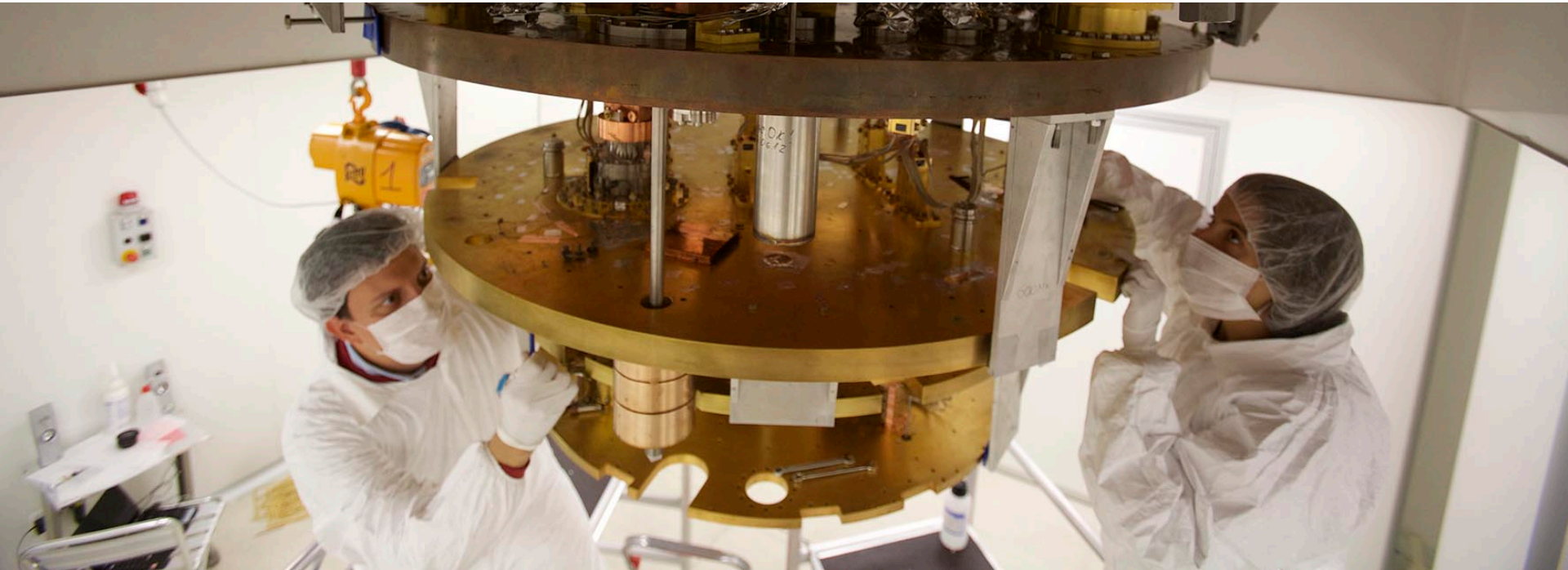


# CUORE-0 performance, and prospects for CUORE

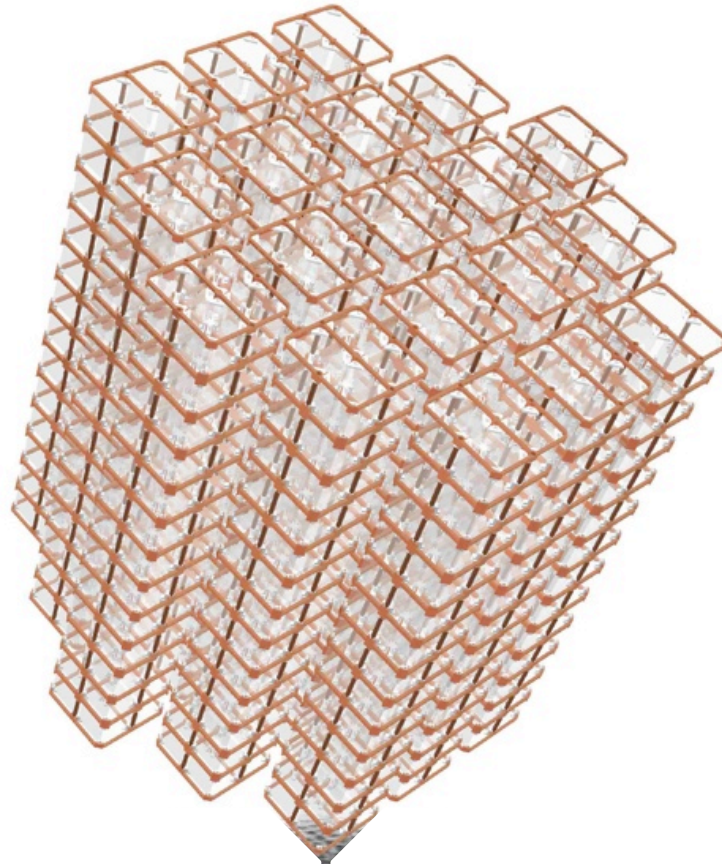
Tom Banks (UC Berkeley / LBNL)  
For the CUORE Collaboration



@ “Neutrinos: Recent Developments and Future Challenges”  
Kavli Institute for Theoretical Physics, UCSB  
November 4, 2014

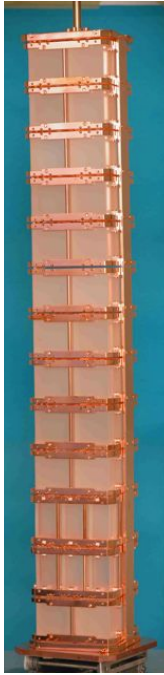
# CUORE

Cryogenic **U**nderground **O**bservatory for **R**are **E**vents



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

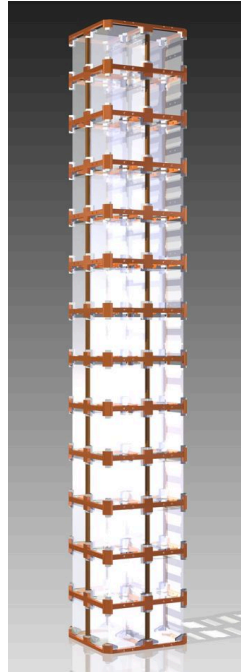
# CUORE program



**Cuoricino**

2003–2008

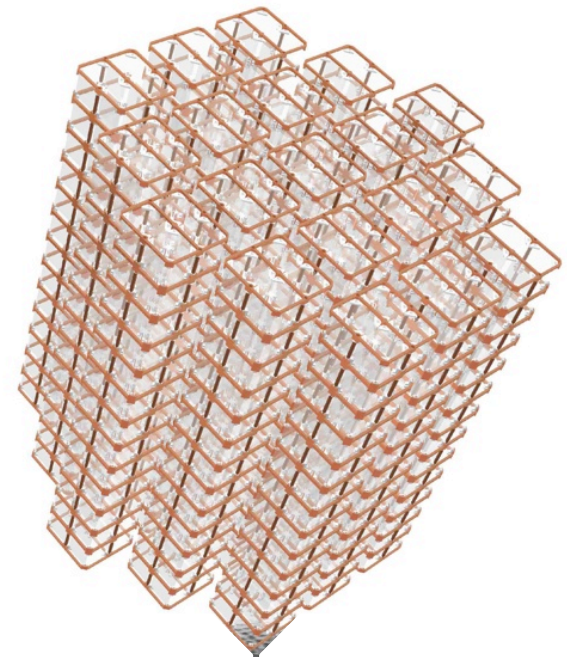
11 kg  $^{130}\text{Te}$



**CUORE-O**

2013–2015

11 kg  $^{130}\text{Te}$



**CUORE**

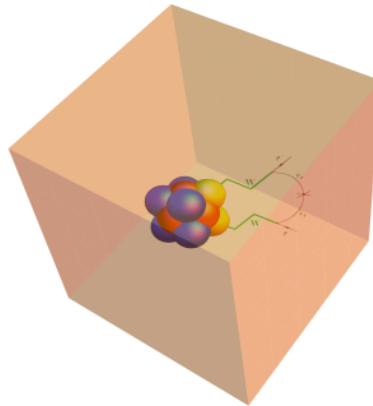
2015–2020

206 kg  $^{130}\text{Te}$

**COMPLETE**

# Cryogenic bolometers

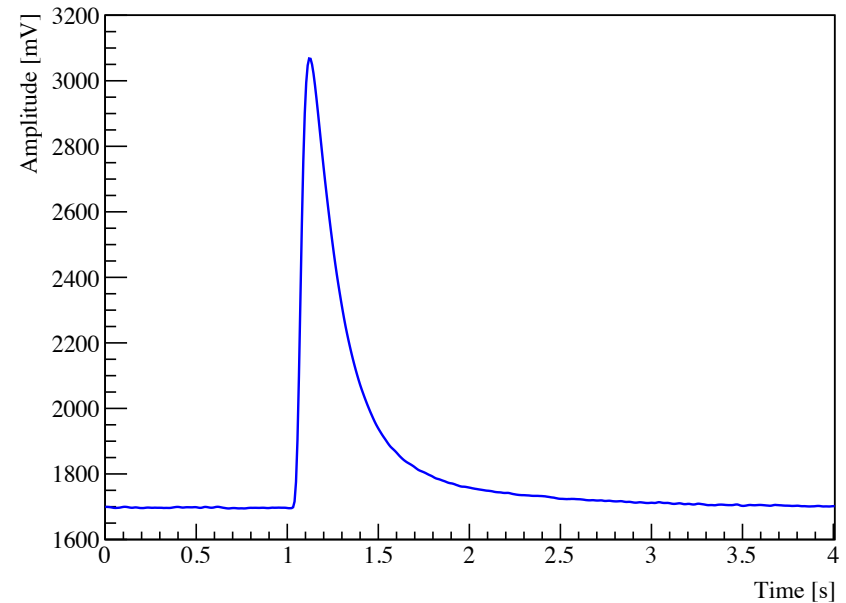
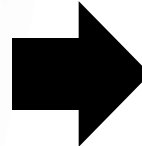
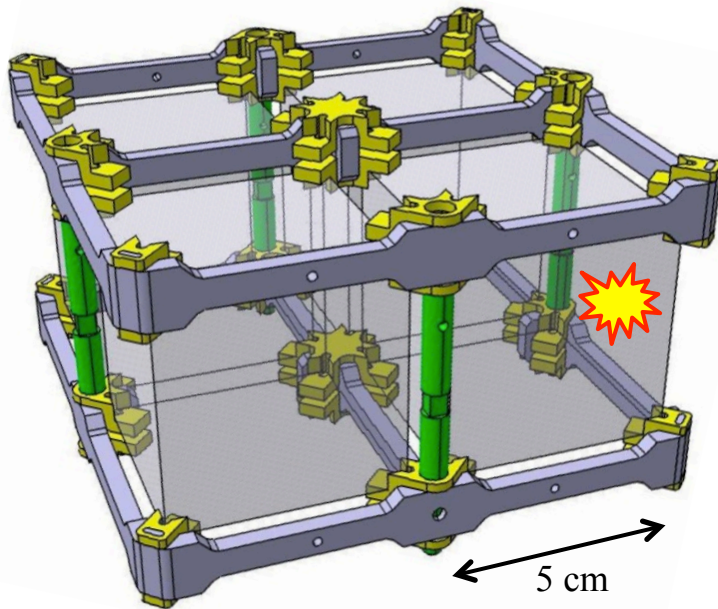
Source = Detector



Ultracold  $\text{TeO}_2$  crystals function as highly sensitive calorimeters



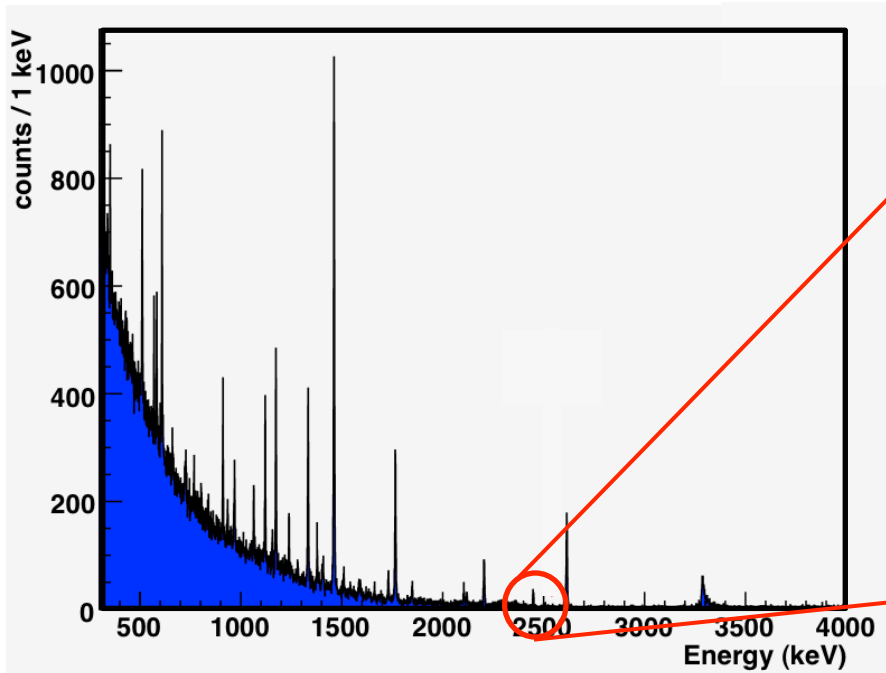
# Cryogenic bolometers



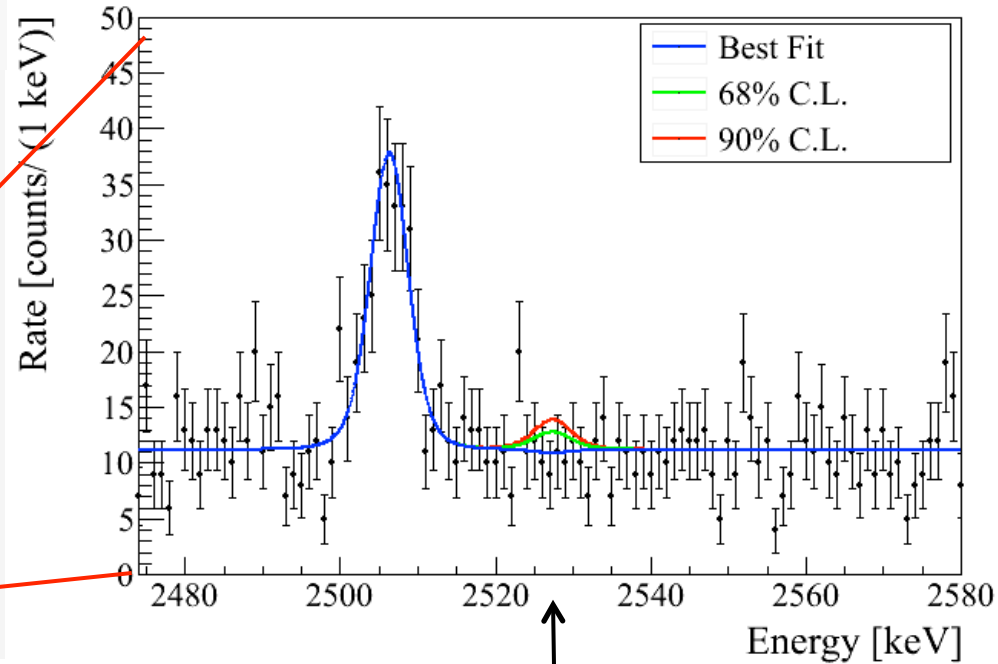
At  $T=10$  mK, particle interactions inside a  $\text{TeO}_2$  crystal produce a measurable rise in its temperature

Amplitude of temperature pulse is proportional to deposited energy

# Experimental method



The energy spectrum of detected pulses is compiled...

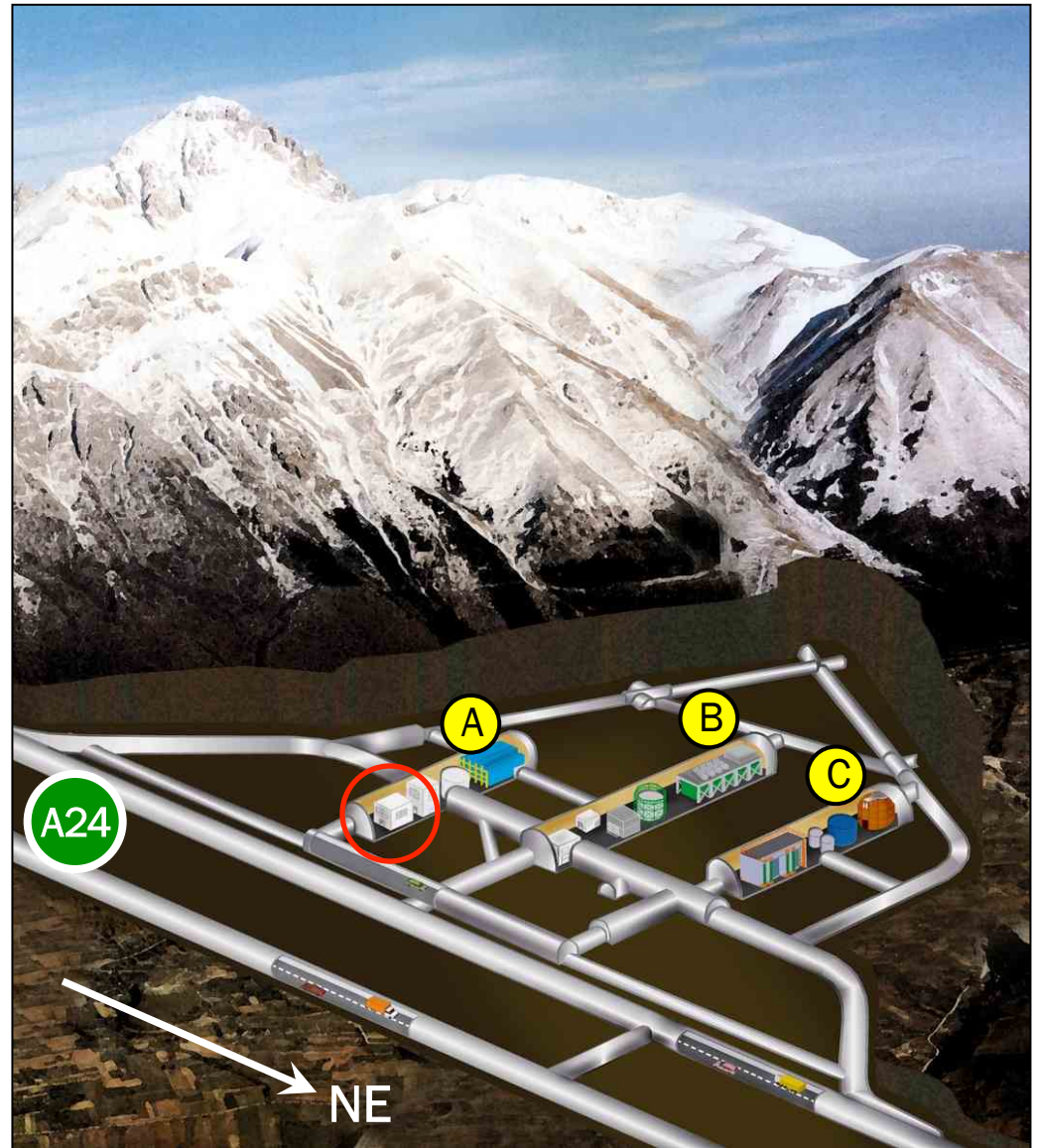


... and the signature of  $0\nu\beta\beta$  in  $^{130}\text{Te}$  would be a small peak at  $\sim 2527$  keV.

