Searching for neutrinoless double beta decay of ^{130}Te with CUORE

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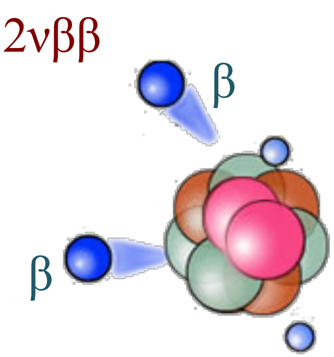
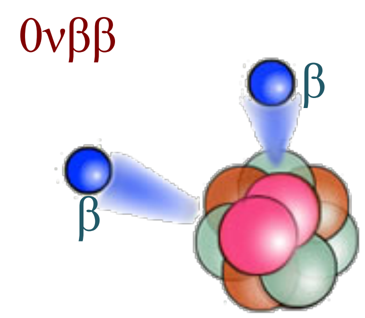
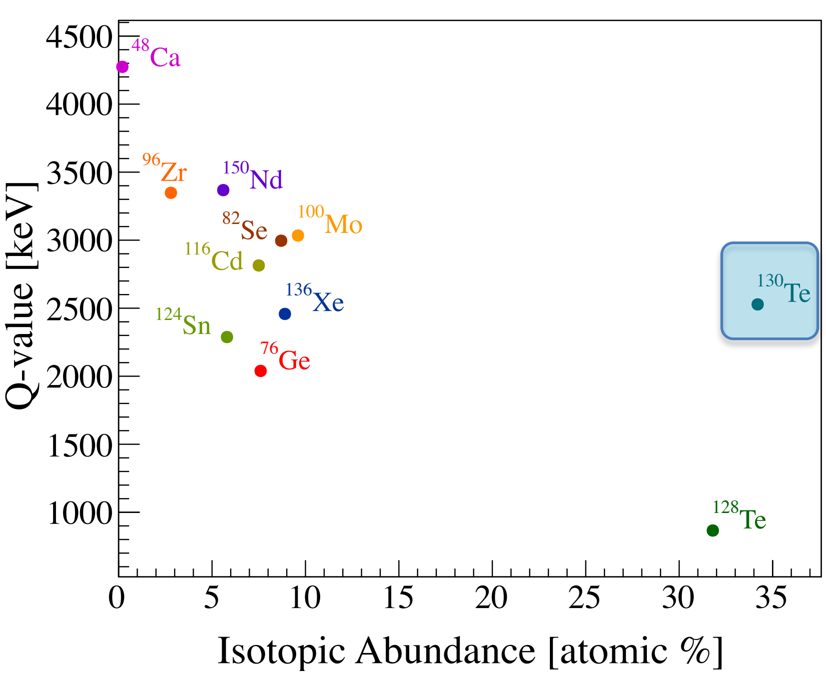
DNP 2015
Santa Fe, NM

