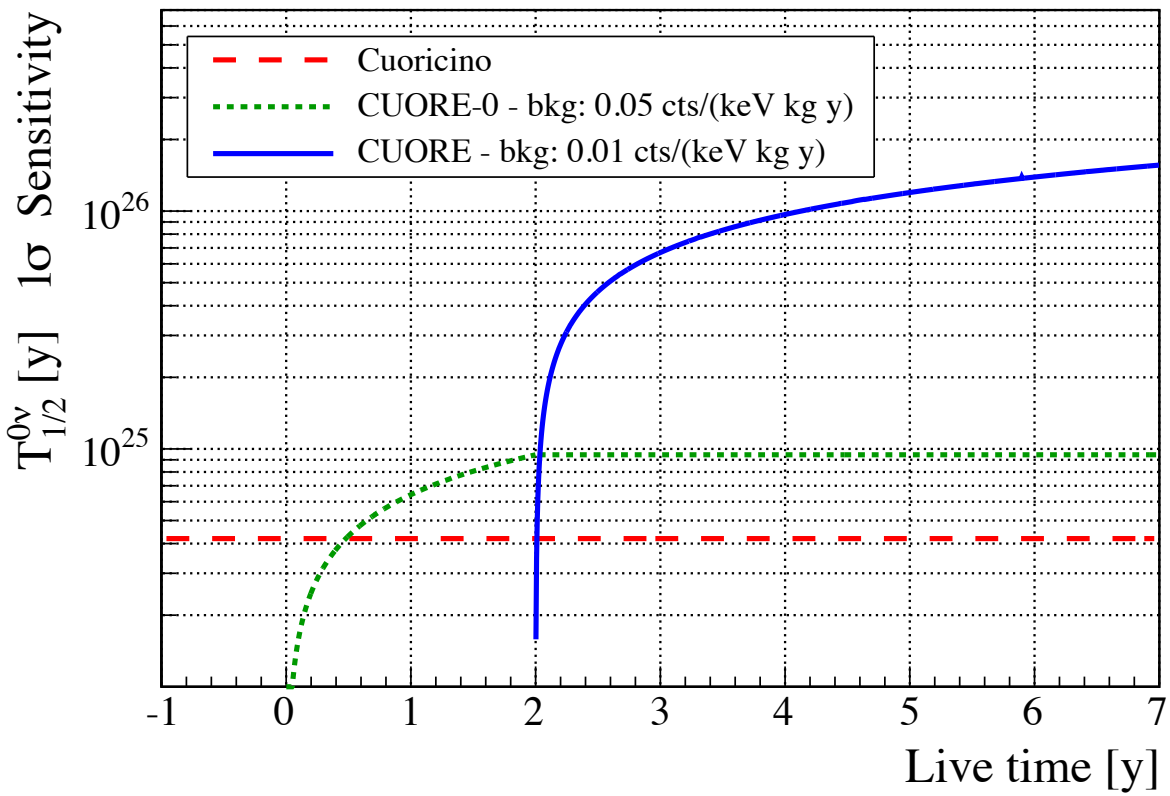
- Hut + clean room commissioned
- All crystals delivered to LNGS
- All thermistors delivered to LNGS
- Outer 3 cryostat vessels delivered to LNGS

IN PROGRESS

- Machining + cleaning of copper tower parts
- Assembly of detector towers
- Manufacture of inner 3 cryostat vessels
- Commissioning of dilution refrigerator
- Commissioning of cryogenic system
- Commissioning of detector calibration system