# LNGS underground lab



- ▶ Gran Sasso, Italy
- ▶ 1.4-km rock overburden





# LNGS underground lab



Hall B after construction

# CUORE facilities in Hall A

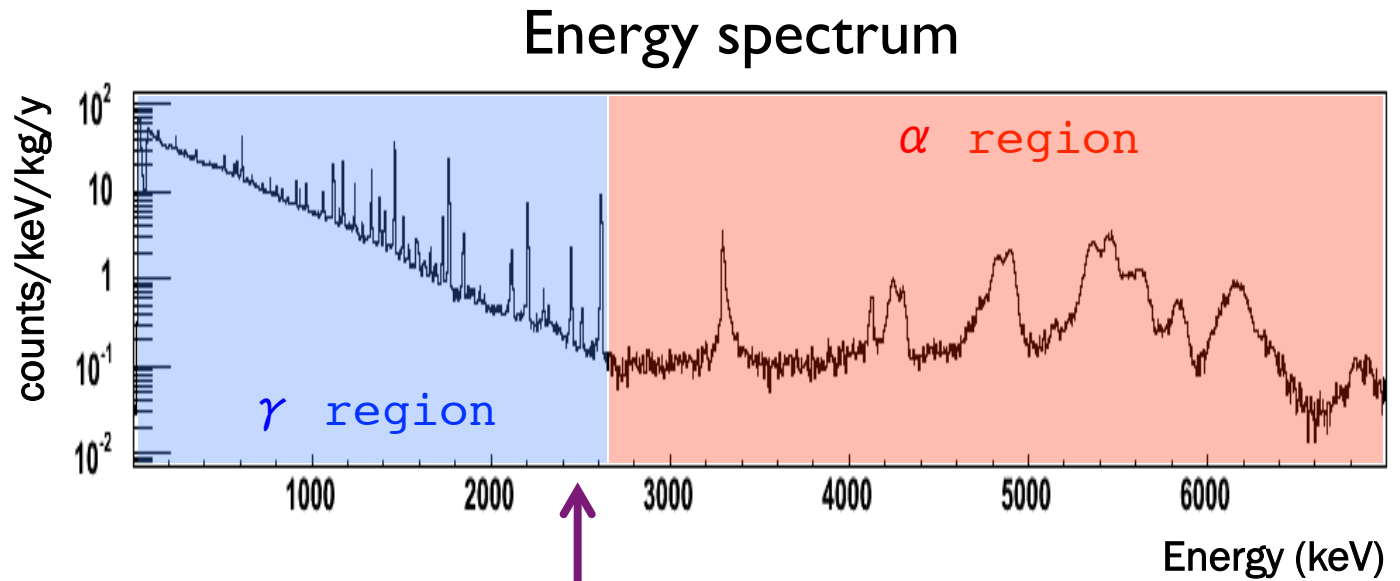
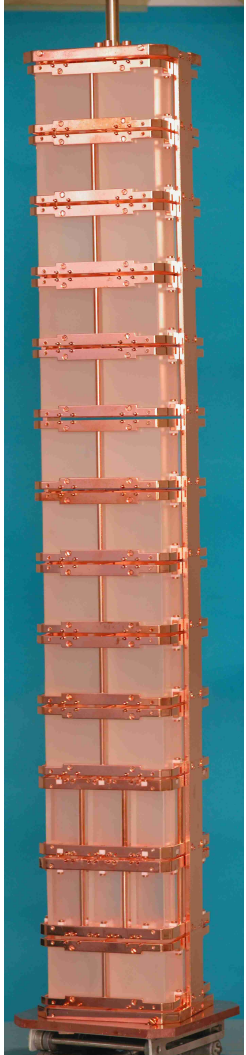
CUORE hut



Cuoricino/  
CUORE-0 hut

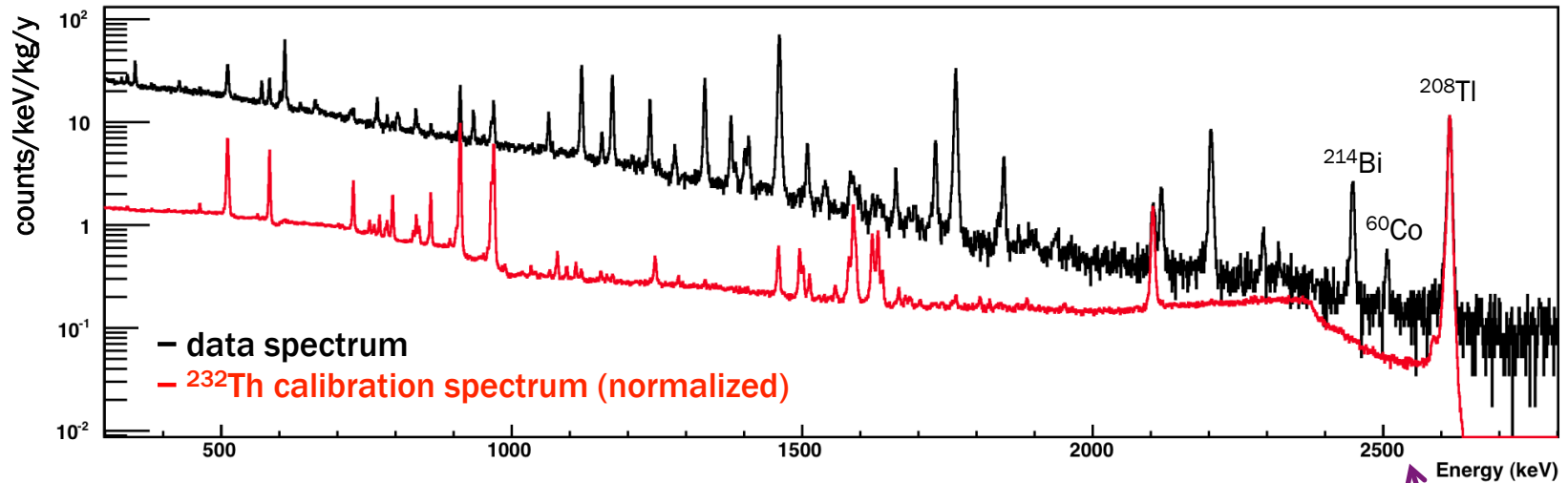


# The past: Cuoricino



$^{130}\text{Te}$  Q-value = 2527.5 keV

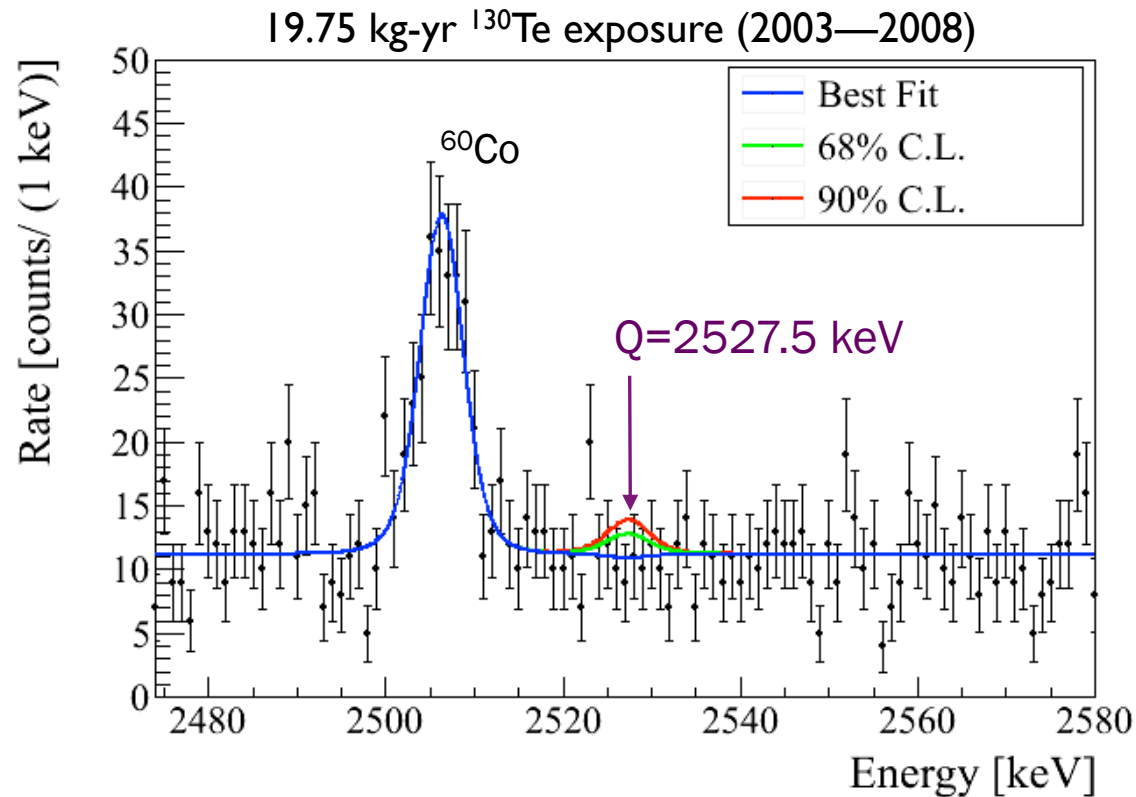
# Cuoricino backgrounds



There were three main sources of background in the region around the  $Q$  value:

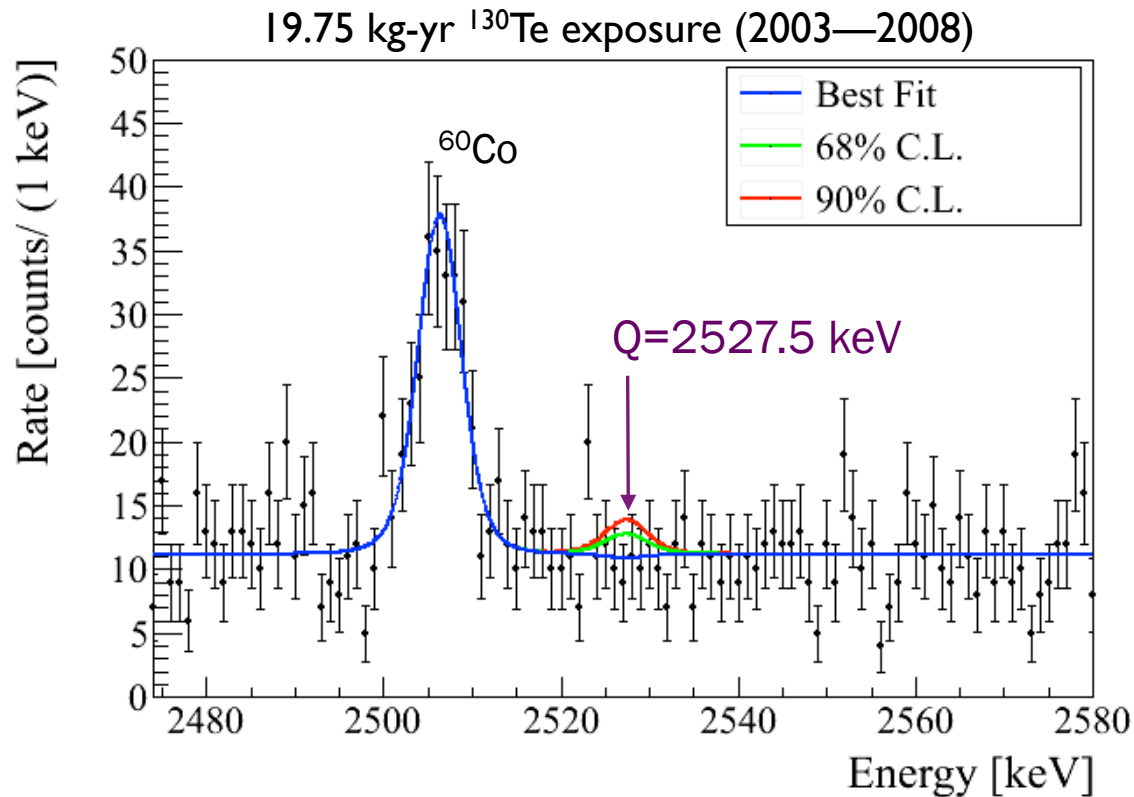
- (~35%) Compton gammas from  $^{208}\text{Tl}$ , from  $^{232}\text{Th}$  in cryostat
- (~55%) Degraded alphas from  $^{238}\text{U}$  and  $^{232}\text{Th}$  on copper surfaces
- (~10%) Degraded alphas from  $^{238}\text{U}$  and  $^{232}\text{Th}$  on crystal surfaces

# The past: Cuoricino



No evidence of  $0\nu\beta\beta$  decay in  $^{130}\text{Te}$

# The past: Cuoricino



**Background:**  $0.169 \pm 0.006$  counts/keV/kg/y ( $^{130}\text{Te}$ )

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

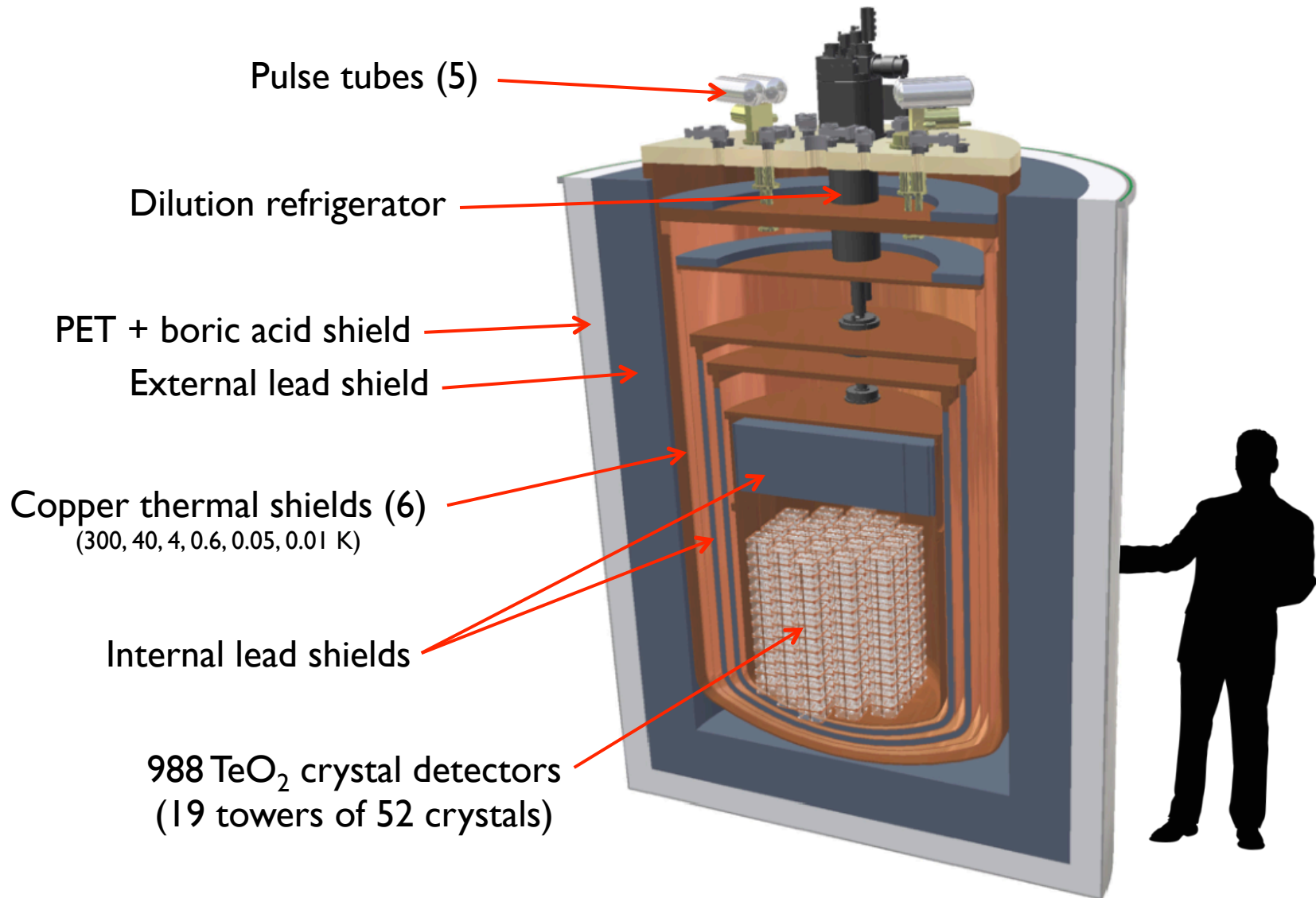
**Upper limit, Majorana  $\nu$  mass:**  $\langle m_{\beta\beta} \rangle < 300 - 710$  meV