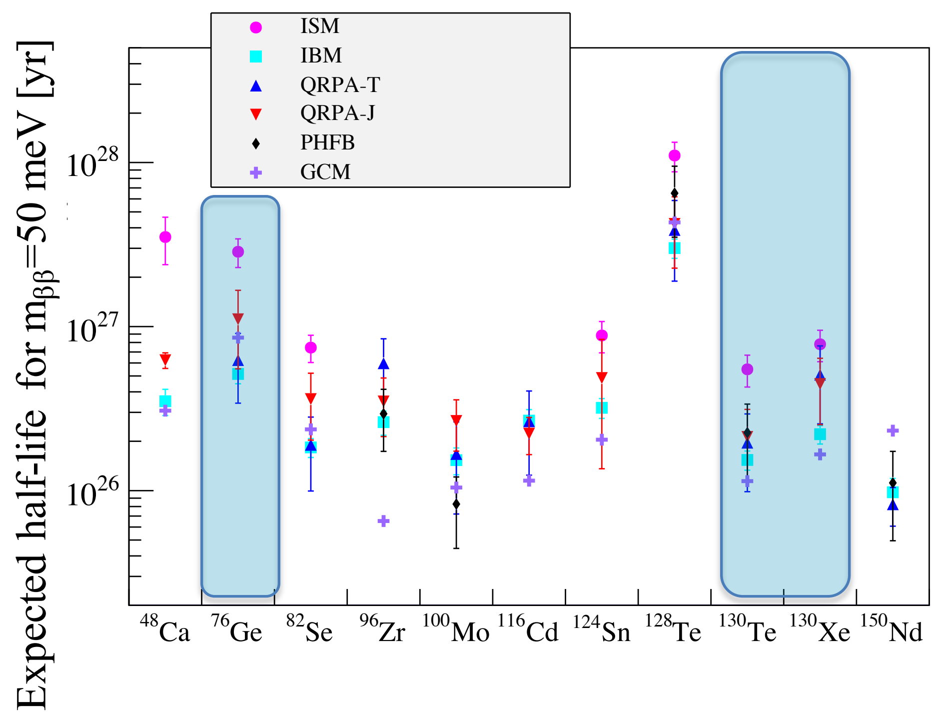
Double beta decay in experiments

- Extremely rare events $T_{1/2} > 10^{24}$ year.
- Experimentally try to search for a peak on the spectrum of total energy of electrons.
- ^{130}Te: isotopically abundant and favorable in terms of half-life requirement





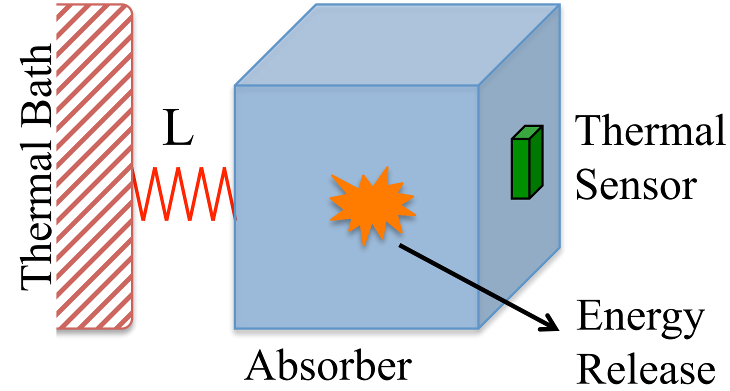




Large mass bolometer

Bolometer: measure the energy via temperature change

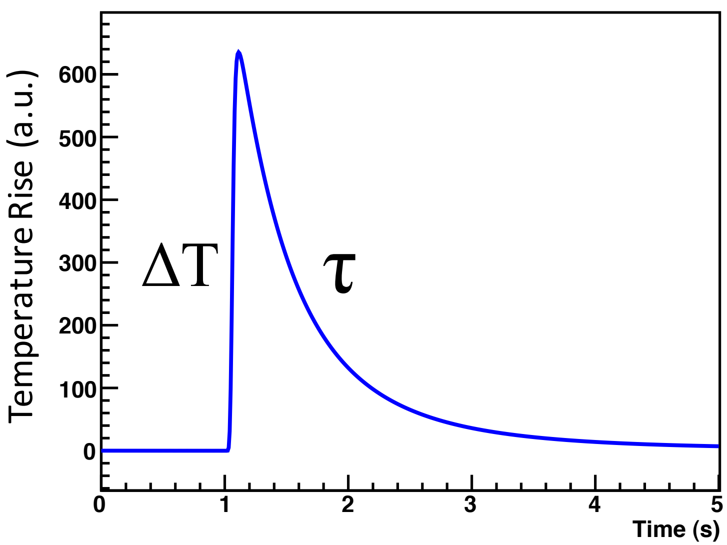
$$\Delta T = \frac{E}{C} \qquad \tau \sim \frac{C}{G}$$