Experimental sensitivities



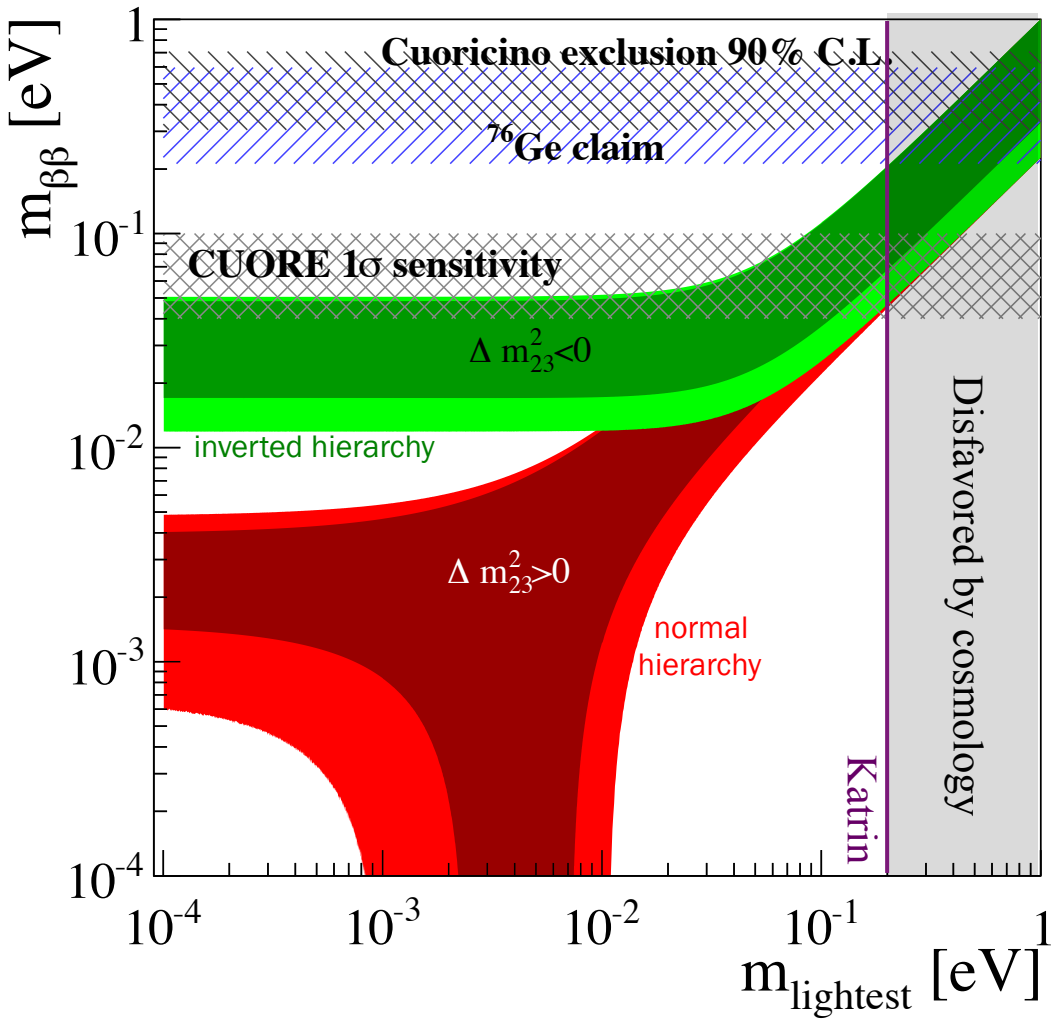
Cuoricino: $T^{0\nu\beta\beta}_{1/2}(^{130}\mathrm{Te}) \geq$ **4.2 × 10²⁴ y** (1σ)

CUORE-0: $T^{0\nu\beta\beta}_{1/2}(^{130}\mathrm{Te}) \geq$ **9.4 × 10²⁴ y** (1σ; 2 years)

CUORE: $T^{0\nu\beta\beta}_{1/2}(^{130}\mathrm{Te}) \geq$ **1.6 × 10²⁶ y** (1σ; 5 years)