# The present: CUORE



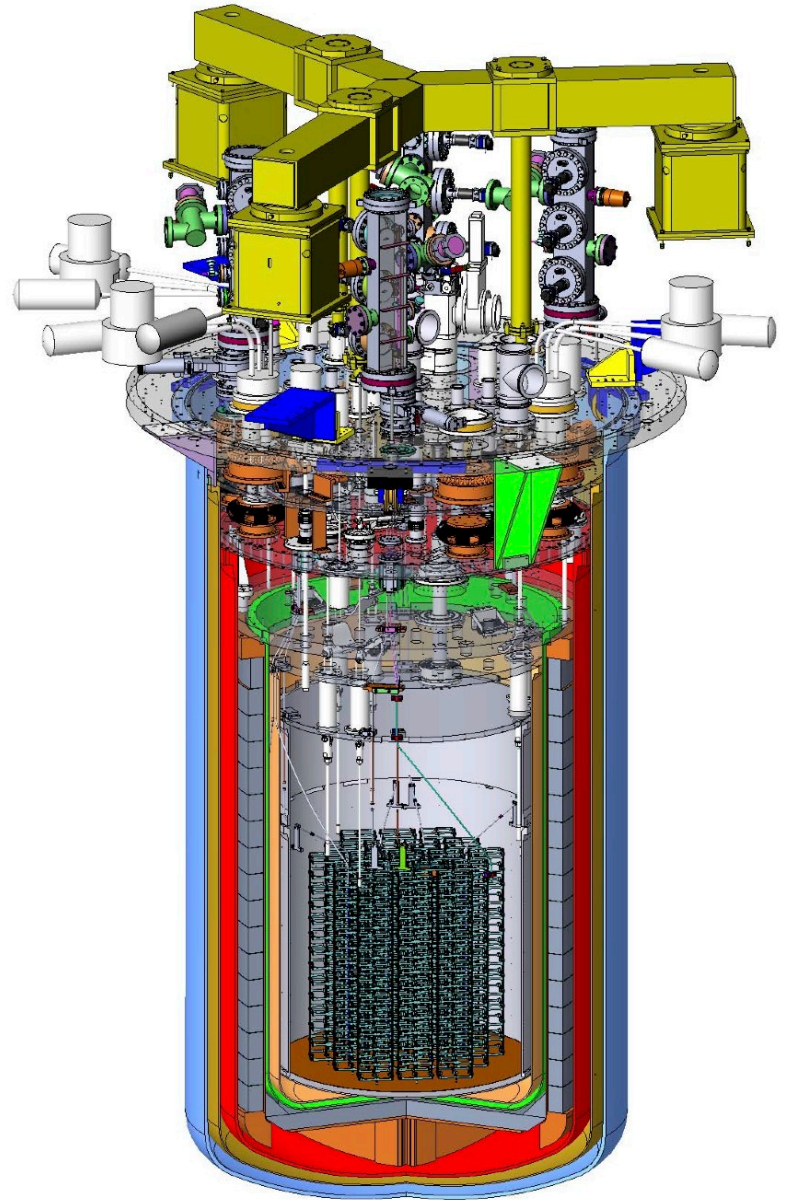


# CUORE



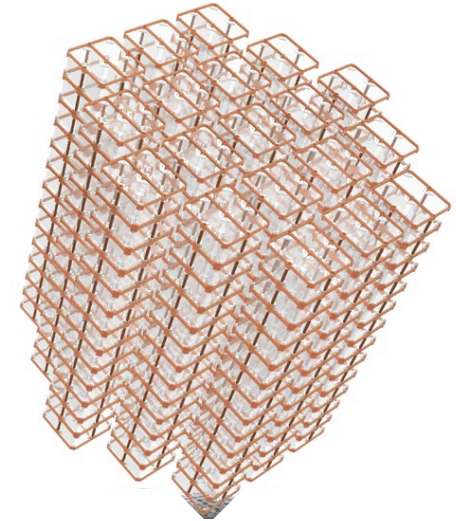
# The challenge

Scale up the bolometric apparatus by 19x  
while also reducing radioactive backgrounds



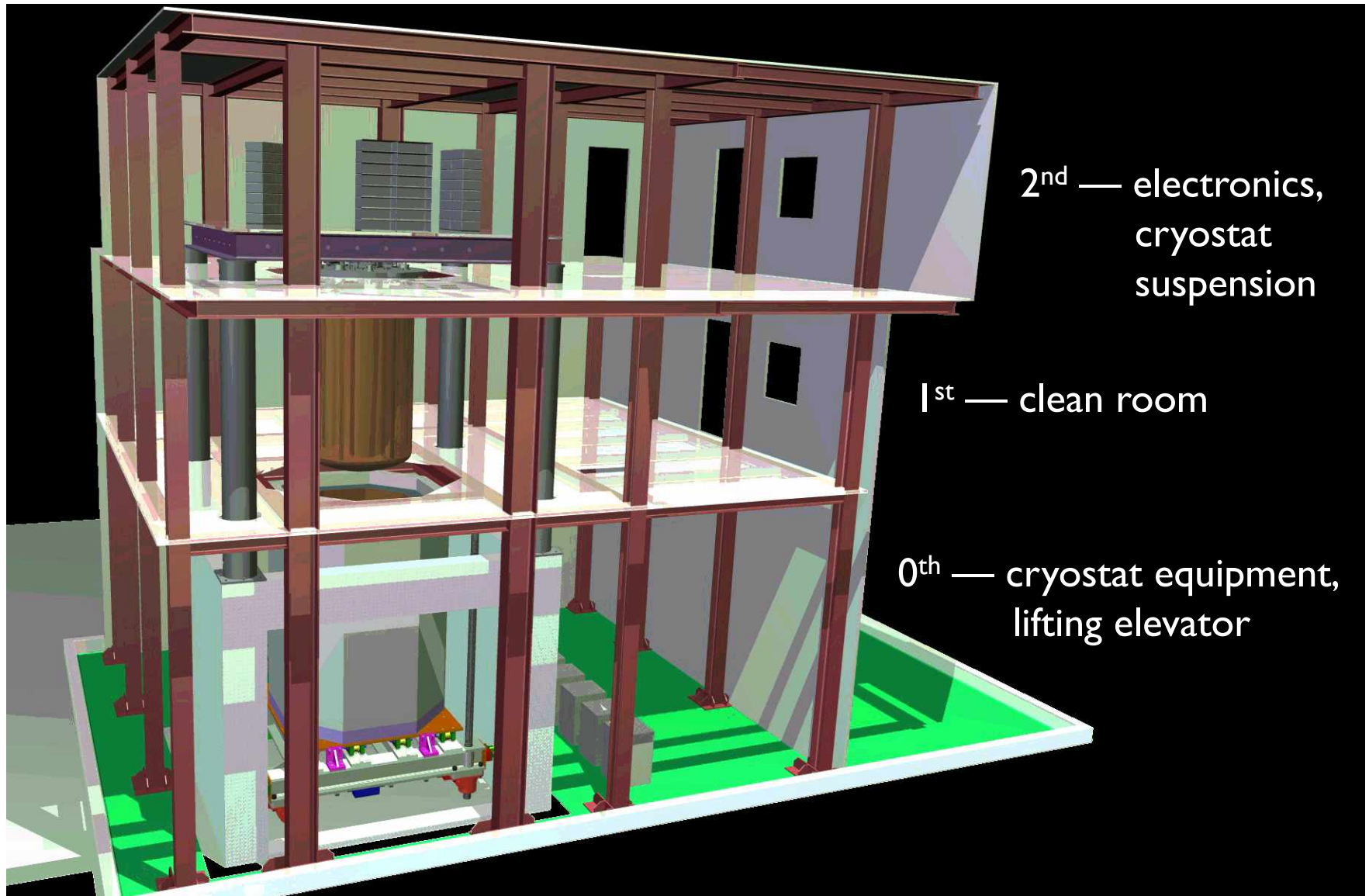
# Detector improvements

- ▶ Larger
- ▶ Cleaner crystals
- ▶ Cleaner copper, and less of it per kg  $\text{TeO}_2$
- ▶ Cleaner assembly environment
- ▶ More robust assembly methods, better wiring
- ▶ Better self-shielding & anticoincidence coverage
- ▶ Less vibration

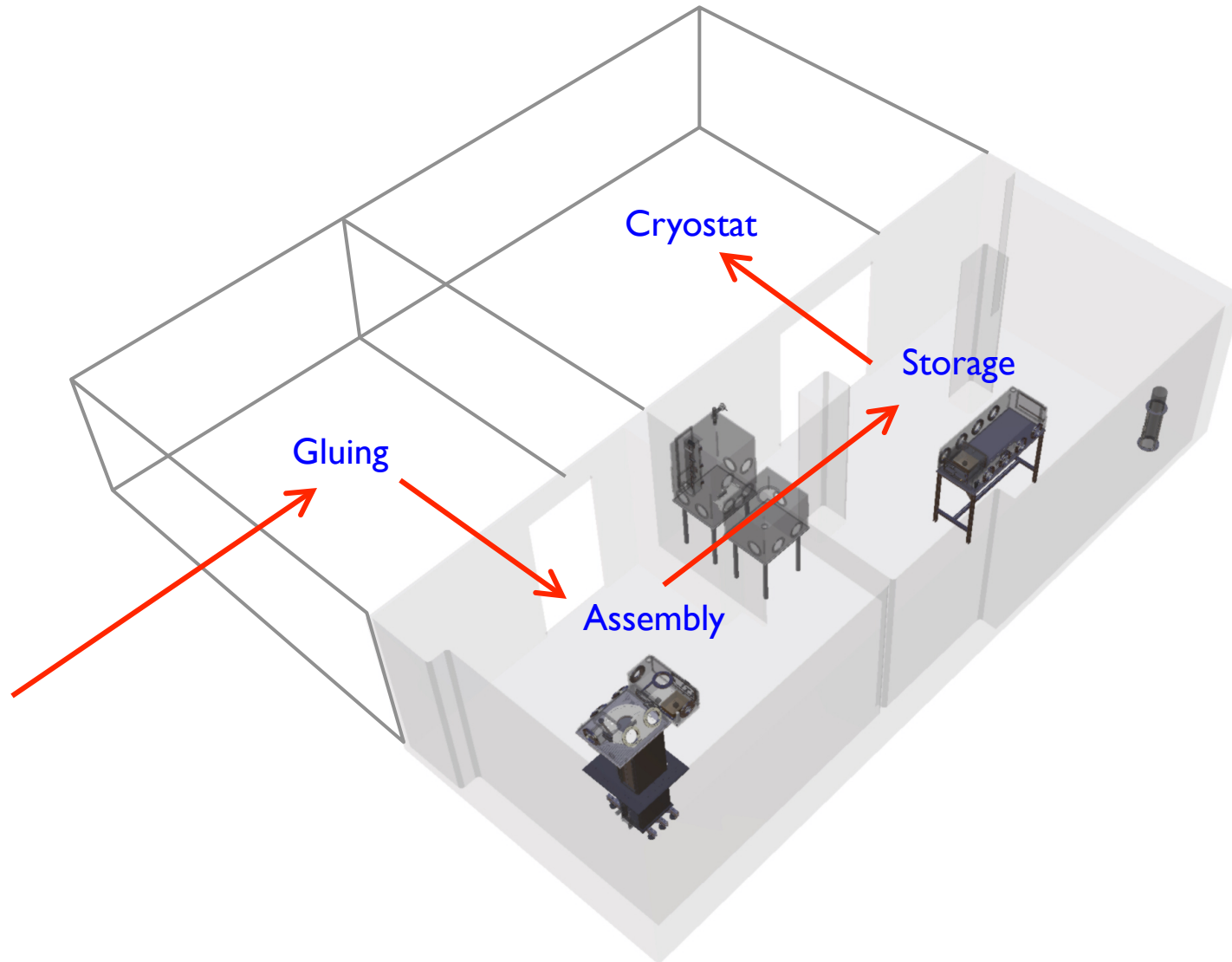


	Cuoricino	CUORE-0	CUORE
$^{130}\text{Te}$ mass (kg)	11	11	206
Background (c/keV/kg/y) @ 2528 keV	0.17	0.06	0.01
$E$ resolution (keV) FWHM @ 2615 keV	6.3	5.2	5
$\langle m_{\beta\beta} \rangle$ (meV) @ 90% C.L.	300–710	204–533	51–133

# Hut



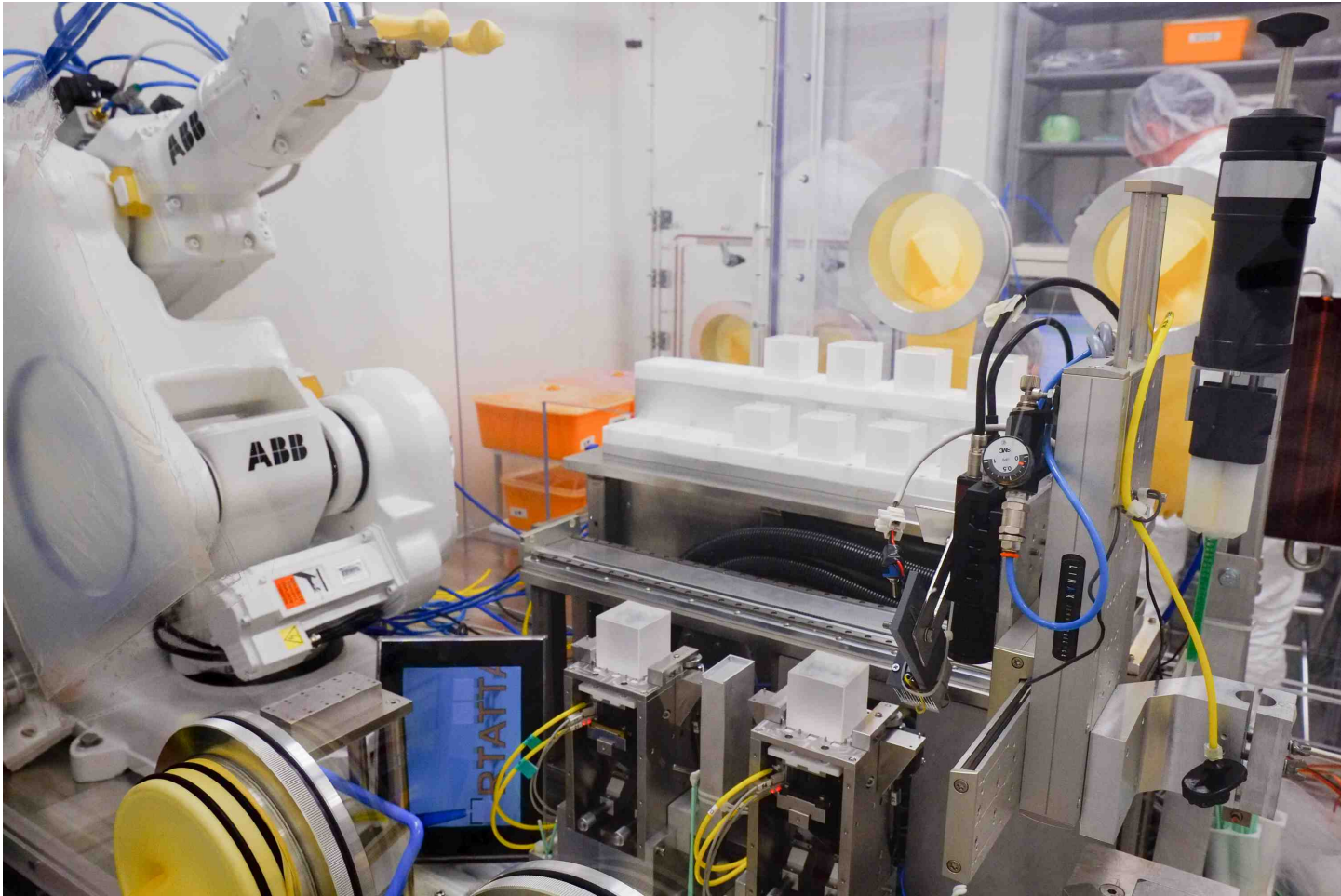
# Detector assembly



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

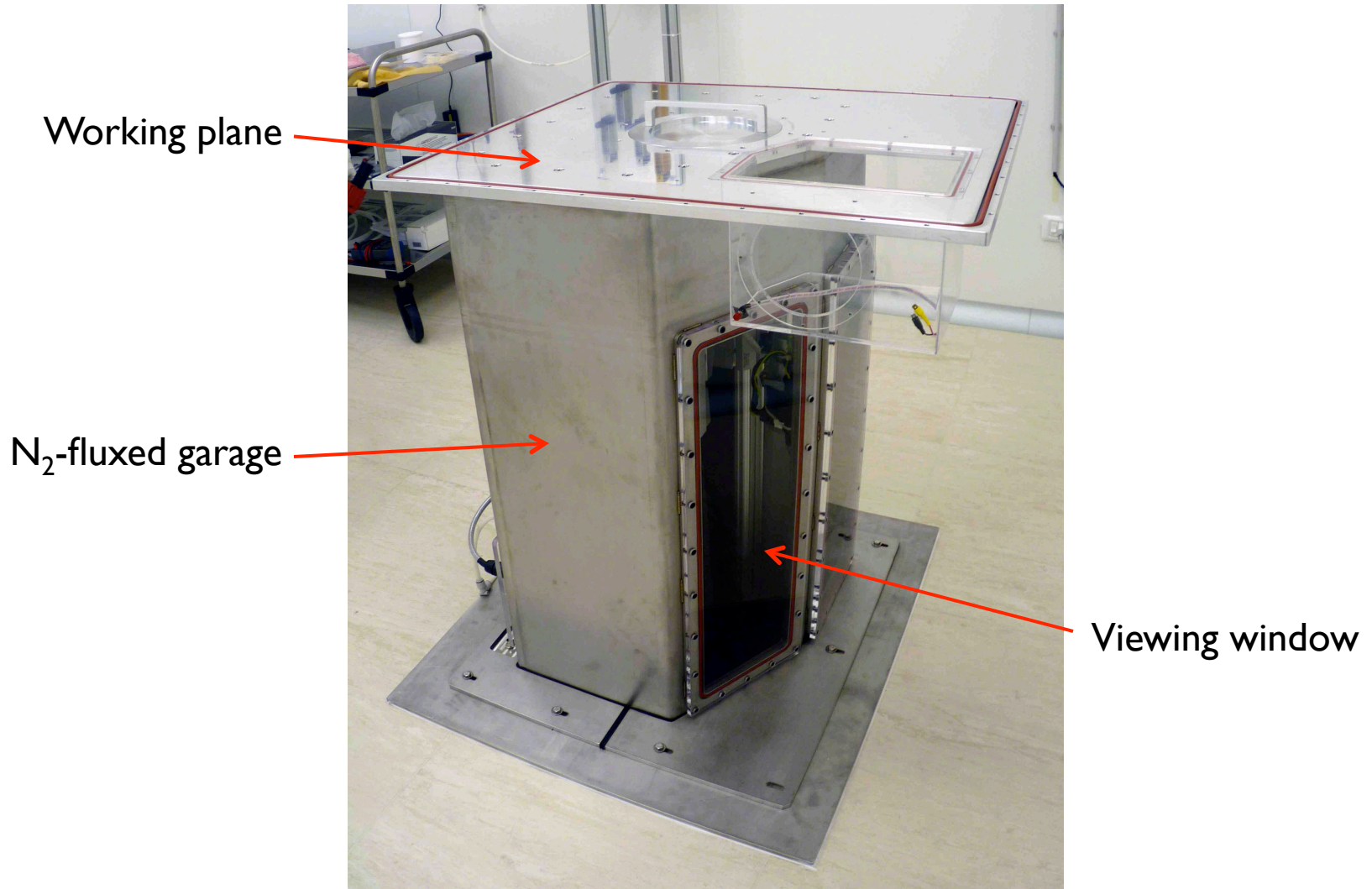


# Gluing of crystals



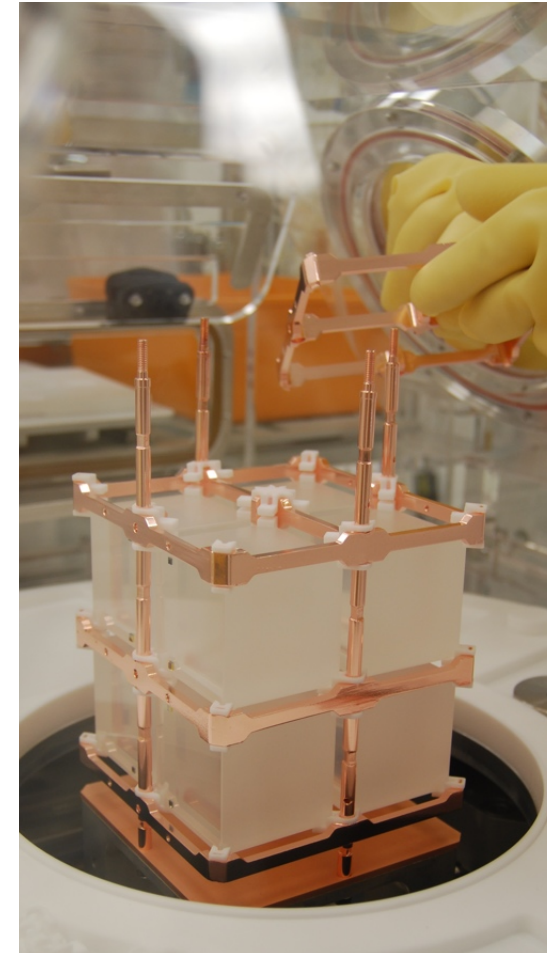
Semi-automated, glovebox-enclosed system for gluing sensors to crystals