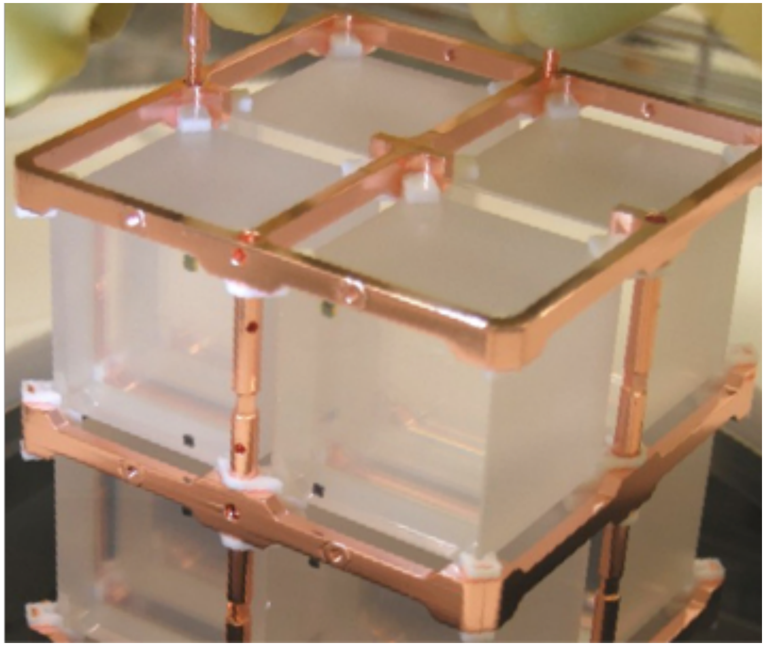


CUORE: TeO_2 crystal

$5 \times 5 \times 5$ cm^3, 750 g

ΔT = 0.1 mK/MeV at 10 mK base temperature





Arrays of TeO_2 bolometers

Cuoricino
(2003-2008)

Astropart. Phys. **34**, 822–831 (2011)

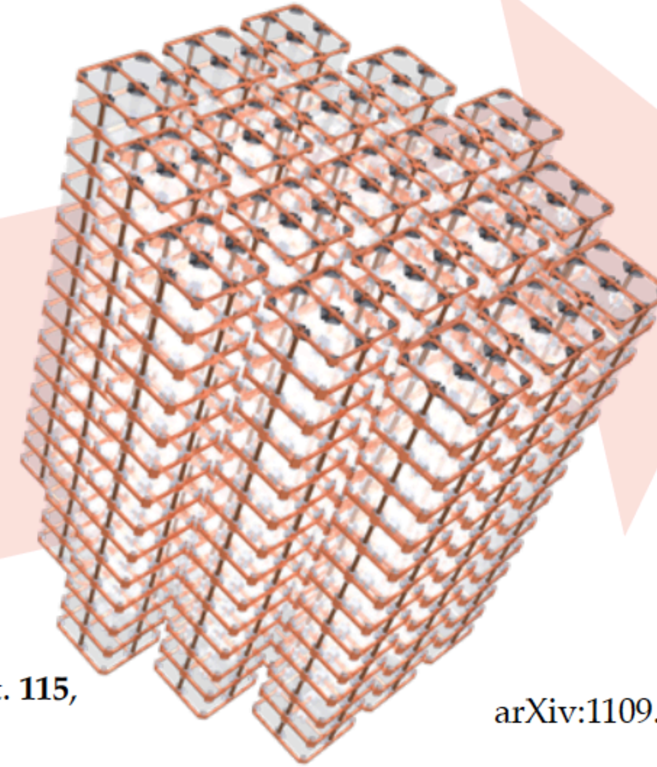
+

CUORE-0
(2013-2015)

Phys. Rev. Lett. **115**, 102502 (2015)

$T_{1/2}^{0\nu\beta\beta} > 4.0 \times 10^{24}$ y (90% C.L.)

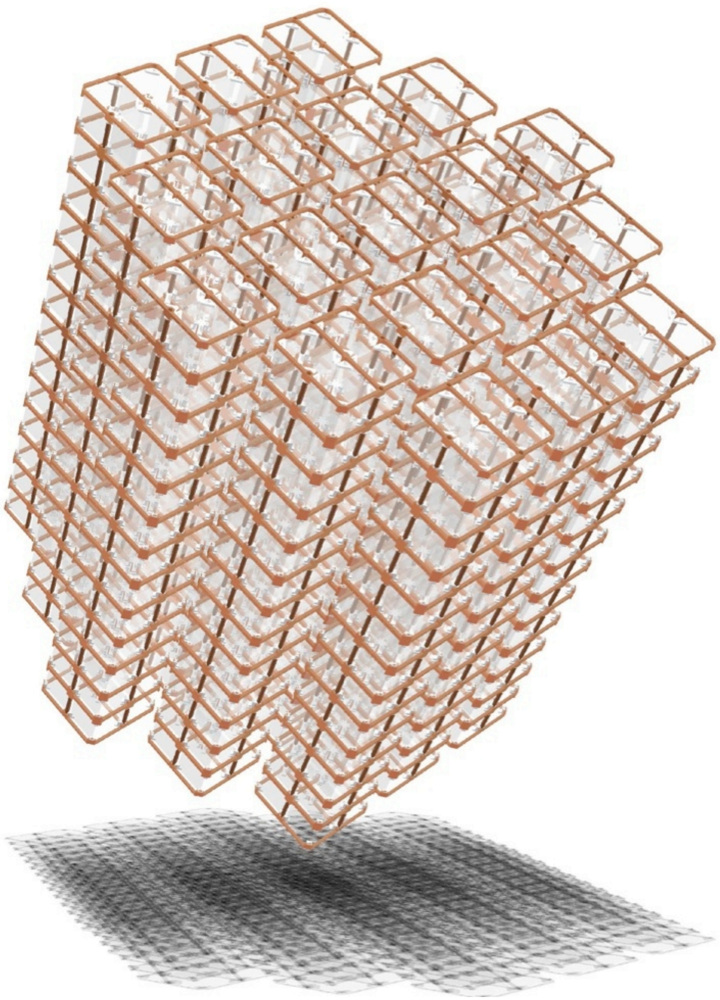
CUORE
(2016-2020)