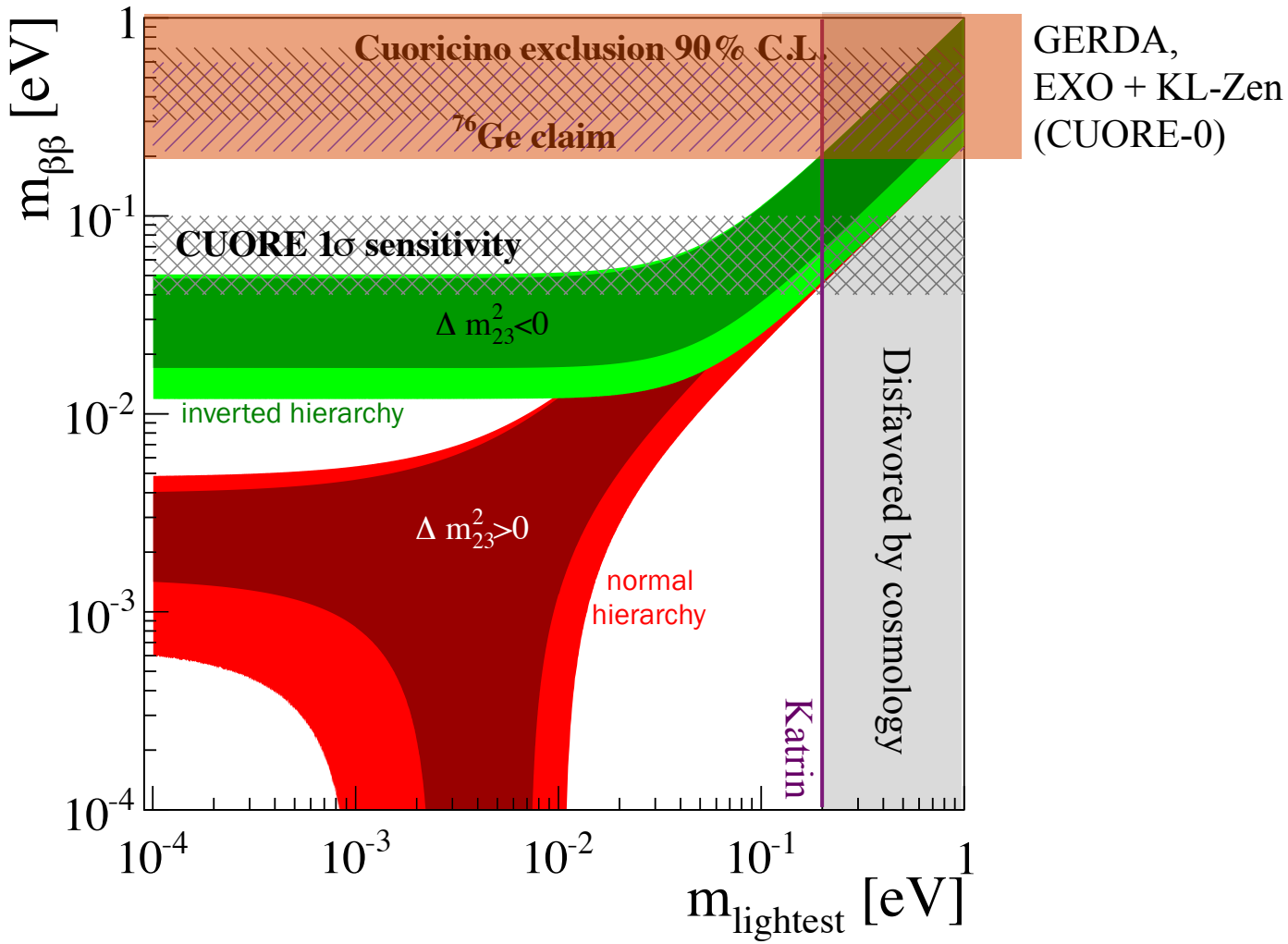
See "Sensitivity of CUORE to Neutrinoless Double-Beta Decay" (arXiv:1109.0494v3 [nucl-ex])

Experimental reach



See "Sensitivity of CUORE to Neutrinoless Double-Beta Decay" [arXiv:nucl-ex/1109.0494v3]

Experimental reach



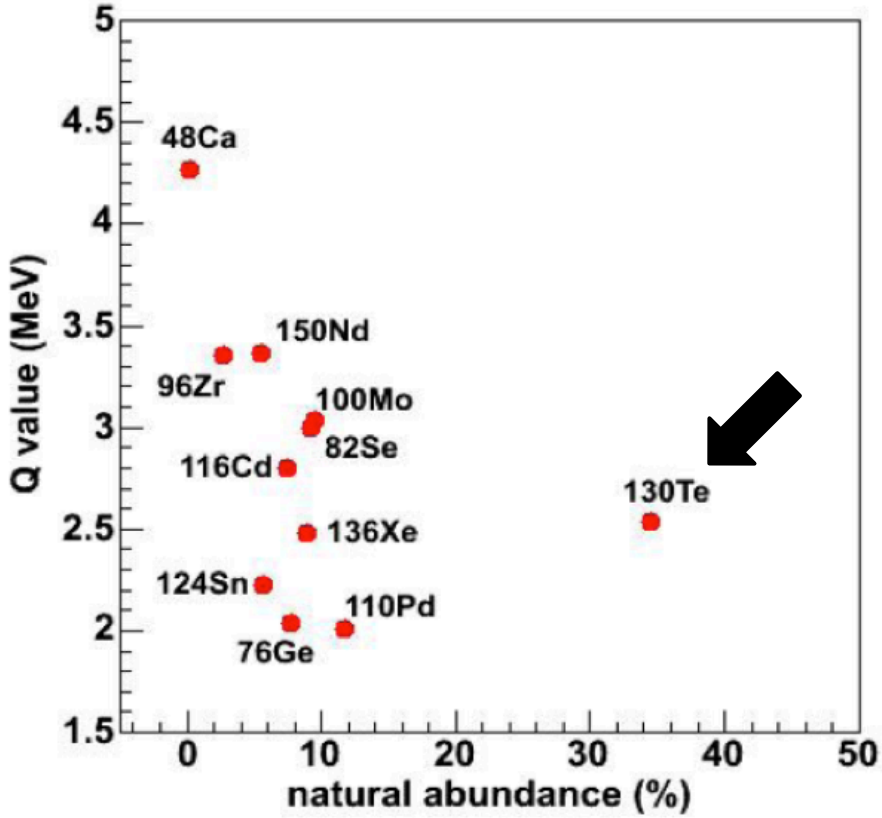
See "Sensitivity of CUORE to Neutrinoless Double-Beta Decay" [arXiv:nucl-ex/1109.0494v3]