# Tower assembly line



Detector towers are built using this workstation, with task-specific glove boxes

# Tower assembly line



Step 1: Physical assembly of a tower

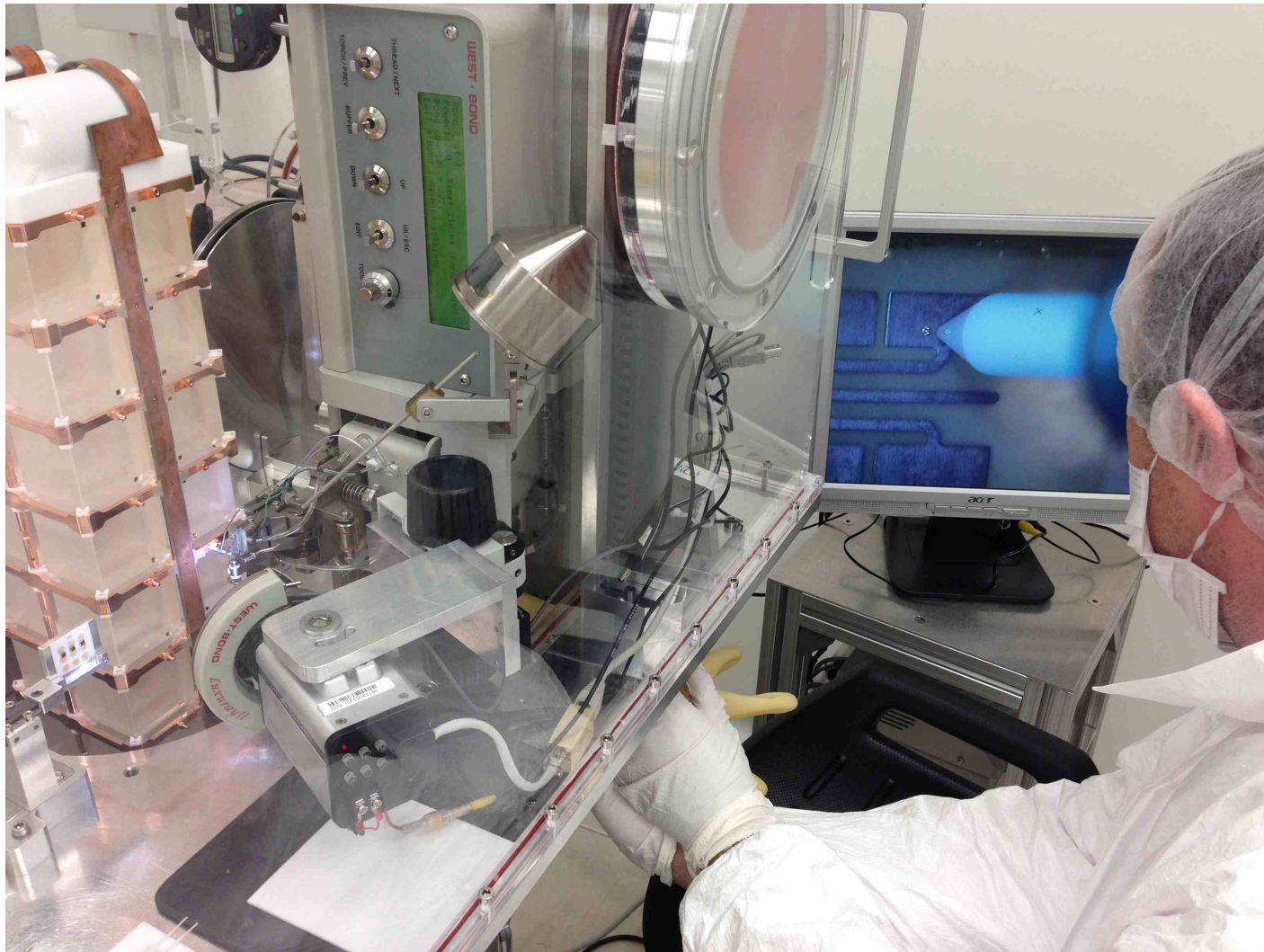


# Tower assembly line



Assembled tower in the garage

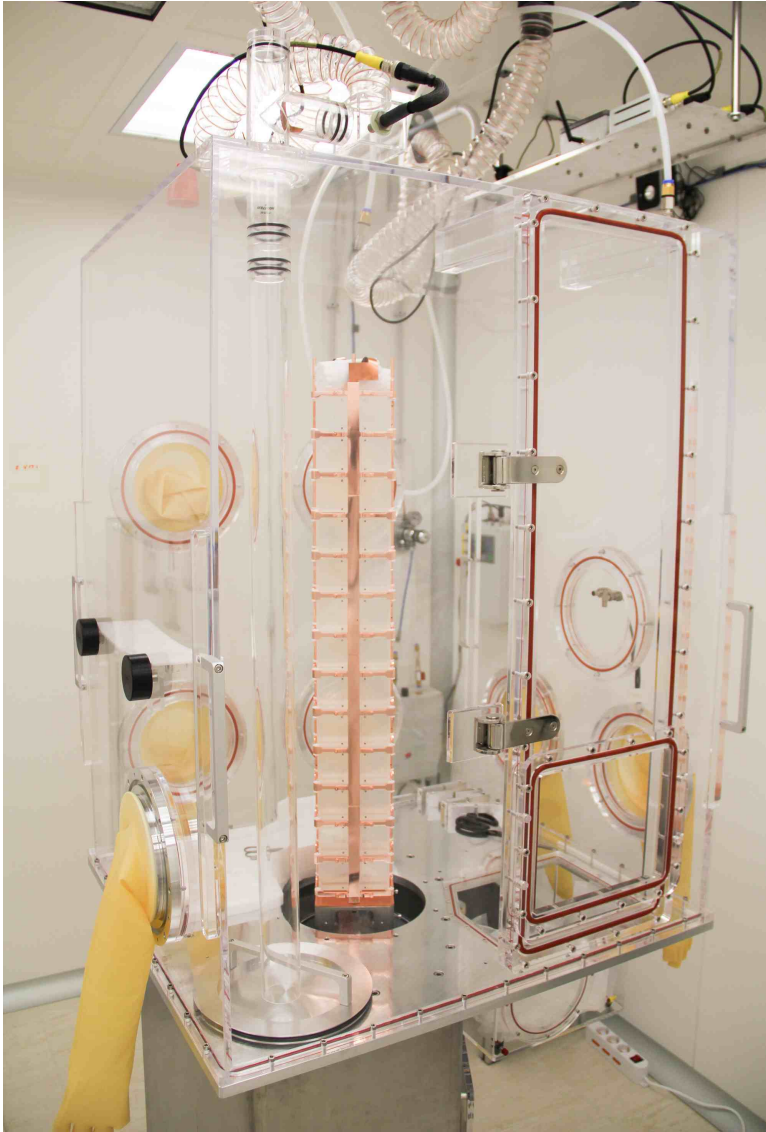
# Tower assembly



Step 2: Wire bonding of the tower



# Tower assembly



Final steps

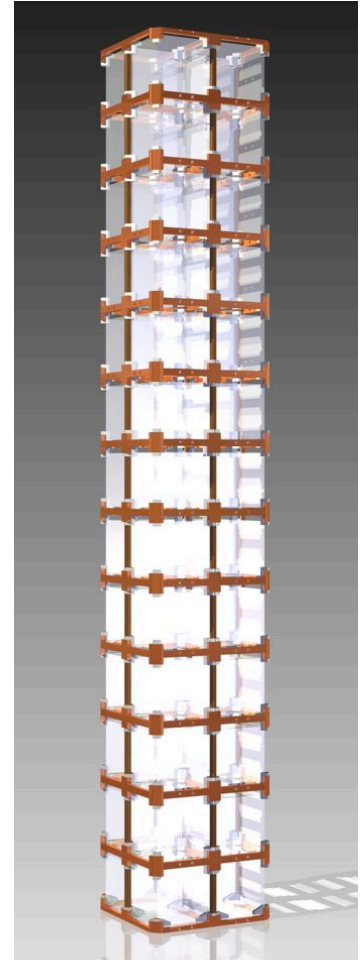
# Towers in storage



All 19 towers are complete! Now sitting in N<sub>2</sub>-fluxed storage

# CUORE-0

- ▶ First tower from the CUORE assembly line
- ▶ Purpose:
  1. Commission assembly line
  2. Surpass Cuoricino while CUORE is being constructed
- ▶ Operating in former Cuoricino cryostat since Mar 2013





# CUORE-0



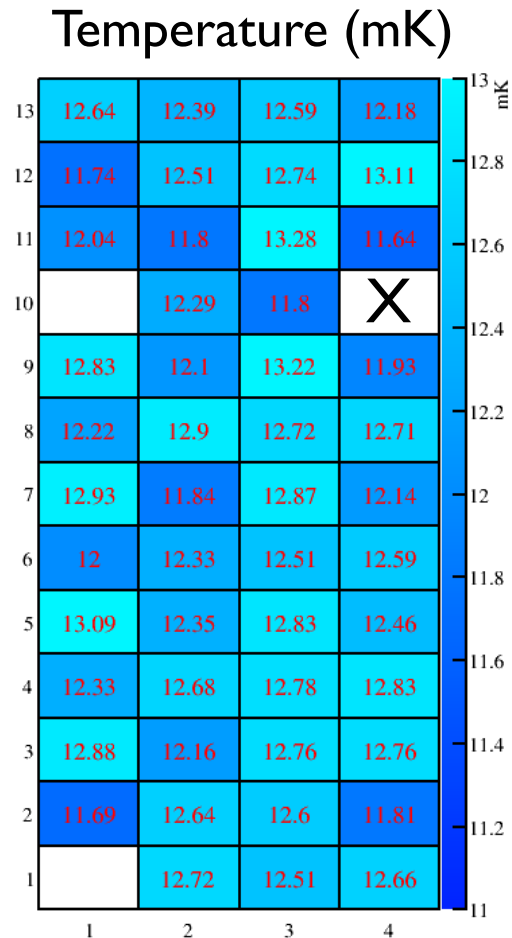
CUORE-0 in its  
thermal shield



Attached to the Cuoricino  
dilution refrigerator



# CUORE-0 performance

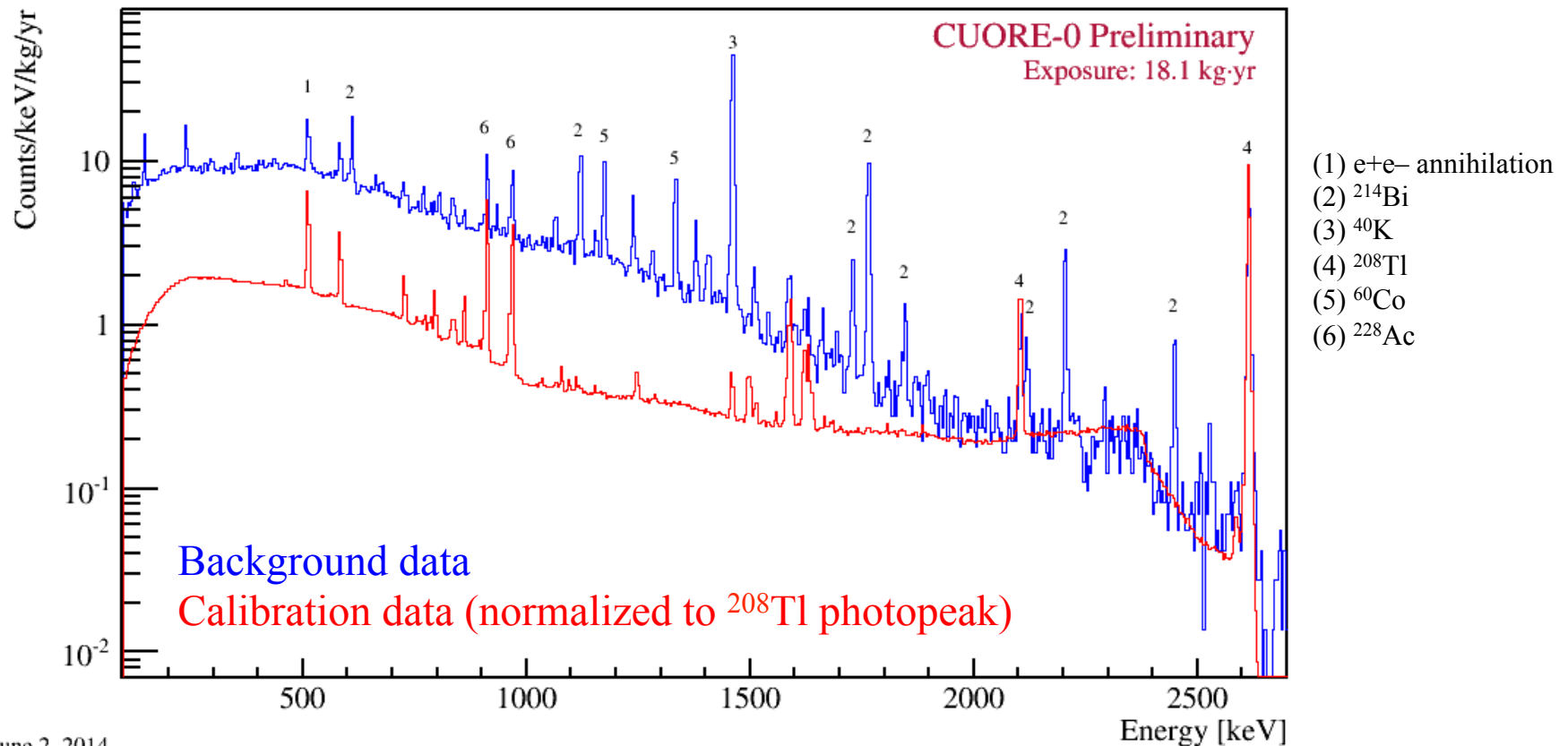


CUORE-0 Preliminary  
Exposure: 18.1 kg-yr

June 2, 2014

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

# CUORE-0 energy spectrum

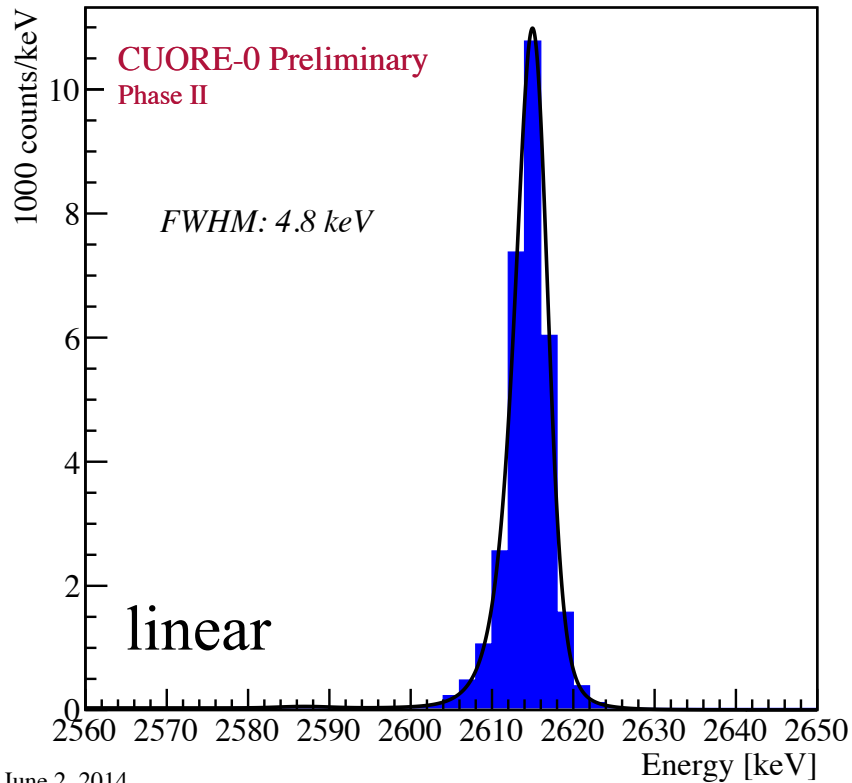


June 2, 2014

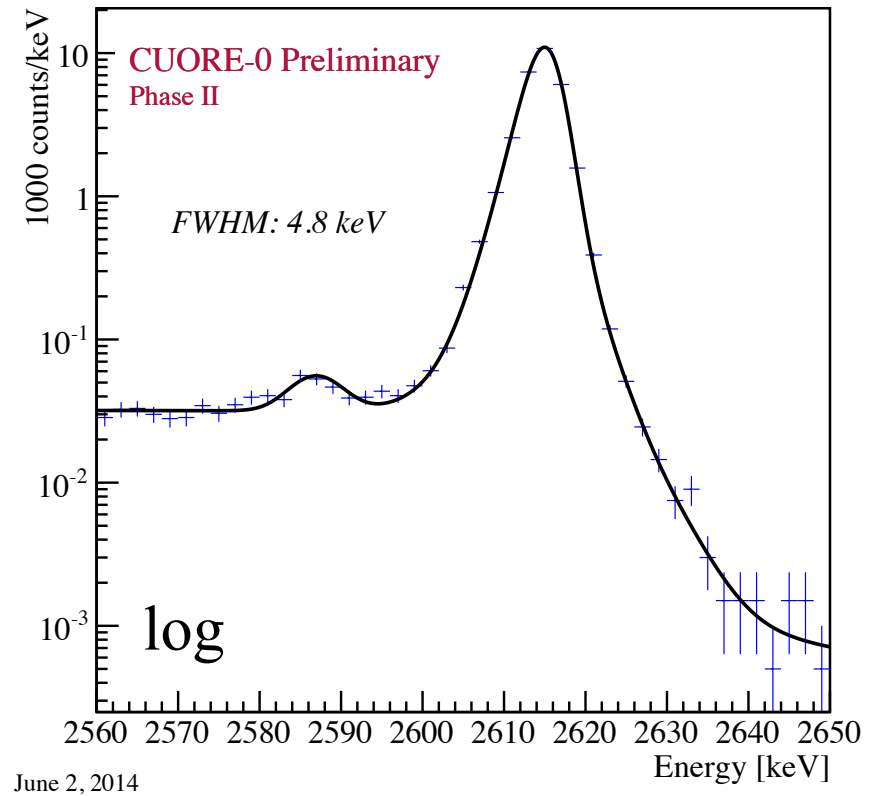
- ▶ We collect two types of data: calibration data and “background” data
- ▶ For calibrations, we lower thoriated-tungsten wires in between the cryostat and outer lead shield