arXiv:1109.0494

Projected:
$T_{1/2}^{0\nu\beta\beta} > 9.5 \times 10^{25}$ yr (90% C.L.)
$m_{\beta\beta} < 50 - 130$ meV

CUORE (Cryogenic Underground Observatory for Rare Events)



- Search for $0\nu\beta\beta$ of ^{130}Te and other rare events
- 988 TeO_2 crystals run as a bolometer array
  - 19 Towers
  - 13 floors
  - 4 modules per floor
  - 741 kg total; 206 kg ^{130}Te
  - 10^{27} ^{130}Te nuclei
- 10 mK base tempearture in a custom dilution refridgrator
- Gran Sasso underground lab (LNGS), Italy

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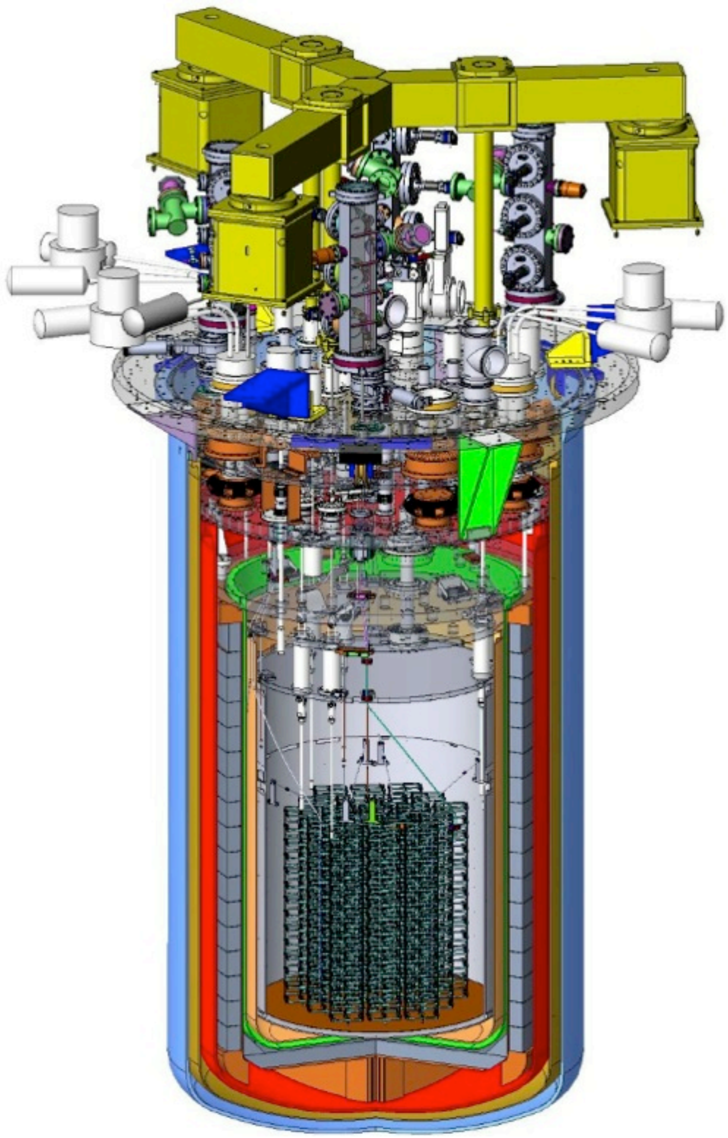