Summary

- TeO_2 bolometers offer a well-established, competitive technique to search for $0\nu\beta\beta$ decay
- Cuoricino did not observe evidence of $0\nu\beta\beta$ decay of ^{130}Te
- CUORE-0 is now taking data in the former Cuoricino cryostat at LNGS; initial results are promising.
- Preparations for CUORE are in progress, with data taking scheduled to start in 2015

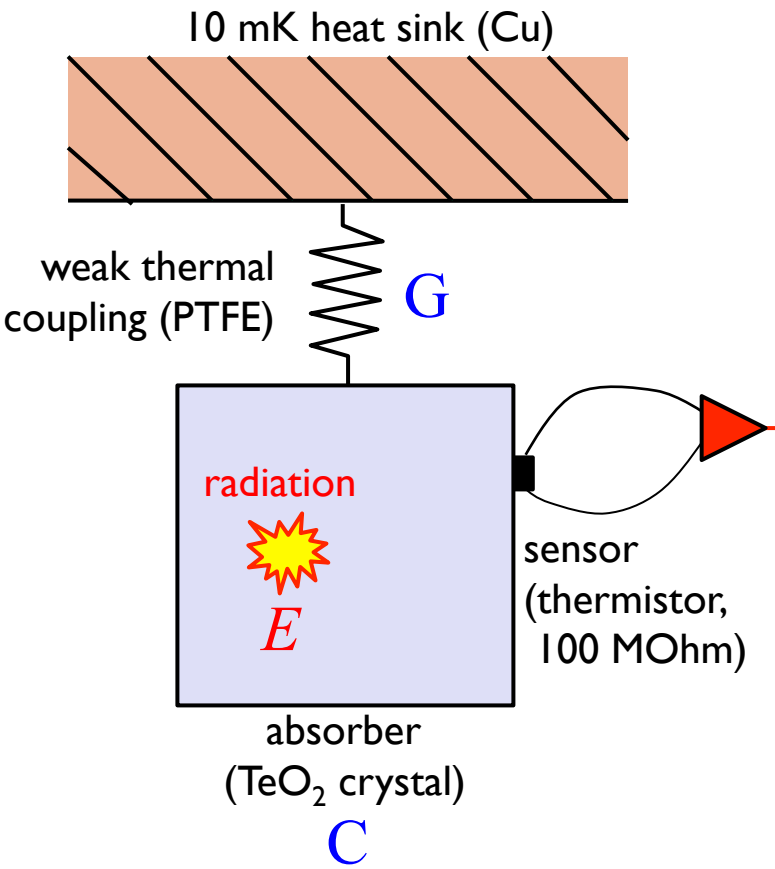
Fine

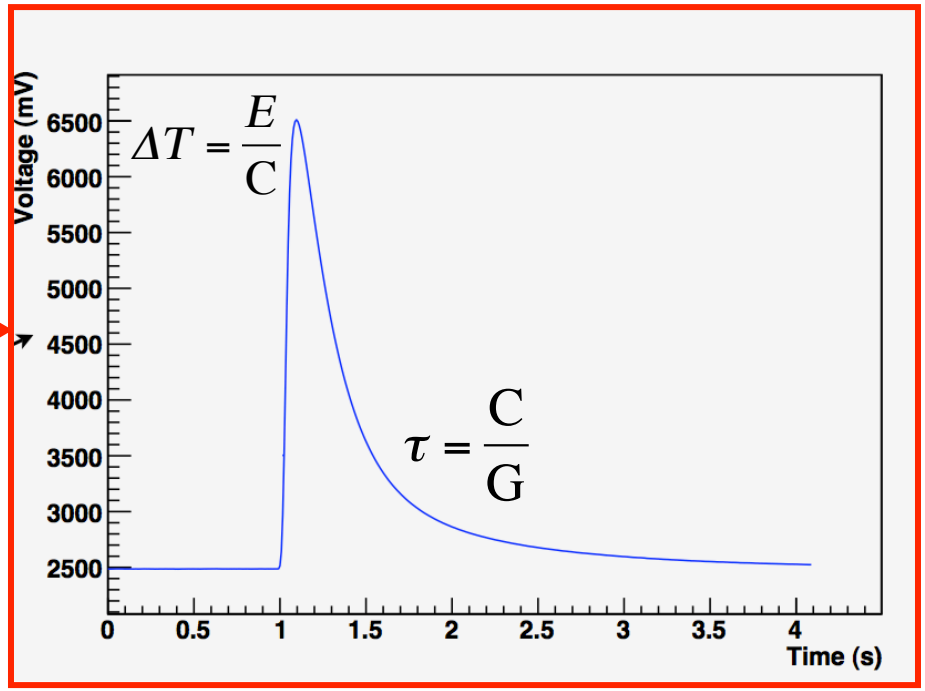
^{130}Te as $0\nu\beta\beta$ decay candidate