# CUORE-0 energy resolution

CUORE-0 Calibration Spectrum (Phase II)

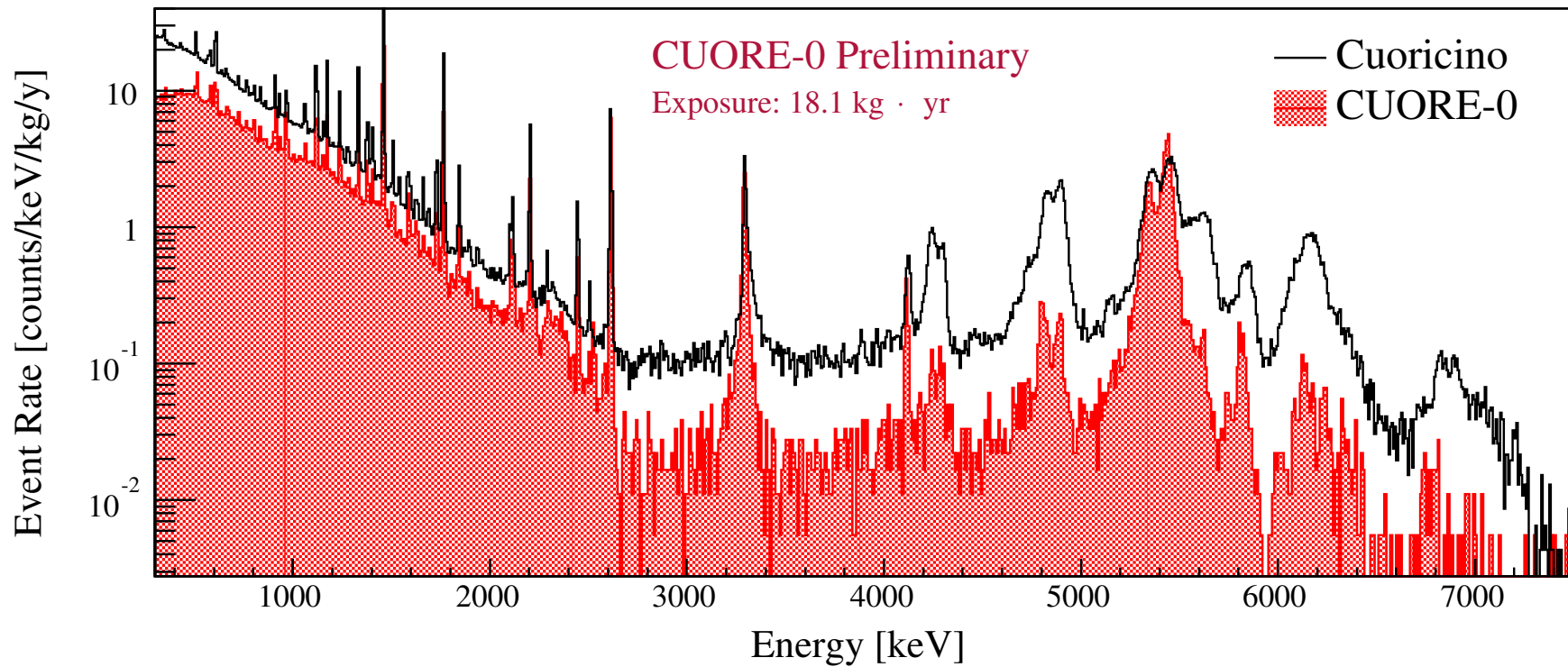


CUORE-0 Calibration Spectrum (Phase II)



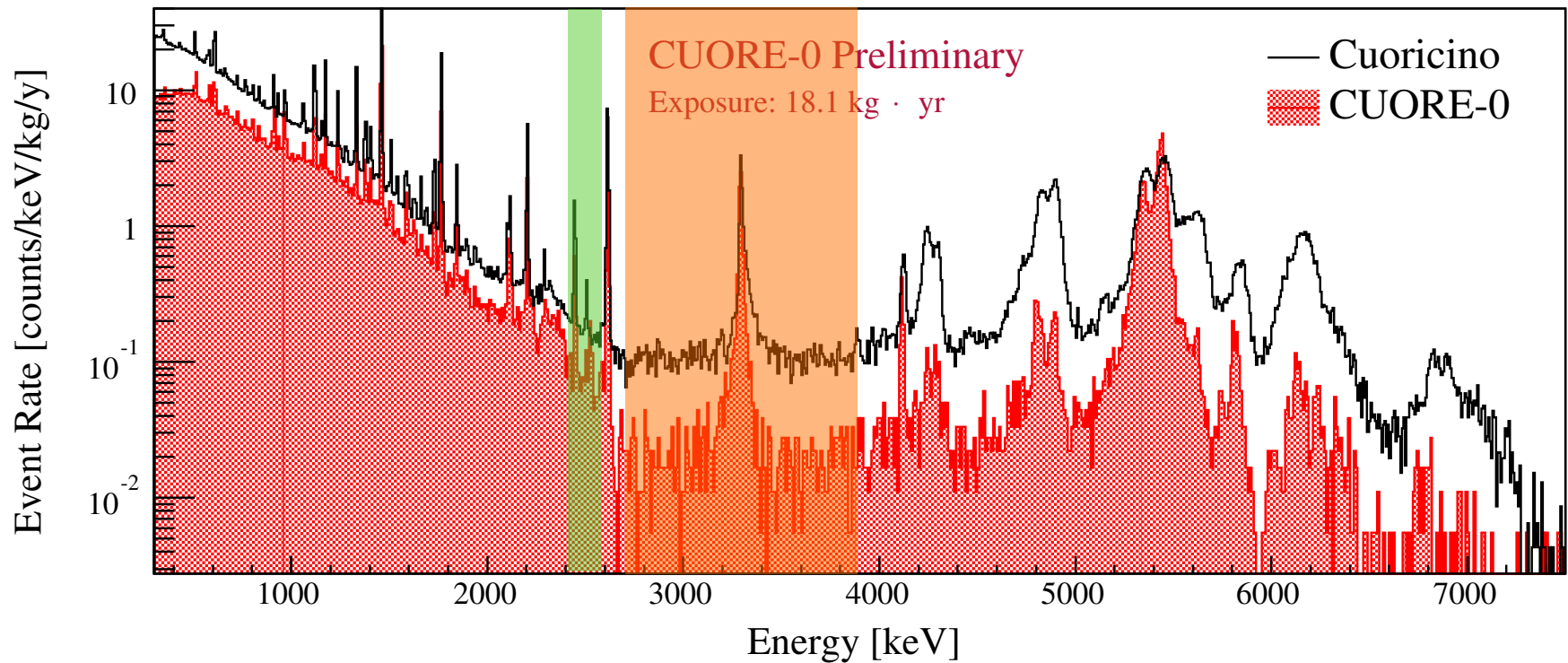
- ▶ We use the  $^{208}\text{Tl}$  photopeak @ 2615 keV to evaluate the detector resolutions
- ▶ Overall FWHM in Phase I was 5.7 keV; in Phase II it improved to 4.8 keV

# CUORE-0 background



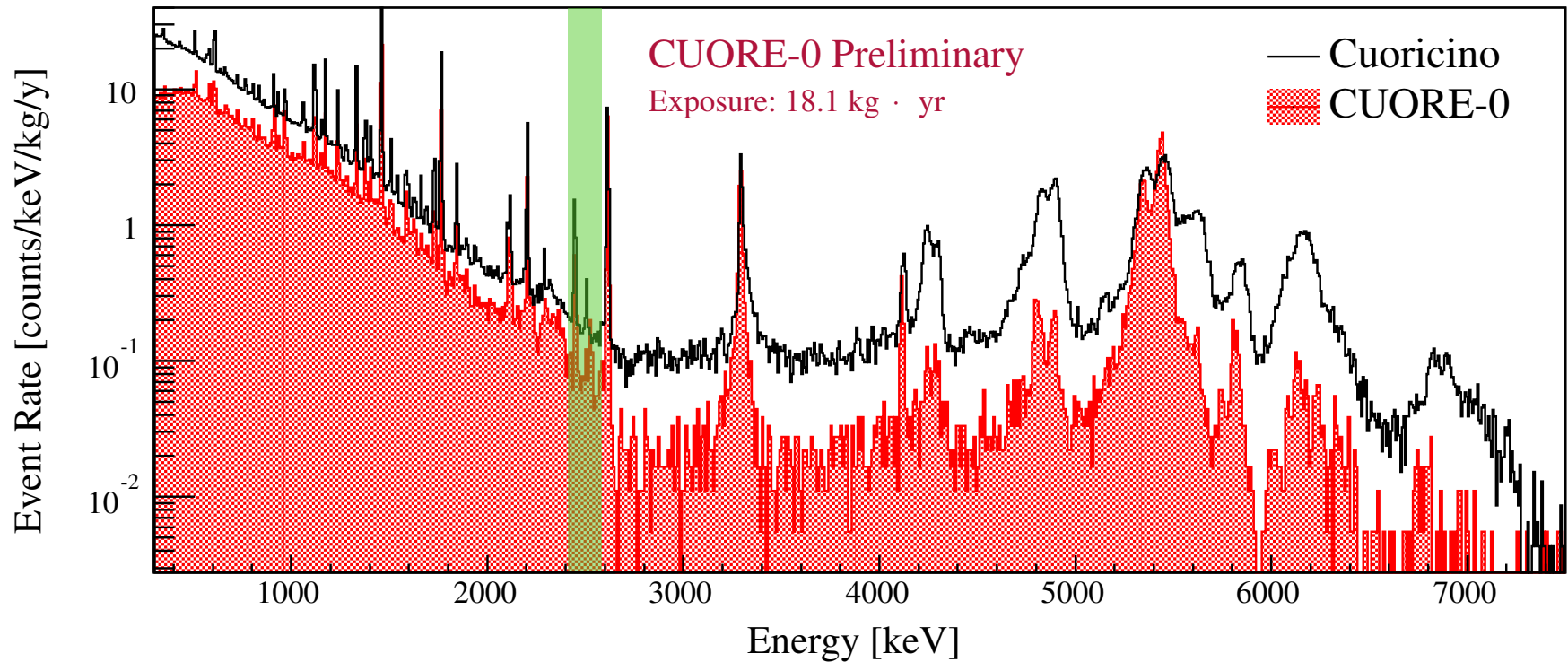


# CUORE-0 background



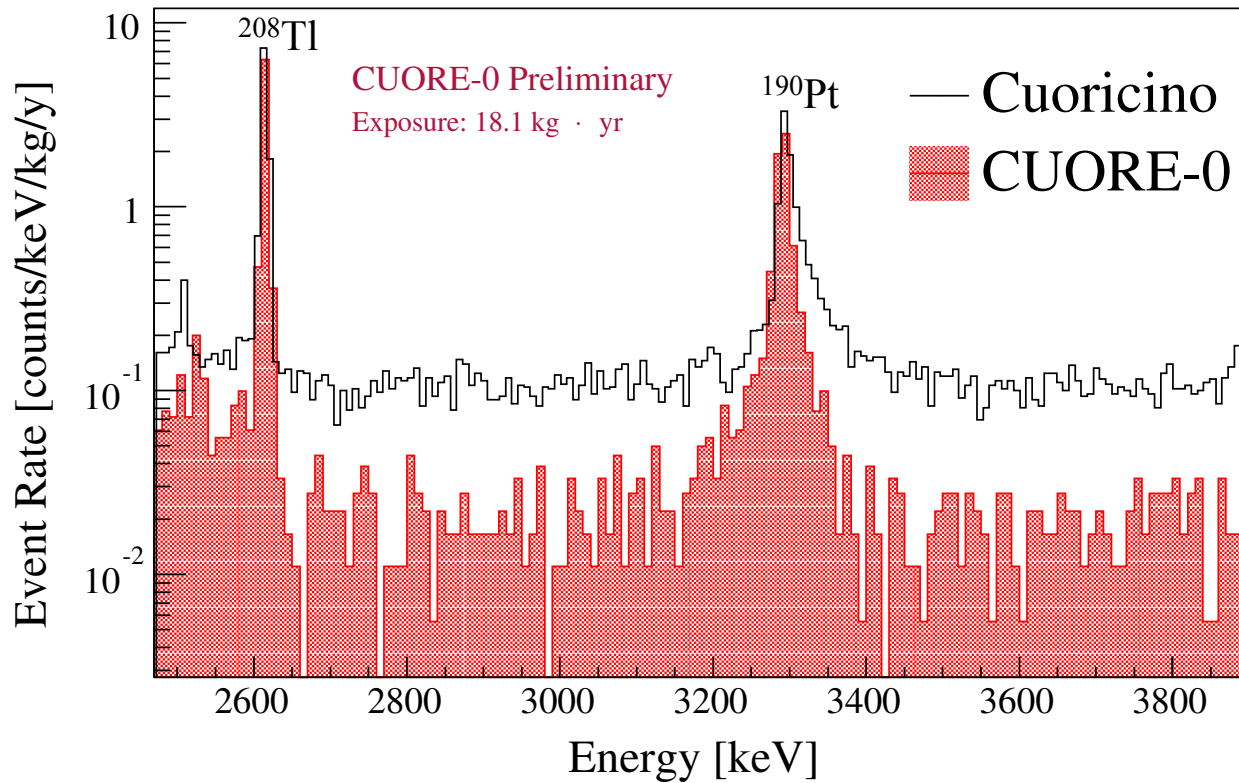
Experiment	Background rate (counts/keV/kg/y)	
	$0\nu\beta\beta$ decay region	Alpha region (excl. peak)
Cuoricino	$0.153 \pm 0.006$	$0.110 \pm 0.001$
<b>CUORE-0</b>	<b><math>0.063 \pm 0.006</math></b>	<b><math>0.020 \pm 0.001</math></b>

# CUORE-0 background



- ▶ Factor of 2.5 reduction in <sup>238</sup>U gammas (less radon contamination)
- ▶ No reduction in <sup>232</sup>Th gammas (due to irreducible cryostat contamination)

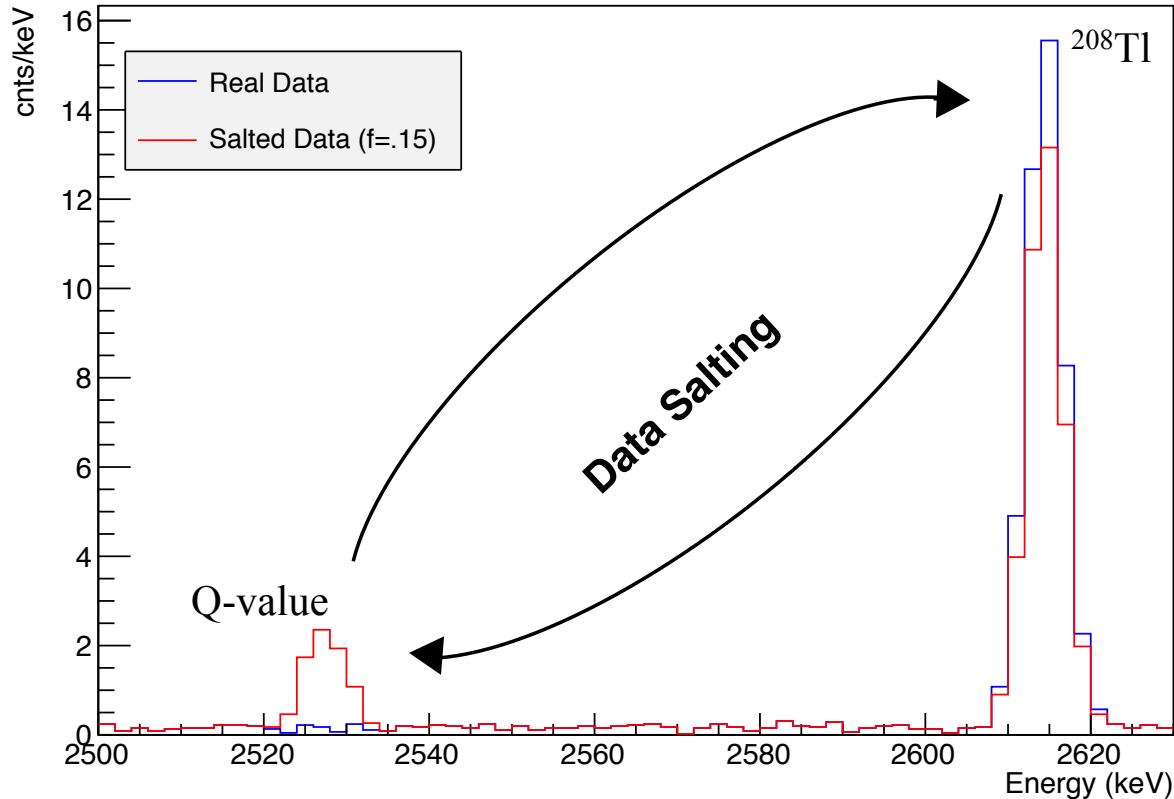
# CUORE-0 background



- ▶ 6-fold reduction in alpha background!
- ▶ Validates enhanced cleaning and assembly techniques
- ▶ Confirms background model developed from Cuoricino
- ▶ Indicates CUORE sensitivity goal is within reach