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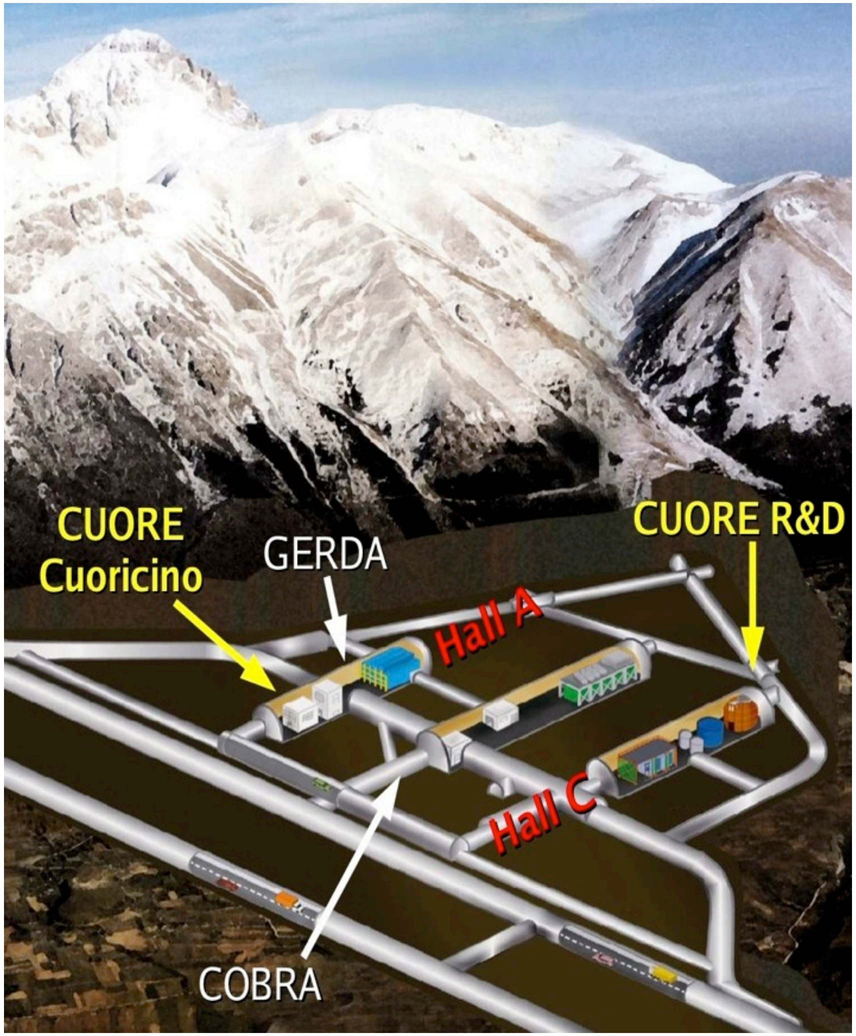