- High natural abundance ➜ no enrichment necessary
- Good Q-value above natural γ energies + large phase space

Cryogenic bolometers



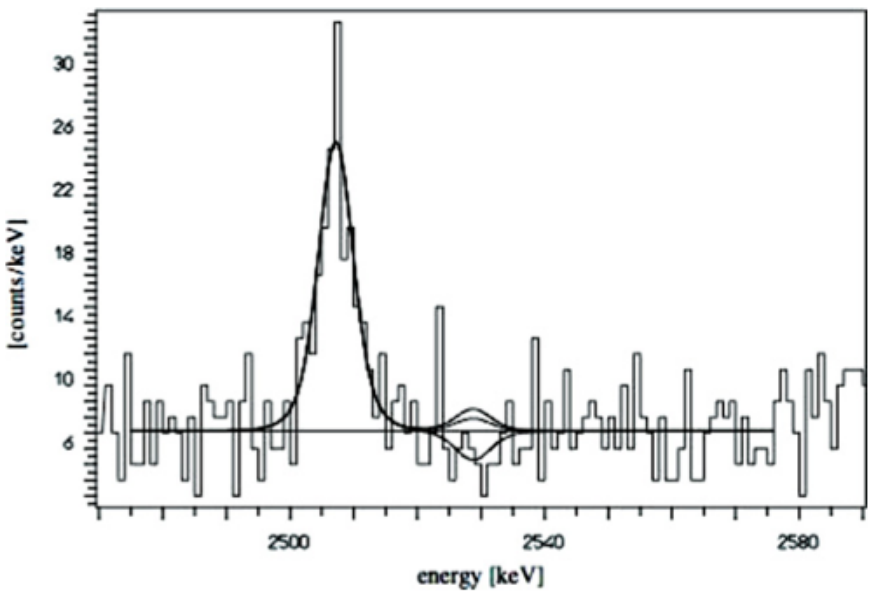


C ~ 10 MeV/mK

Cuoricino results

2008 Result

data: 2003 — 2006
11.8 kg-yr ^{130}Te exposure

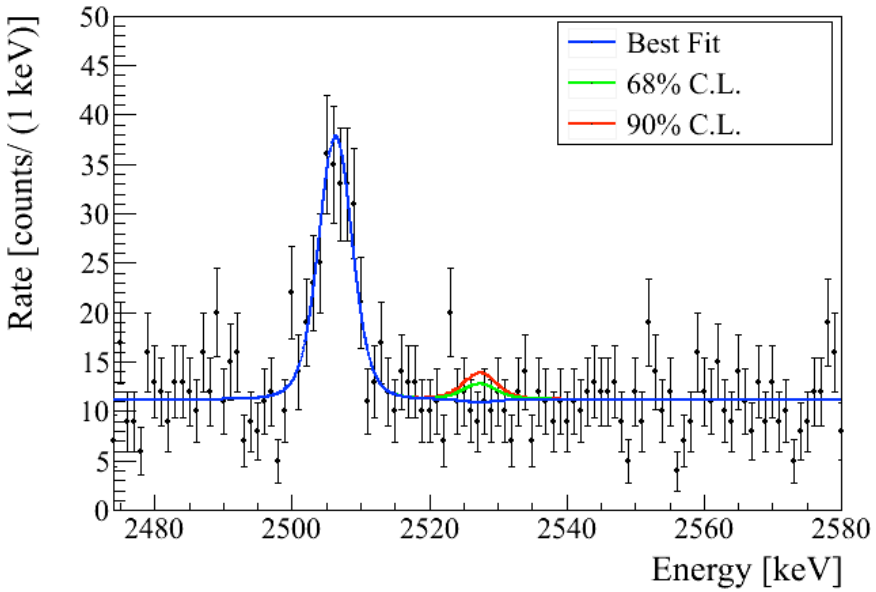


$$T_{1/2}^{0\nu\beta\beta}(^{130}\mathrm{Te}) > 3.0 \times 10^{24}\ \mathrm{y}\ (90\%\ \mathrm{C.L.})$$