# CUORE-0 data blinding

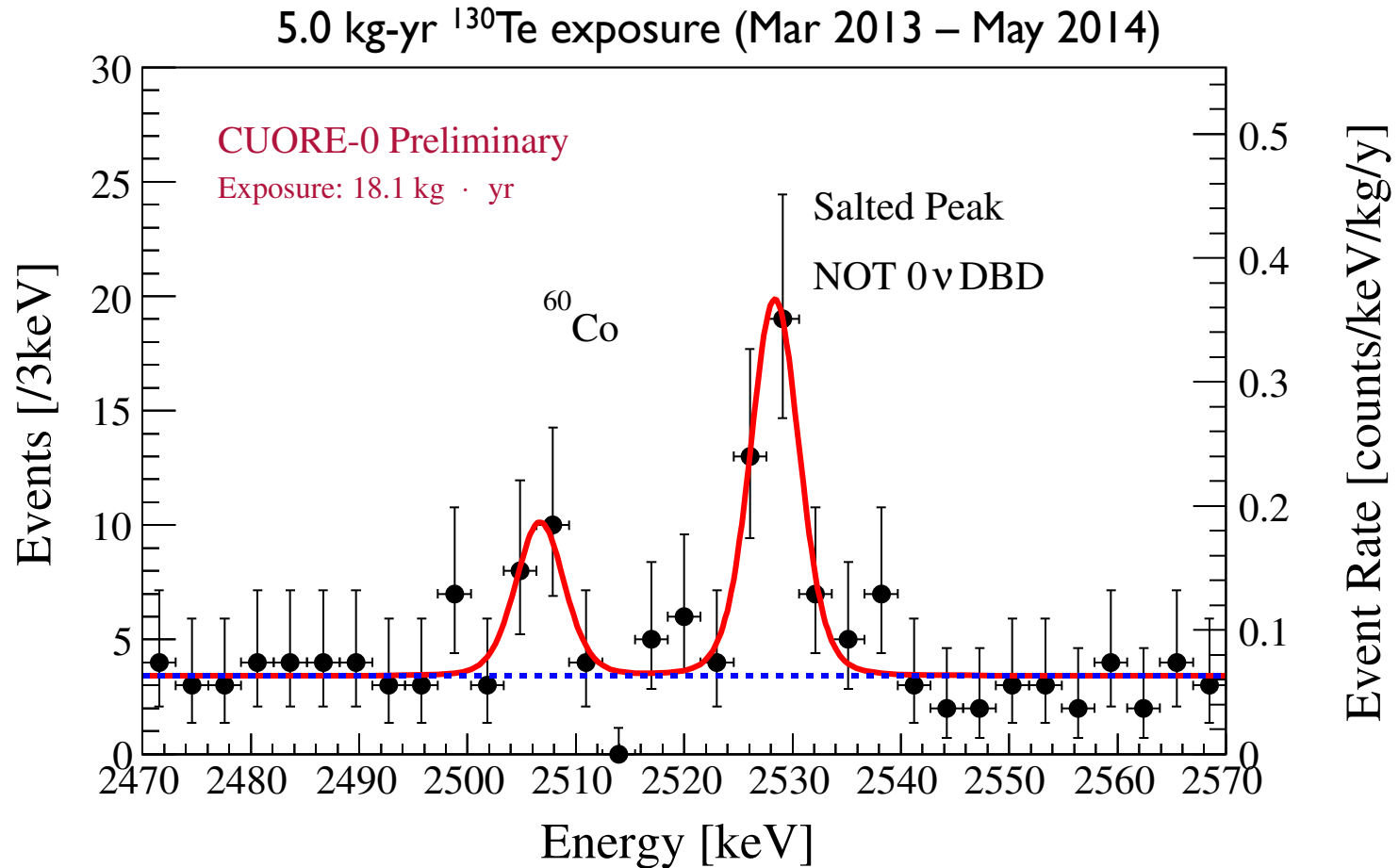
## Illustration of “salting” technique



Small (and blinded) fraction of events within  $\pm 10$  keV of  $^{208}\text{Tl}$  photopeak are moved to within  $\pm 10$  keV of  $^{130}\text{Te}$   $0\nu\beta\beta$  decay Q-value, and vice versa

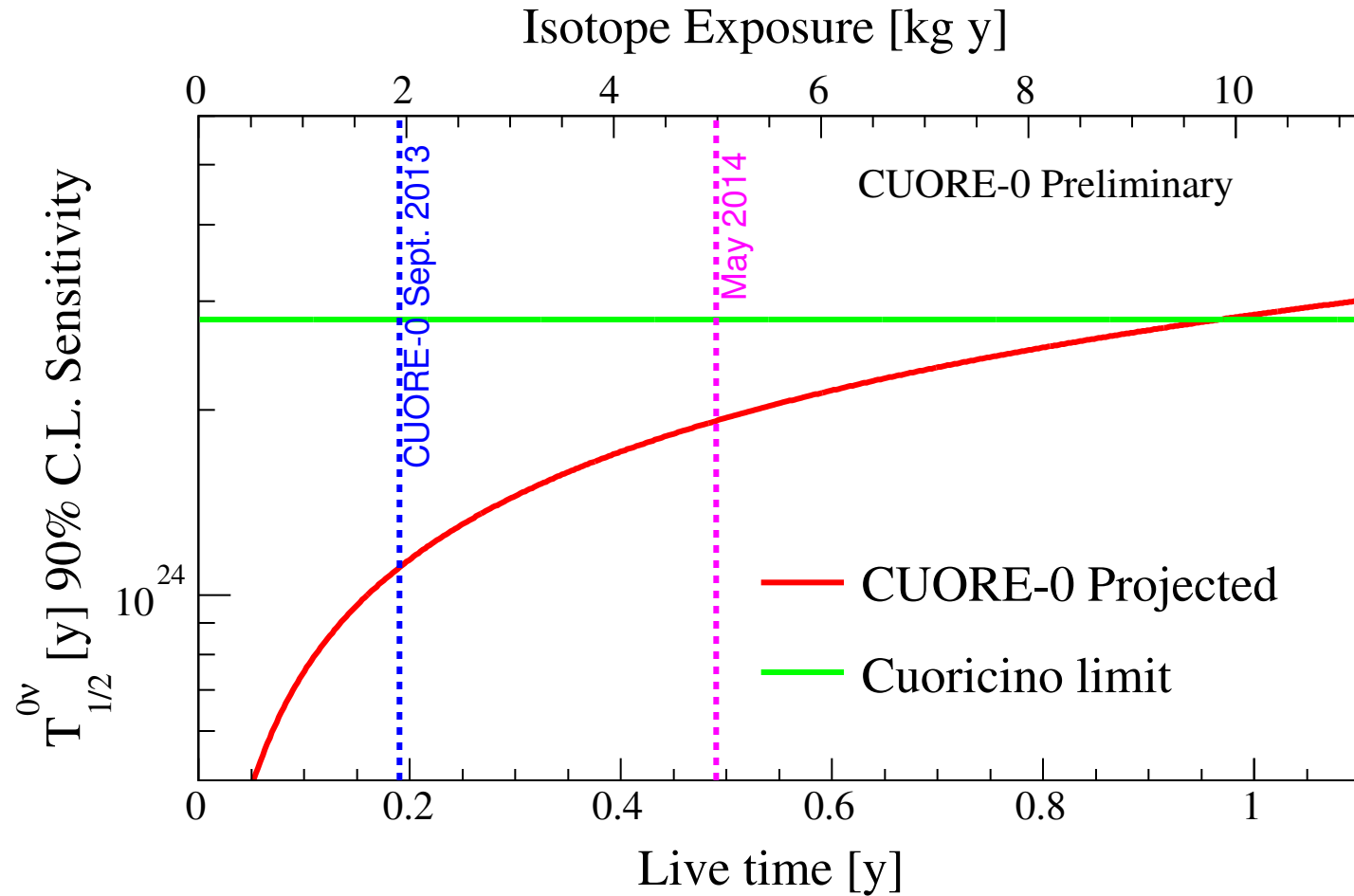


# CUORE-0 region of interest



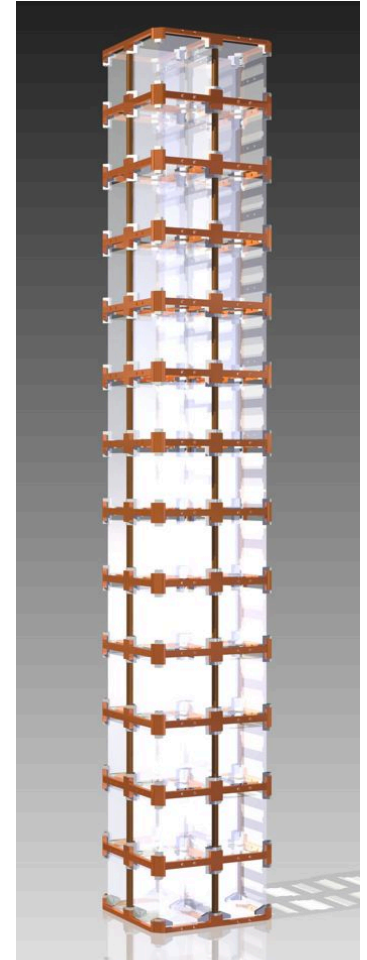
Signal detection efficiency =  $77.6 \pm 1.3\%$   
(~87% containment efficiency & ~89% identification efficiency)

# CUORE-0 sensitivity



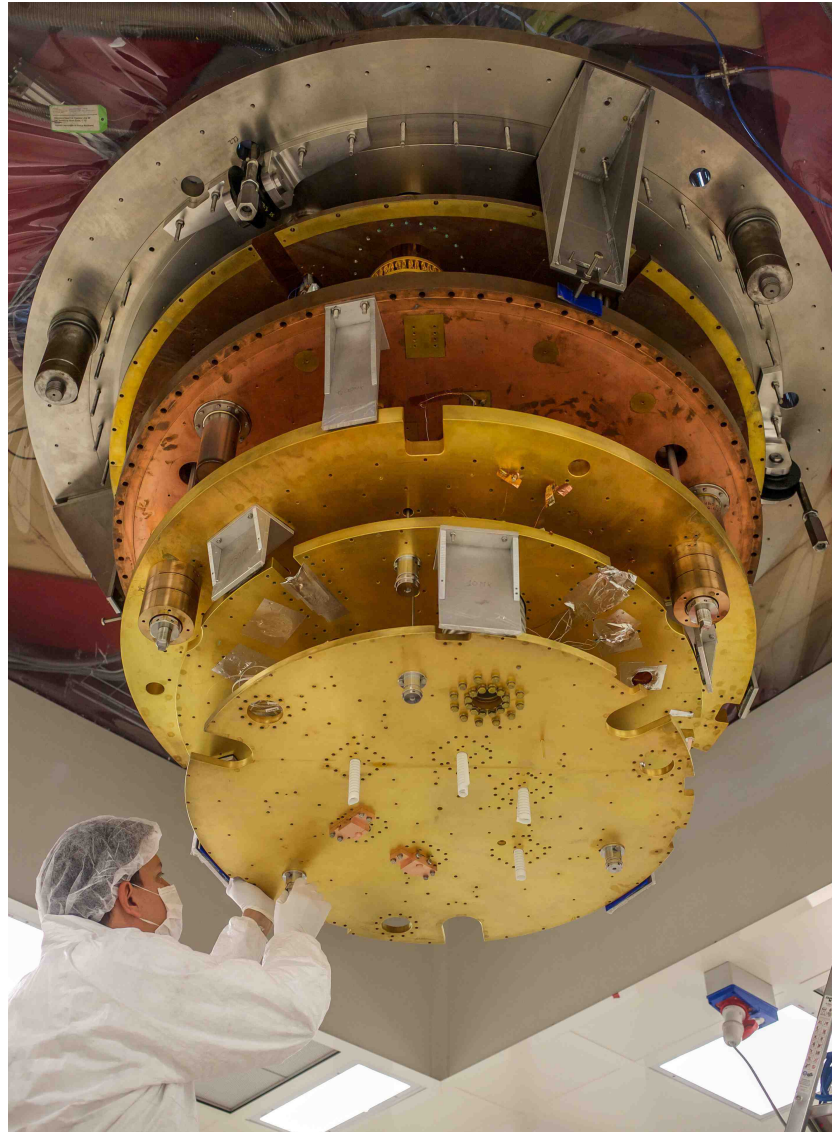
# CUORE-0 story

- ▶ Successful radiopurity & resolution demonstrator
- ▶ Data analysis is ongoing, with improvements being made in:
  - noise decorrelation
  - heaterless gain stabilization
  - pulse shape and coincidence cuts
  - background model
- ▶ Data taking will continue into 2015
- ▶ Expect to unblind and publish in 2015



Meanwhile, next door...

# Cryostat commissioning



We are following a phased integration plan



# “No-load” cooldowns



- ▶ In 2013 we achieved 4K cooldown with outer 3 vessels + pulse tubes
- ▶ In Sep 2014 we achieved base-temp cooldown with all vessels + dilution refrig.

---

# CUORE In The News

---



*or*

The Truth of the Gell-mann Effect

# The Coldest Cubic Meter in the Known Universe

Jonathan L. Ouellet

*University of California, Berkeley\**

(Dated: October 15, 2014)

CUORE is a 741 kg array of TeO<sub>2</sub> bolometers that will search for the neutrinoless double beta decay of <sup>130</sup>Te. The detector is being constructed at the Laboratori Nazionali del Gran Sasso in Italy, where it will begin taking data in 2015. The CUORE cryostat will cool several metric tonnes of material to below 1 K and the CUORE detector itself will operate at a typical temperature of 10 mK. At this temperature, the CUORE detector will be the coldest contiguous cubic meter in the known Universe.

<http://arxiv.org/abs/1410.1560>

Last month, UCB graduate student and CUORE member Jon Ouellet posted a fun paper to the arXiv

# GIZMODO

+ FOLLOW

## Scientists Are Creating the Coldest Cubic Meter in the Universe



Sarah Zhang

Filed to: MONSTER MACHINES 10/13/14 4:00pm

14,494 🔥 1 ★



Actually →  
CUORE-0,  
but OK

It got noticed







HOME

PHOTOWALK

ABOUT INTERACTIONS

IMAGE BANK

VIDEO CHANNEL

BLOG WATCH

NEWSWIRE ARCHIVE

BENEFITS TO SOCIETY

PEER REVIEWS

ADDITIONAL RESOURCES

COLLABORATION  
WORKSPACES

CONTACT US

Interactions NewsWire #71-14

21 October 2014 <http://www.interactions.org>

\*\*\*\*\*

Source: INFN

Content: Press Release

Date Issued: 21 October 2014

\*\*\*\*\*

## CUORE: The Coldest Heart in the Known Universe

The CUORE collaboration at the INFN Gran Sasso National Laboratory has set a world record by cooling a copper vessel with the volume of a cubic meter to a temperature of 6 milliKelvins; it is the first experiment ever to cool a mass and a volume of this size to a temperature this close to absolute zero (0 Kelvin). The cooled copper mass, weighing approx. 400 kg, was the coldest cubic meter in the universe for over 15 days.

CUORE is an international collaboration involving some 130 scientists mainly from Italy, USA, China, Spain, and France. CUORE is supported by the Istituto Nazionale di Fisica Nucleare (INFN) in Italy; the Department of Energy Office of Science (Office of Nuclear Physics), the National Science Foundation, and Alfred P. Sloan Foundation in the United States.



Recognizing the potential public interest, we issued some press releases



**RELATED KEYWORDS:** [Lowest-temperature](#) | [cuore](#) | [absolute-zero](#)

## Lowest temperature ever in universe recorded at Italian lab

Subodh Varma, TNN | Oct 22, 2014, 12.46PM IST

[Like](#) [Share](#) { 1k } [Tweet](#) { 146 } [g+](#) { 25 } [in](#) [Share](#) { 28 }

NEW DELHI: Scientists at an Italian institute have set a world record of the lowest temperature ever achieved in the universe. They cooled a copper vessel with a volume of one cubic meter to -273.144 degrees celsius. This is stunningly close to 'absolute zero', which is equal to -273.15 degrees celsius. Theoretical physics says that temperature can never go below this limit.

No experiment on Earth has ever cooled a similar mass or volume to temperatures such a low; similar conditions are also not expected to arise in nature. This gives CUORE the distinction of being the coldest cubic meter in the known universe.

The cooled copper mass, weighing approximately 400 kg, was the coldest cubic meter in the universe for over 15 days.



A rubber ball, frozen to near absolute zero by liquid helium, shatters and vaporizes as it strikes floor. (Source: Getty Images)

RELATED KEYWORDS: Lowest-temperature | cuore | absolute zero

# Lowest temperature ever in universe recorded at Italian

By [S. Prerna](#), TNN | Oct 22, 2014, 12.46PM IST

Like Tweet 146 Share 28

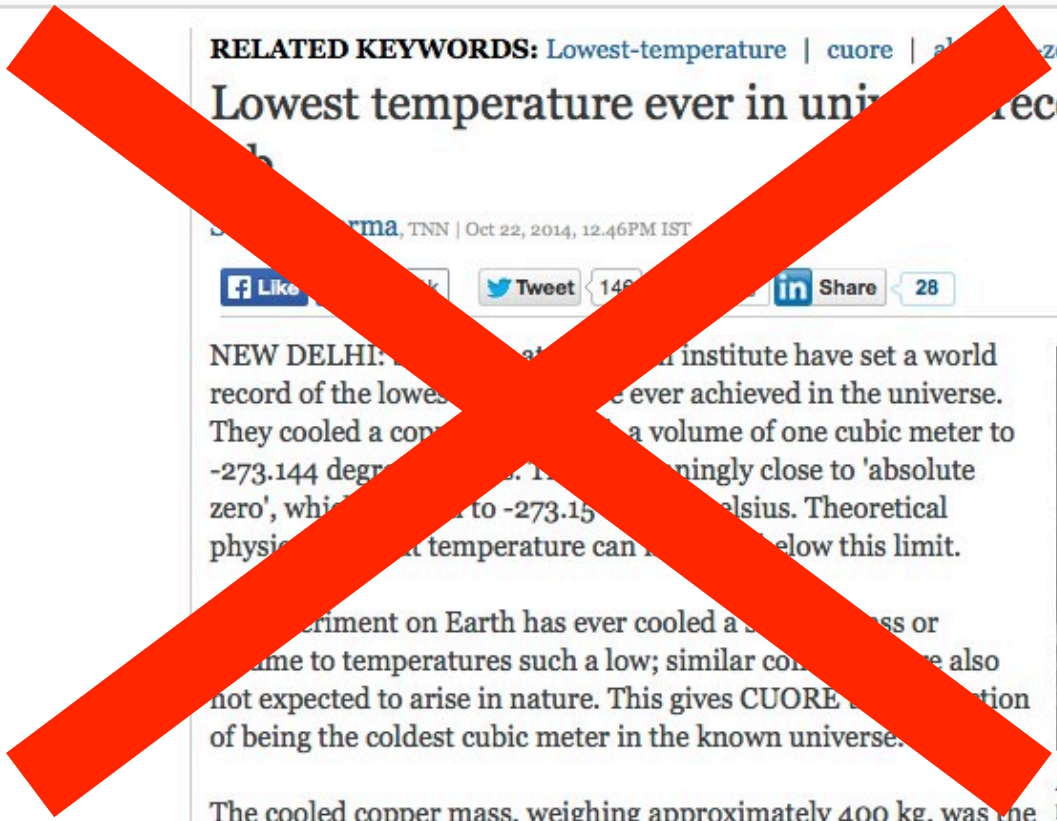
NEW DELHI: Scientists at the Italian institute have set a world record of the lowest temperature ever achieved in the universe. They cooled a copper mass of a volume of one cubic meter to -273.144 degrees Celsius. This is strikingly close to 'absolute zero', which is -273.15 degrees Celsius. Theoretical physicists say that temperature can't go below this limit.