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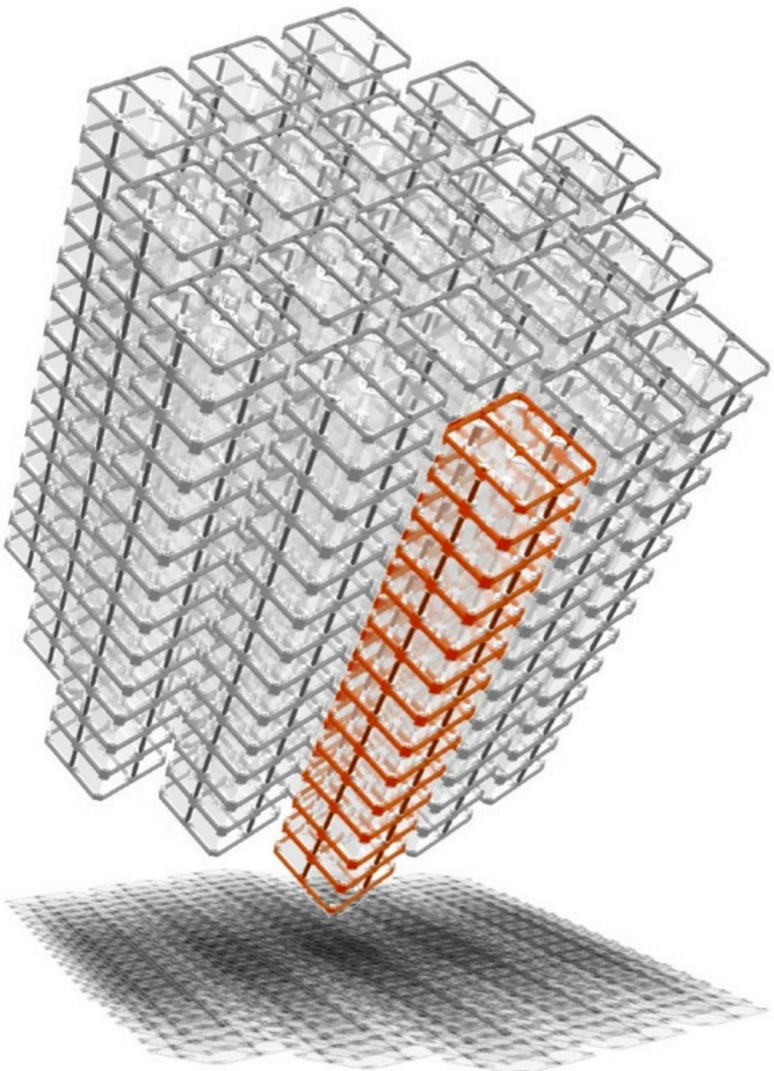
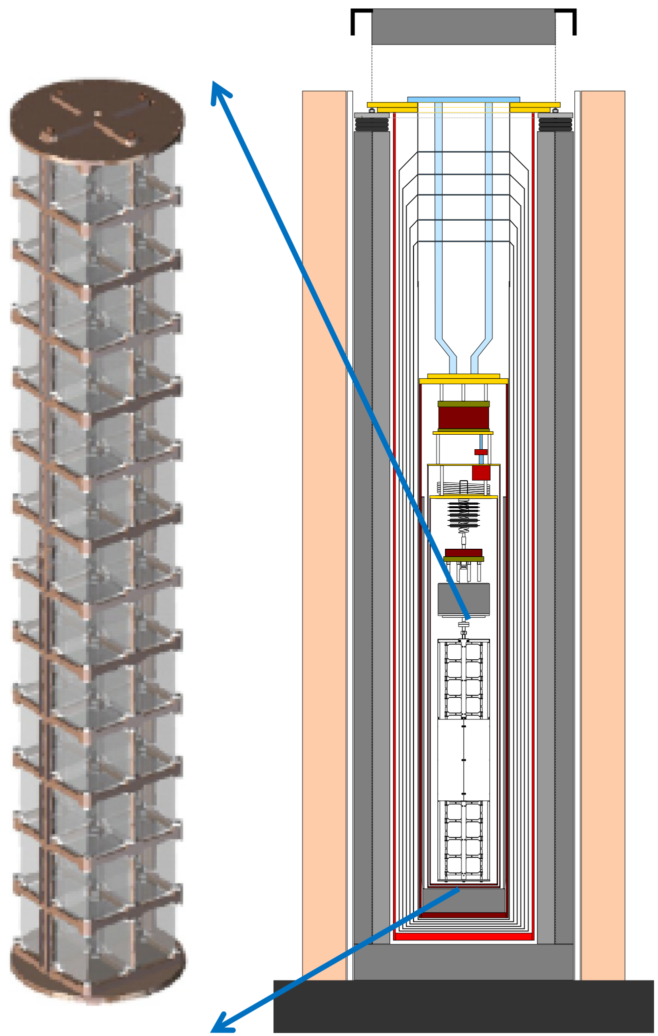
CUORE-0



- The first CUORE tower assembled with CUORE standards
  - Cleaning components
  - Assembly procedure
- Tower Properties
  - 52 crystals, total mass 39 kg
  - Total ^{130}Te mass 11 kg
- CUORE-0 tower was installed in the original Cuoricino cryostat.
- Data taking: March 2013 to Aug 2015.
- 9.8 kg · yr of ^{130}Te exposure
- Reached CUORE goal of 5 keV FWHM around Q-value