C. Arnaboldi et al. (CUORICINO Collaboration), Phys. Rev. C78, 035502 (2008) [arXiv:nucl-ex/0802.3439].

2010 Result

data: 2003 — 2008
19.8 kg-yr ^{130}Te exposure

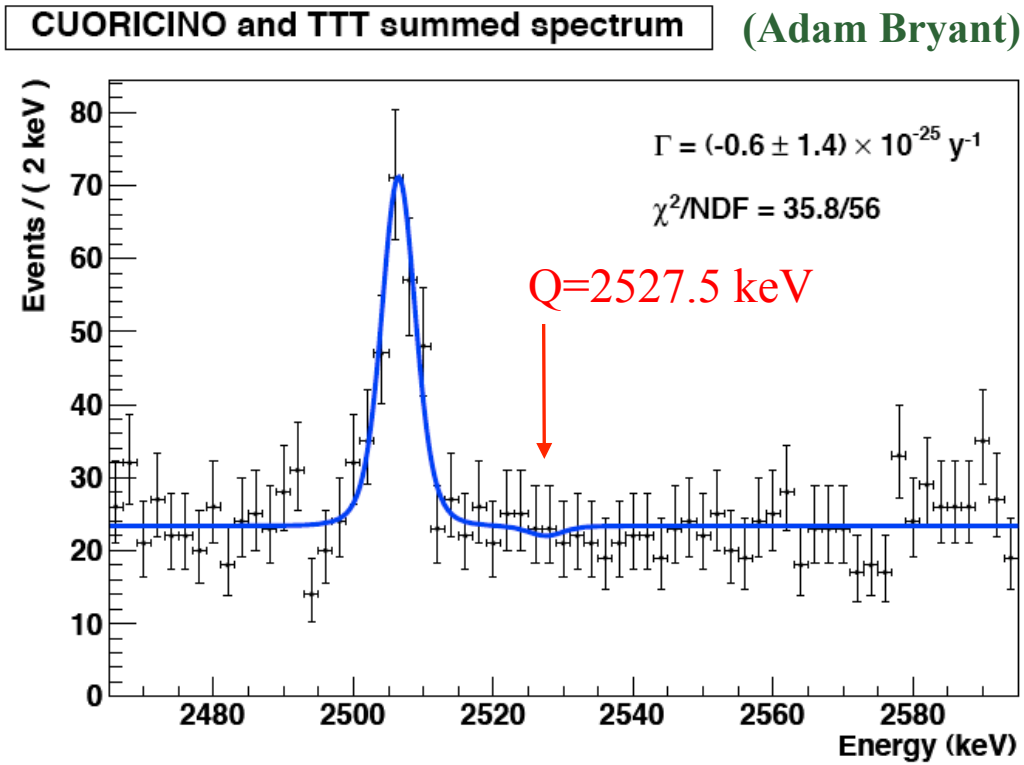


$$T_{1/2}^{0\nu\beta\beta}(^{130}\mathrm{Te}) > 2.8 \times 10^{24}\ \mathrm{y}\ (90\%\ \mathrm{C.L.})$$

E. Andreotti et al. (CUORICINO Collaboration), Astropart. Phys. 34: 822–831 (2011) [arXiv:nucl-ex/1012.3266].

Cuoricino + TTT results

data: 2003 — 2010
19.9 kg-yr ^{130}Te exposure



Background: ~ 0.16 counts/keV/kg/y

Lower limit, half-life: $T_{1/2}^{0\nu\beta\beta}$ (^{130}Te) > 3.0×10^{24} y (90% C.L.)