The experiment on Earth has ever cooled a substance or brought it to temperatures such a low; similar conditions are also not expected to arise in nature. This gives CUORE the distinction of being the coldest cubic meter in the known universe.

The cooled copper mass, weighing approximately 400 kg, was the coldest cubic meter in the universe for over 15 days.



A rubber ball, frozen to near absolute zero by liquid helium, shatters and vaporizes as it strikes the floor. (Source: Getty Images)



# WRONG



# Chilly Record! Coldest Object on Earth Created in Lab

by Kelly Dickerson, Staff Writer | October 29, 2014 07:25am ET

12

Share

8

Tweet

67

Submit

1

Reddit

More



Scientists cooled a copper cube inside a cryostat, the first such container built that can keep substances so close to absolute zero. [Pin it](#)

[Credit](#): Instituto Nazionale di Fisica Nucleare (INFN)

[View full size image](#)

A chunk of copper became the coldest cubic meter (35.3 cubic feet) on Earth when researchers chilled it to 6 millikelvins, or six-thousandths of a [degree](#) above absolute zero (0 Kelvin).

This is the closest a substance of this mass and volume has ever come to [absolute zero](#).


Researchers put the 880-lb. (400 kilograms) [copper cube](#) inside a container called a cryostat that is specially designed to keep items extremely cold. This is the first cryostat built that is capable of

keeping substances so close to absolute zero.

# Chilly Record! Coldest Object on Earth Created in Lab

by Kelly Dickerson, Staff Writer October 29, 2014 07:27

12

 Share

8

 Tweet

67

 Submit



Scientists cooled a copper cube inside a cryostat, the first such container built that can keep substances so close to absolute zero.

A chunk of copper became the coldest cubic meter (35.3 cubic feet) on Earth when researchers cooled it to 6 millikelvins, or a few thousandths of a [degree](#) above absolute zero (0 Kelvin).

This is the coldest substance of this mass and volume ever to come to absolute zero. Researchers put the 800-lb. (400 kilograms) [copper cube](#) inside a

NOPE



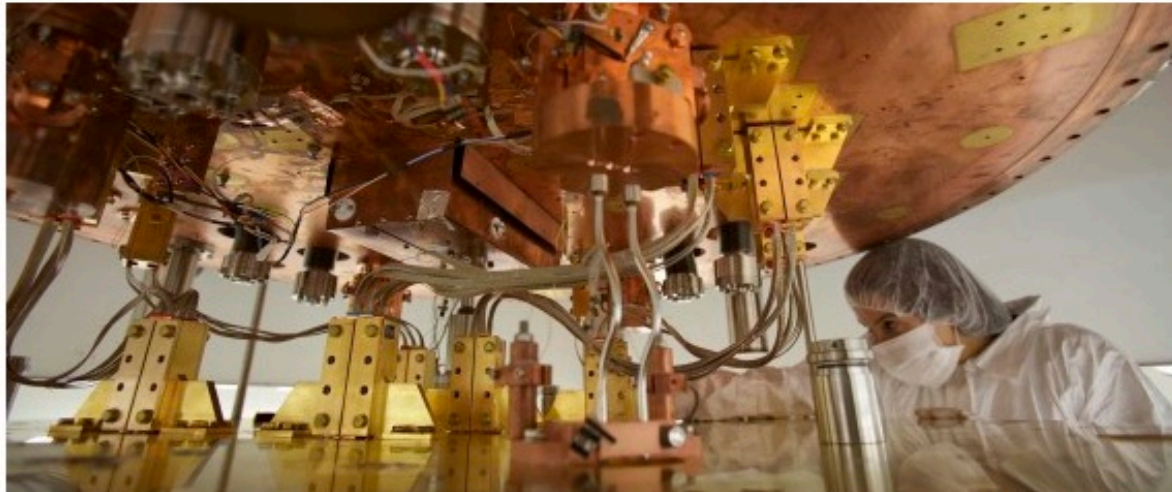
October 29, 2014

# Scientists Create Coldest Cubic Meter In The Universe, Claim New World Record

The Huffington Post | By Jacqueline Howard



Posted: 10/27/2014 9:31 am EDT | Updated: 10/27/2014 9:59 am EDT



402 163 51 9 18 15

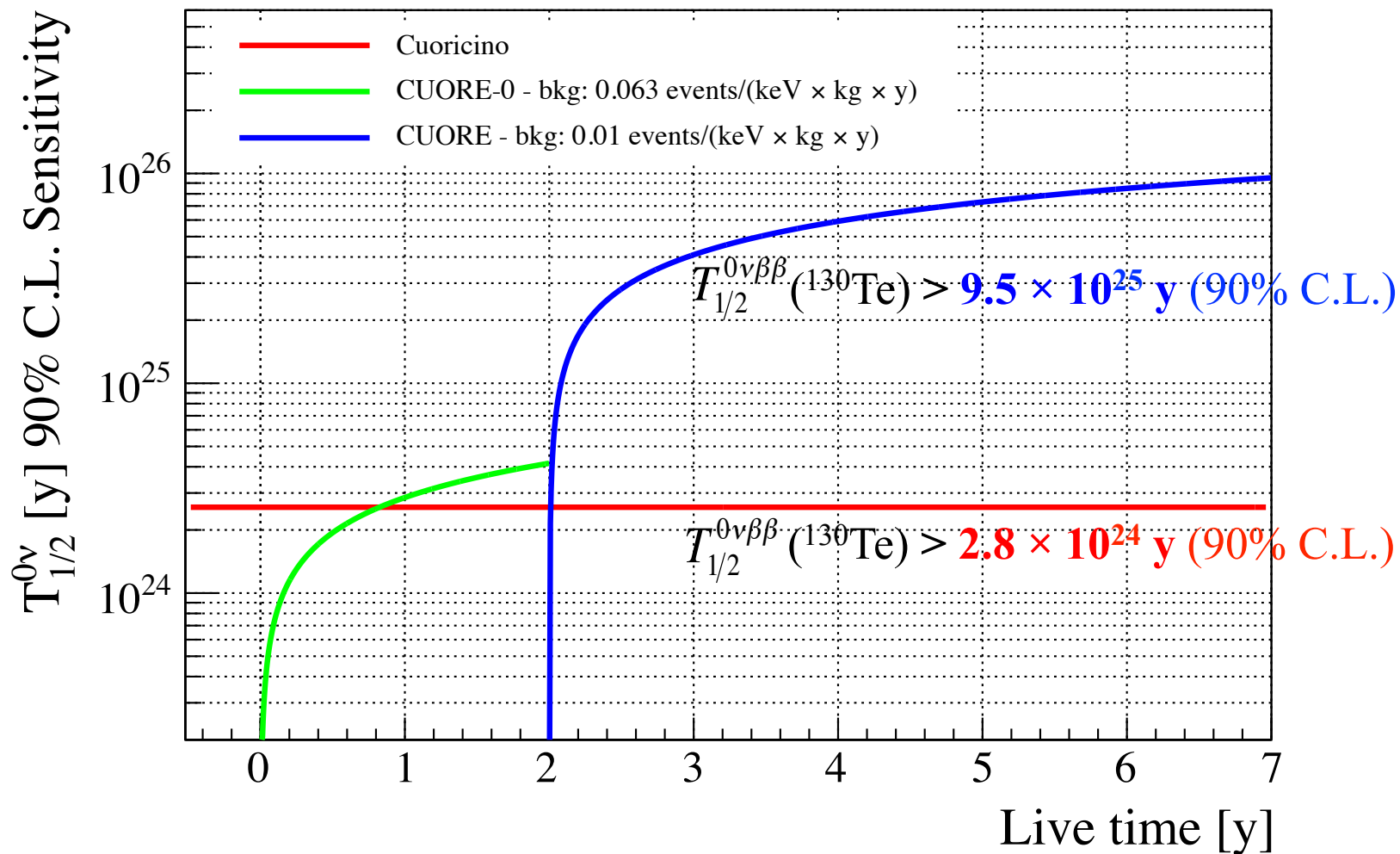
Like Share Tweet Share Email Comment



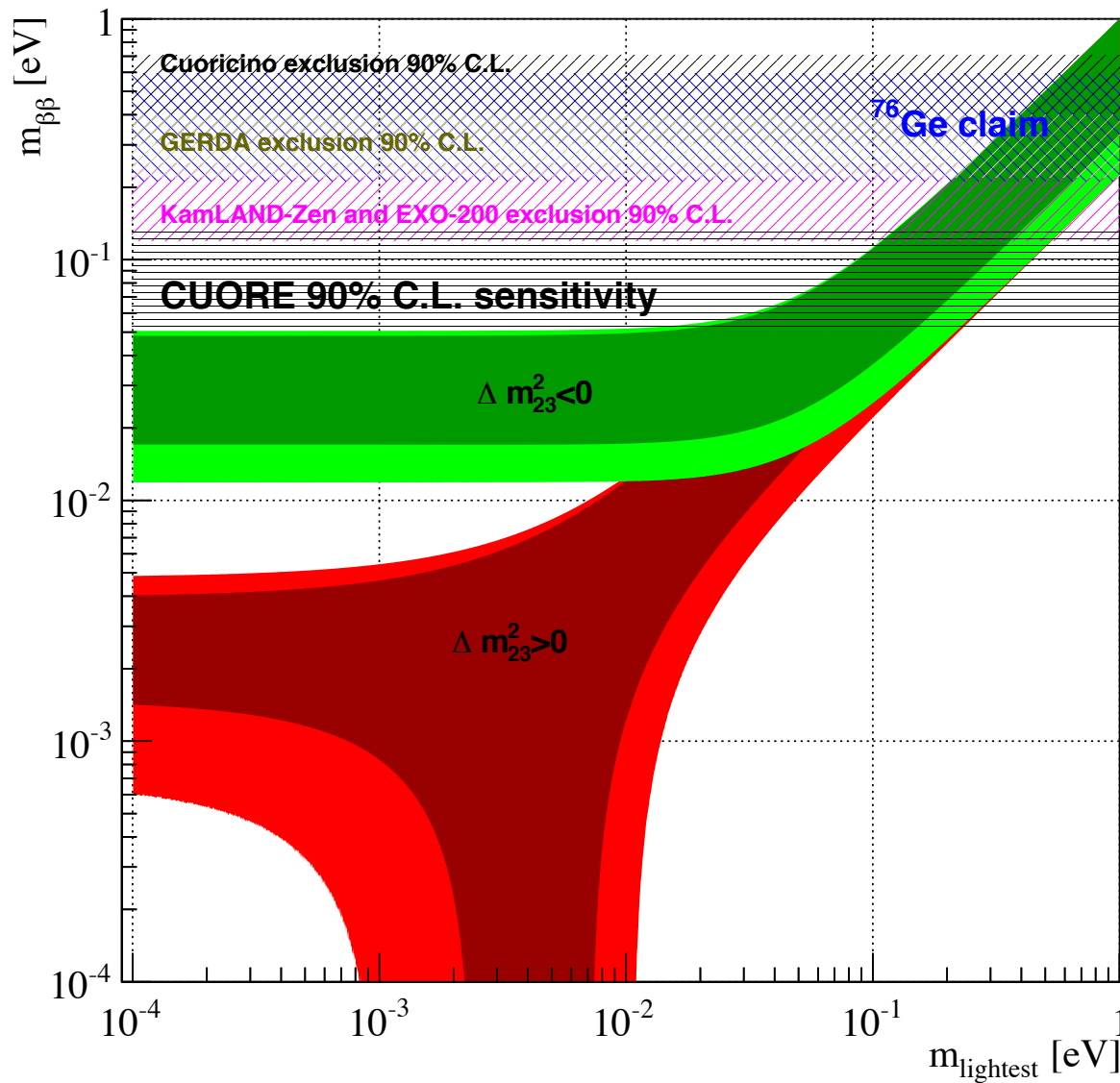
*Brrr!* An international team of scientists claims to have set a world record by cooling an 880-pound [block of copper to a temperature of six milliKelvins](#) (or -459.659 degrees Fahrenheit).