Cuoricino ⟶ CUORE

Isotope mass fraction

Detector mass (×19)

Detector efficiency

Exposure time (×2)

$$\hat{T}_{1/2}^{0\nu\beta\beta}(n_\sigma) \propto \frac{\varepsilon \cdot a}{n_\sigma} \sqrt{\frac{M \cdot t}{B \cdot \delta E}}$$

Confidence level

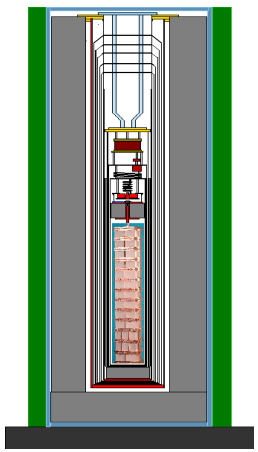
Energy resolution (÷1.6)

Background (÷18)

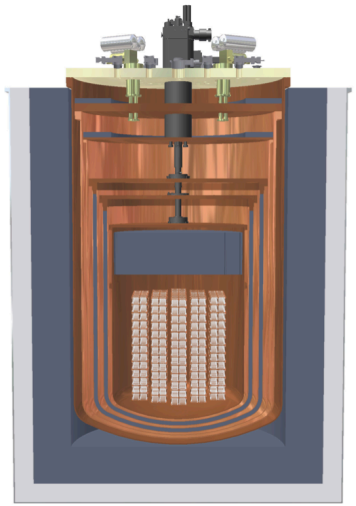
- Half-life sensitivity depends on detector parameters
- Sensitivity is the max signal that could be hidden by a background fluctuation (at specified confidence level)

Cryostat improvements

Cuoricino

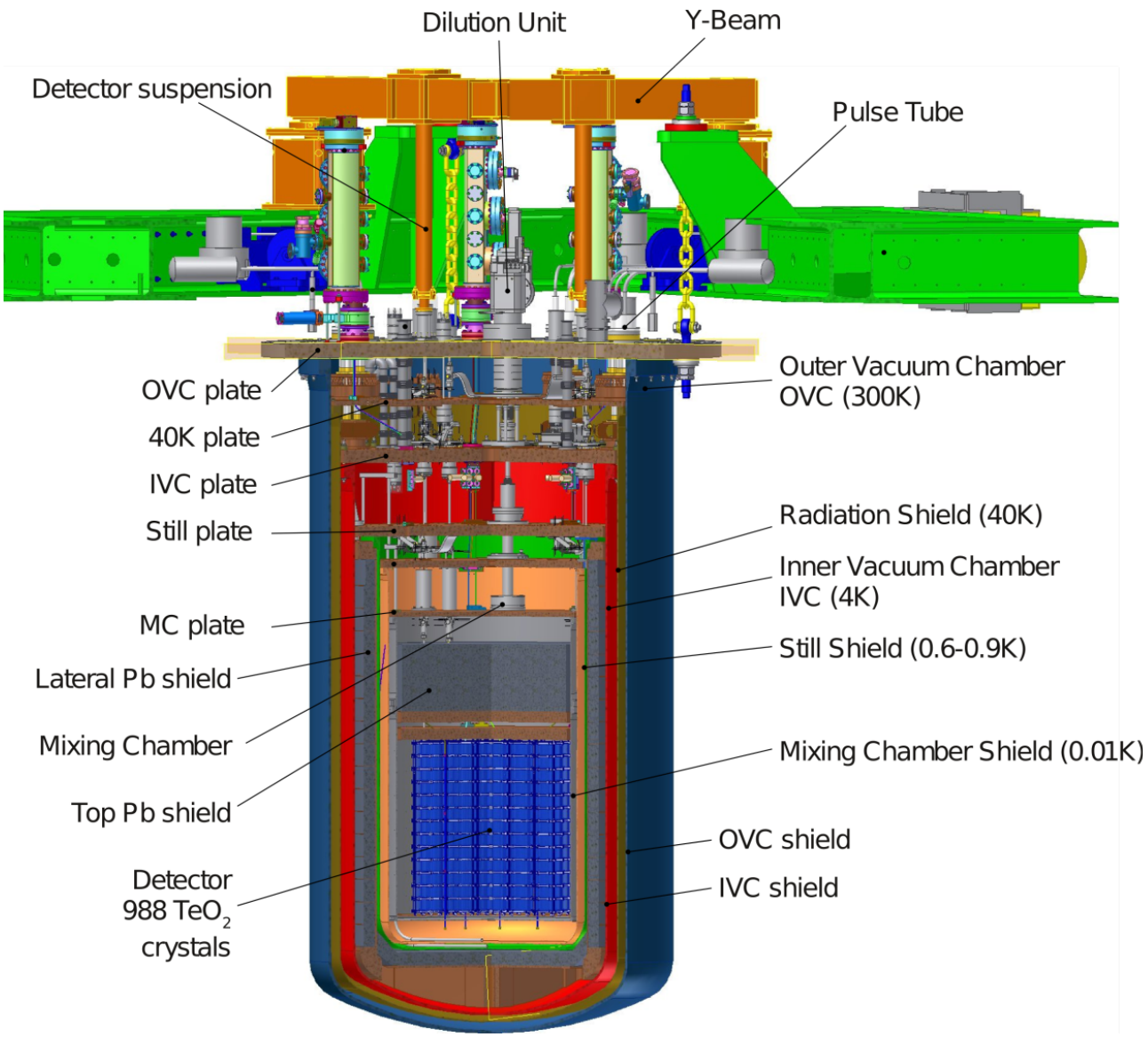


CUORE



- New custom dilution refrigerator
- Cryogen-free ➜ more live time
- Better suspension ➜ less vibration
- 50% more Pb shielding
- Cleaner

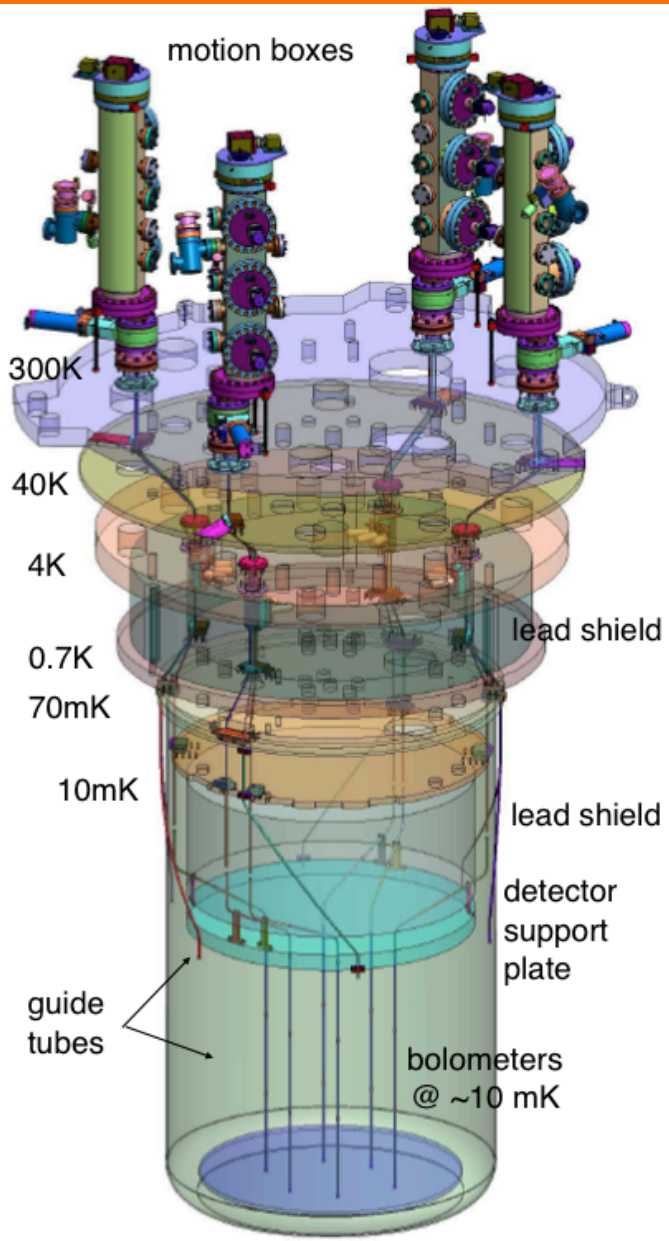
Cryostat


Dilution Unit
Y-Beam
Detector suspension
Pulse Tube
OVC plate
40K plate
IVC plate
Still plate
MC plate
Lateral Pb shield
Mixing Chamber
Top Pb shield
Detector
988 TeO_2
crystals
Outer Vacuum Chamber
OVC (300K)
Radiation Shield (40K)
Inner Vacuum Chamber
IVC (4K)
Still Shield (0.6-0.9K)
Mixing Chamber Shield (0.01K)
OVC shield
IVC shield

Calibration system

DCS = **D**etector **C**alibration **S**ystem

- 12 gamma source strings lowered in between crystal towers through guide tubes – no vertical access
- strings are Kevlar with crimped ^{56}Co and/or ^{232}Th source capsules at intervals
- thermalization requirements
- integration with other systems



Roman lead shield

- Ancient Roman lead bricks for low-activity shielding
- Recovered in late '80s from shipwreck off Sardinian coast
- Obtained through agreement between INFN and Italian historical society
- 270 bricks, 33 kg each = 7 tons (after inscriptions removed)