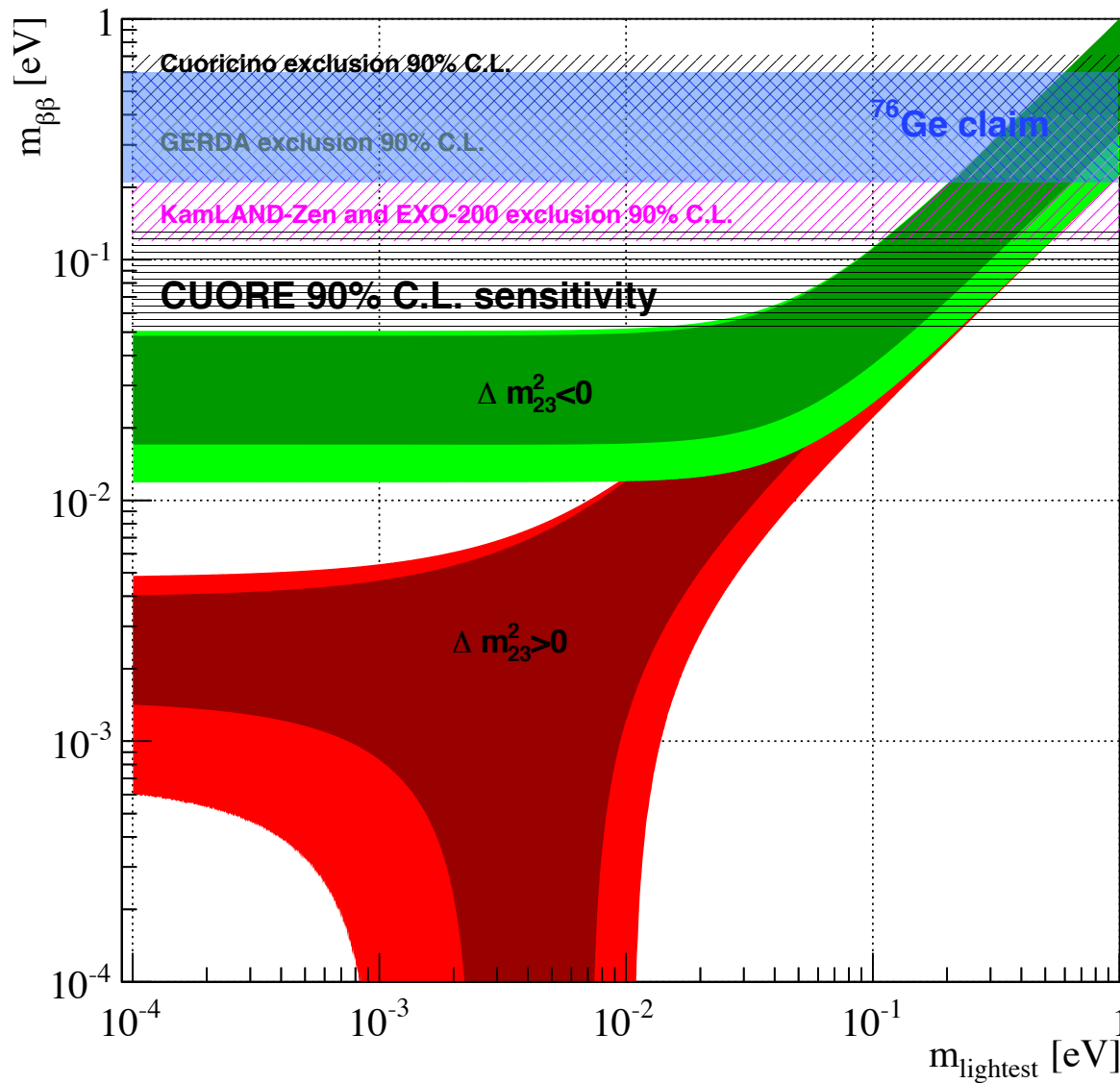
# Experimental sensitivities



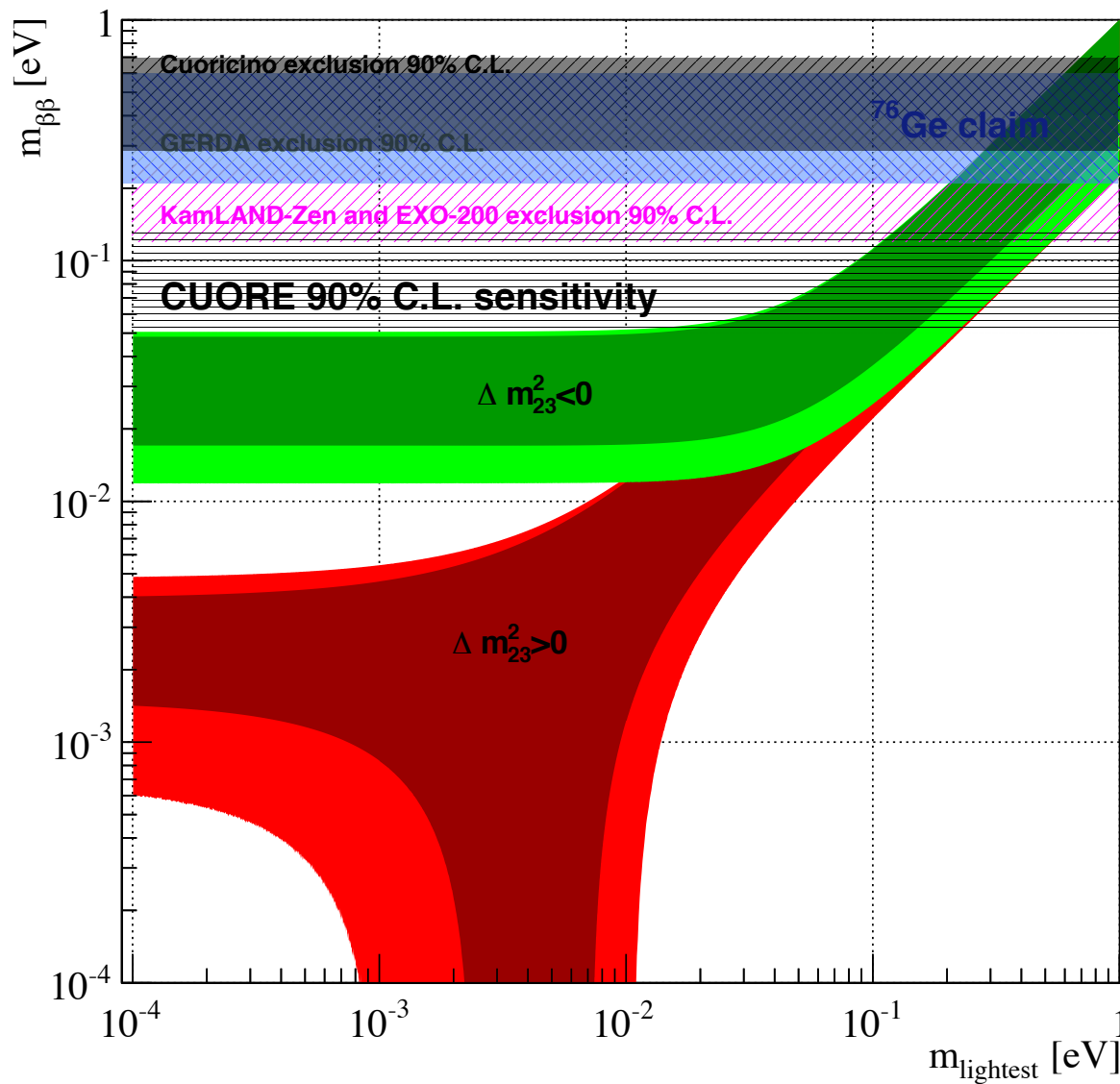
# Experimental reach



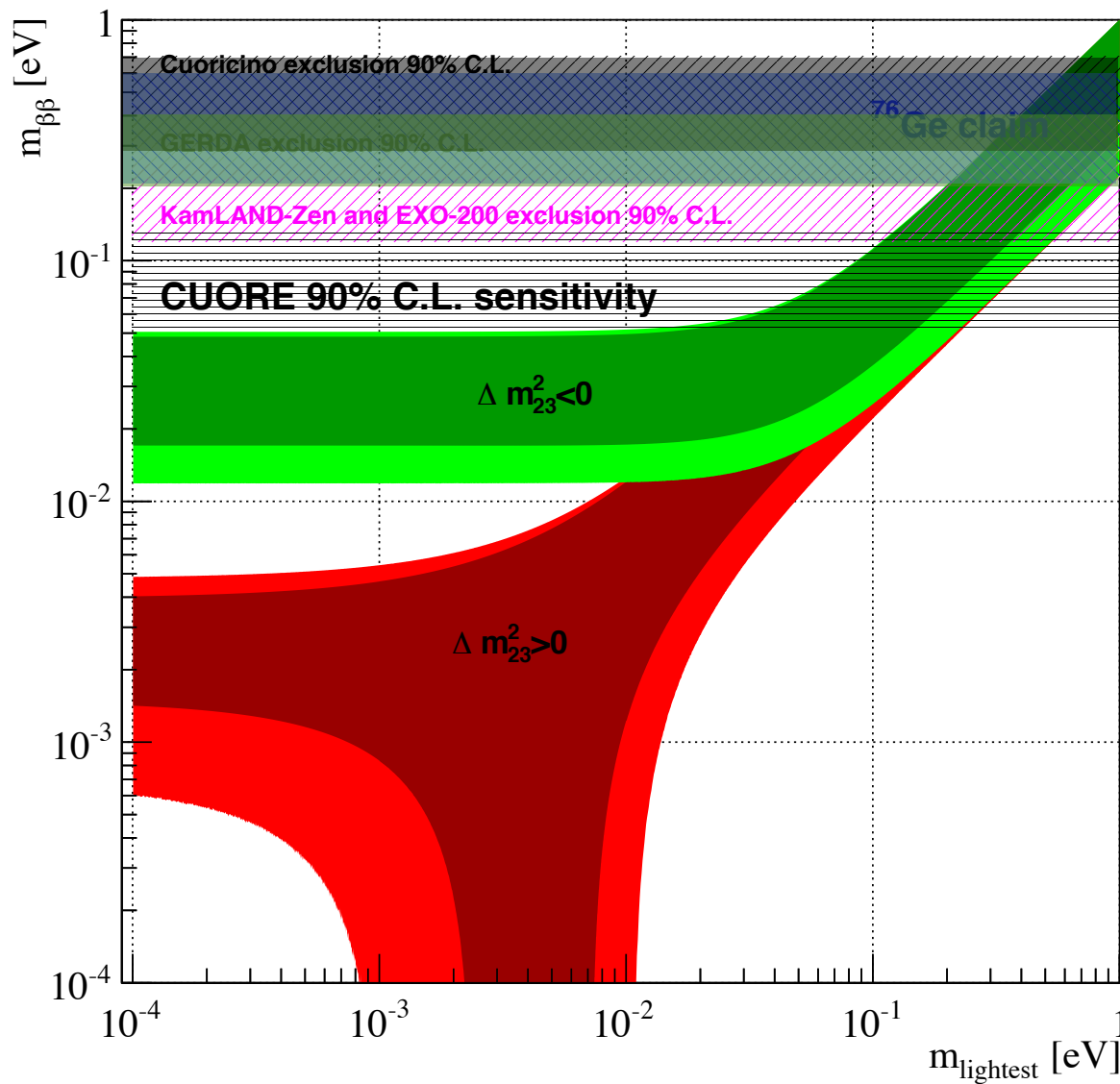
# Experimental reach



# Experimental reach

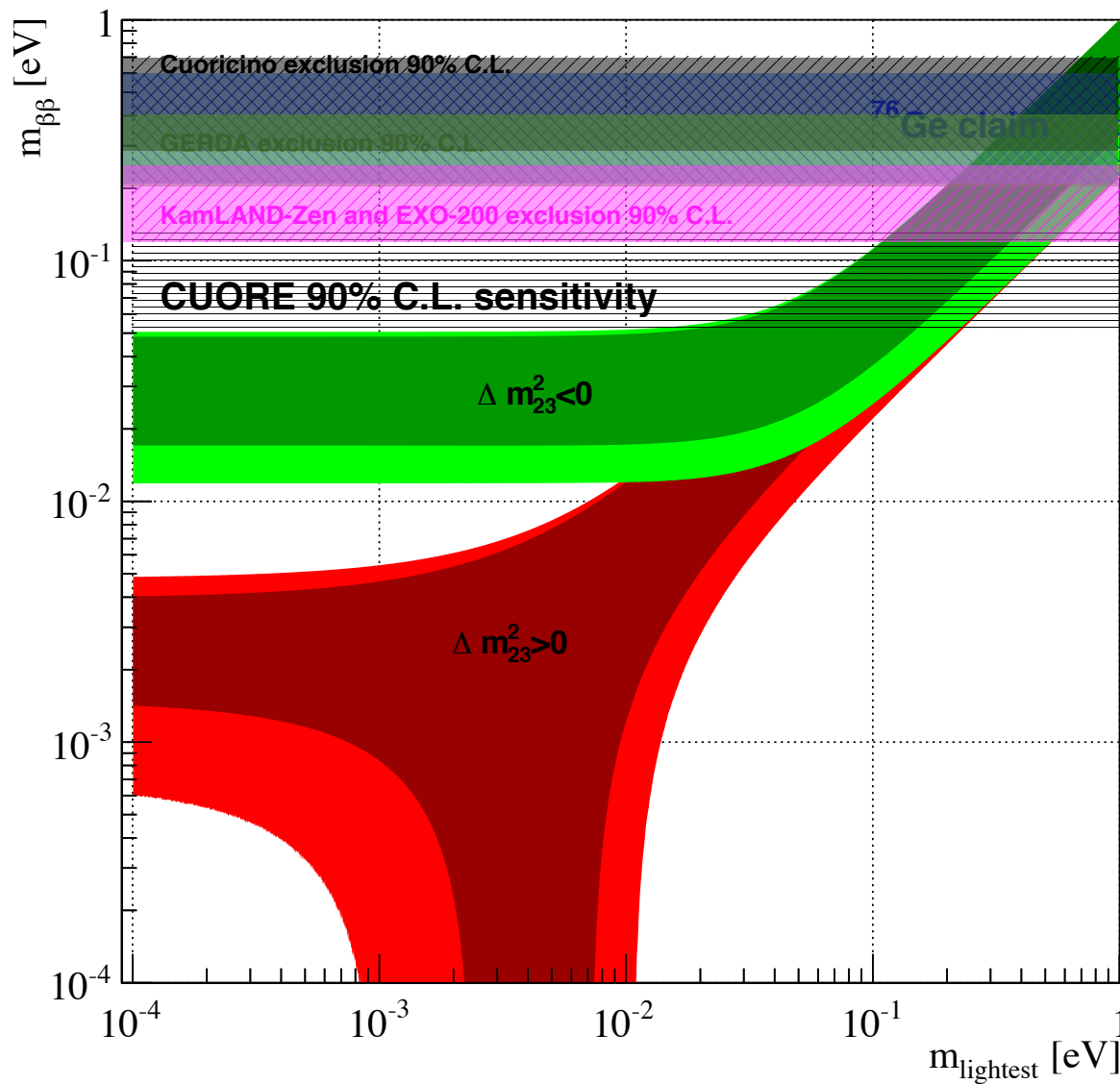


# Experimental reach

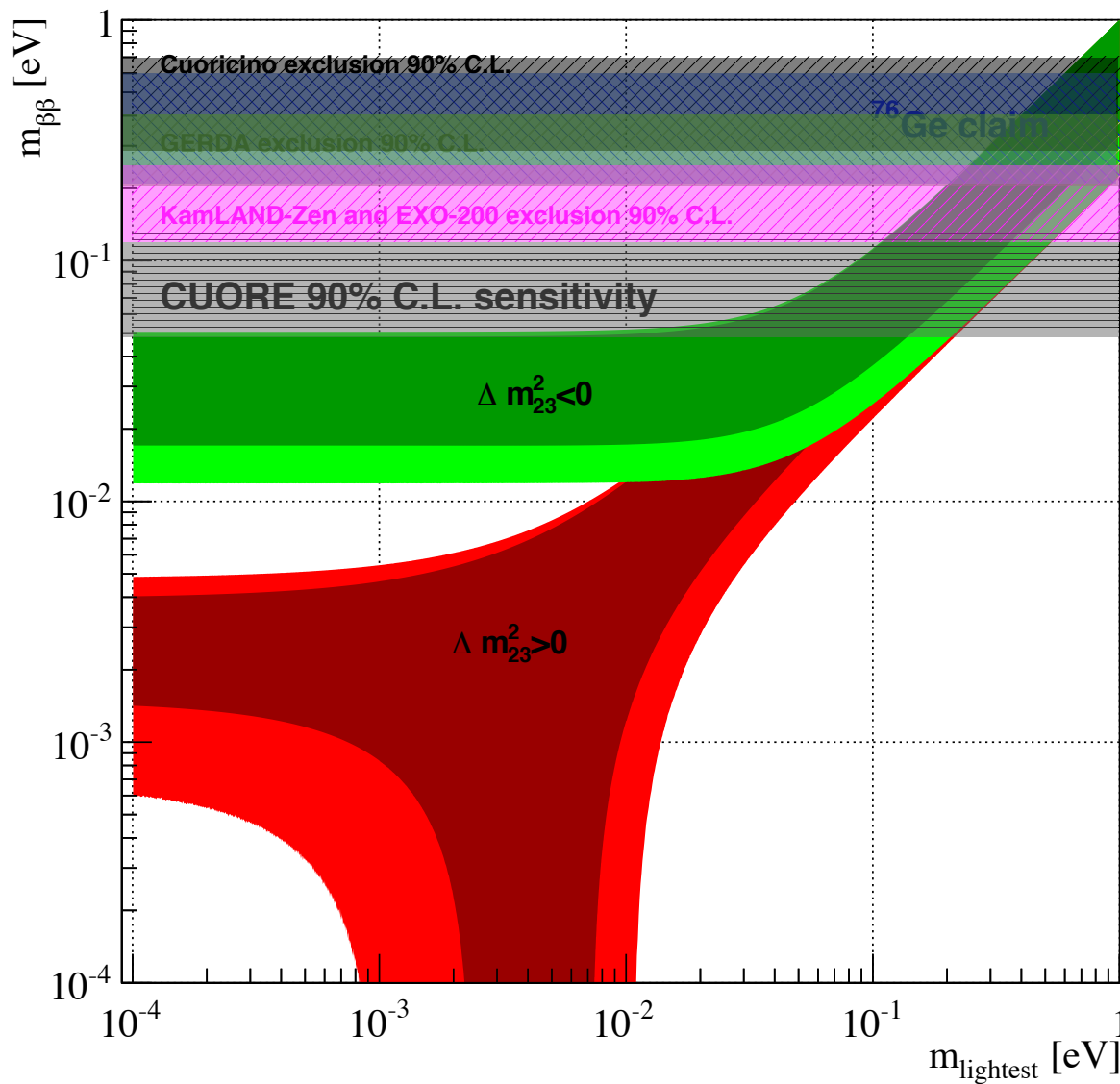




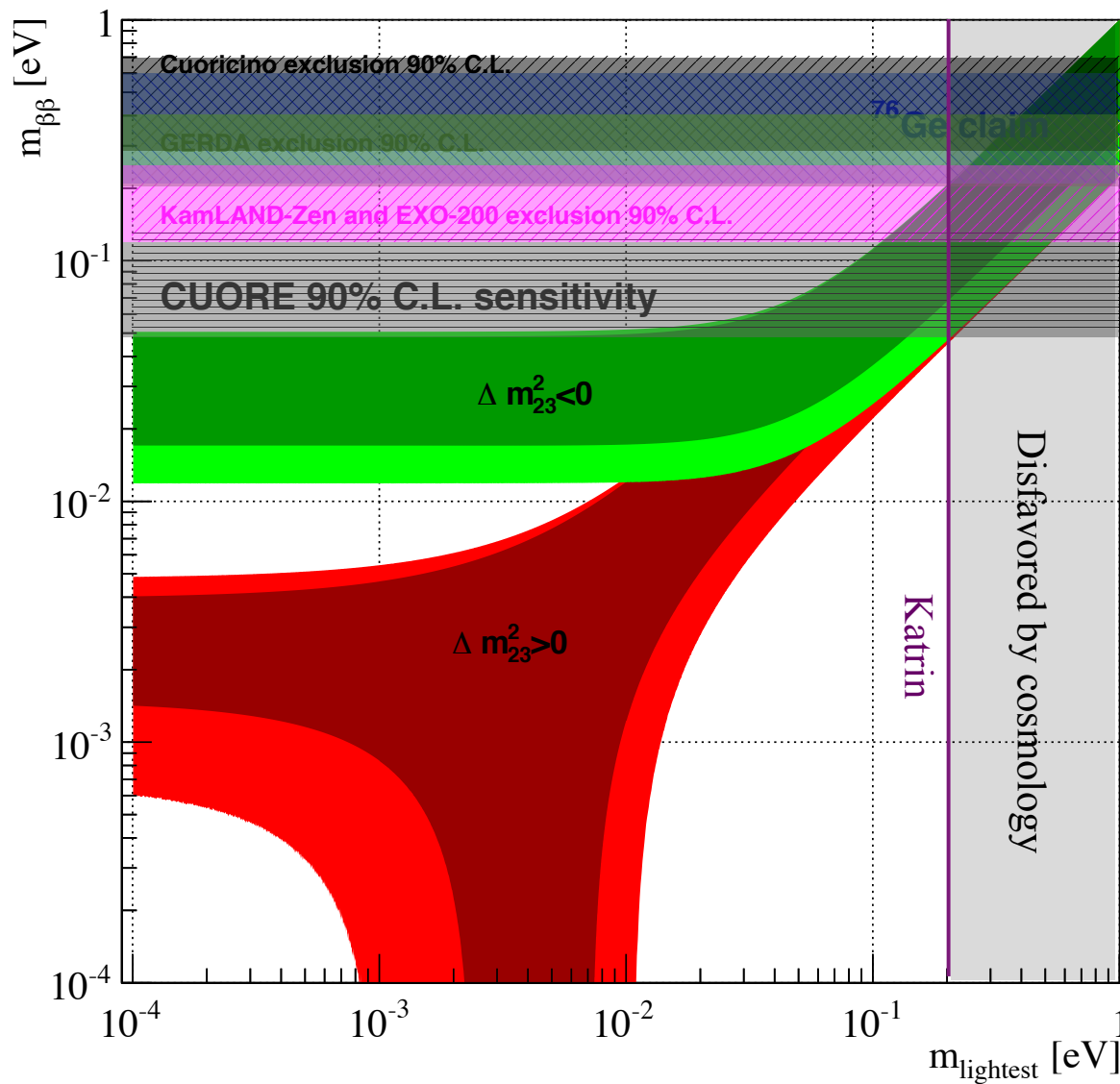
# Experimental reach



# Experimental reach



# Experimental reach



# Summary

- ▶ TeO<sub>2</sub> bolometers offer a well-established, competitive technique in the search for  $0\nu\beta\beta$  decay
- ▶ CUORE builds on the success of Cuoricino (2003–2008), which did not see evidence of  $0\nu\beta\beta$  decay in TeO<sub>2</sub>
- ▶ CUORE-0 has been taking data since Mar 2013, has already validated improvements for CUORE, & should surpass Cuoricino soon
- ▶ Assembly of the 19 CUORE towers is complete
- ▶ Commissioning of the CUORE cryogenic system and experimental infrastructure is progressing well
- ▶ Start of CUORE data taking is expected in 2015

*Fine*