CUORE-0



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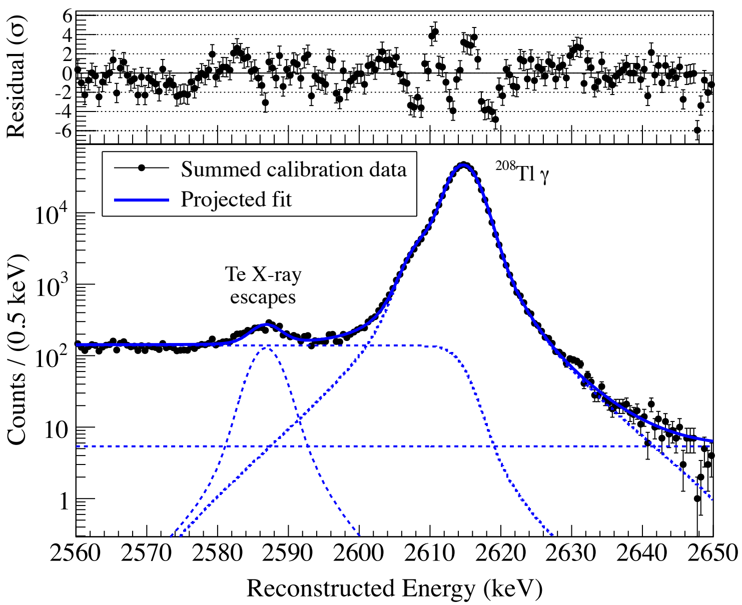
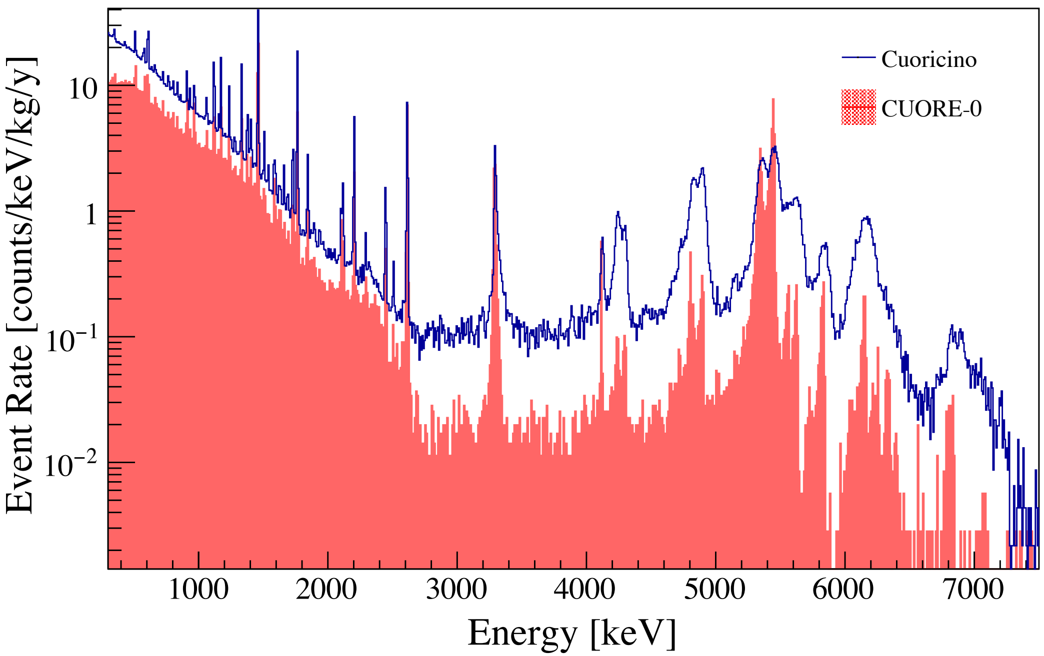
Detector performance: CUORE-0 vs. Cuoricino





keV	Average FWHM	RMS of FWHM
Cuoricino	5.8	2.1
CUORE-0	4.9	2.9

c/keV/kg/y	2.7-3.9 MeV	ROI
CUORE-0	0.016 ± 0.001	0.058 ± 0.004
Cuoricino	0.110 ± 0.001	0.169 ± 0.006

- Channel and dataset independent fit
- The 5 keV CUORE goal has been reached

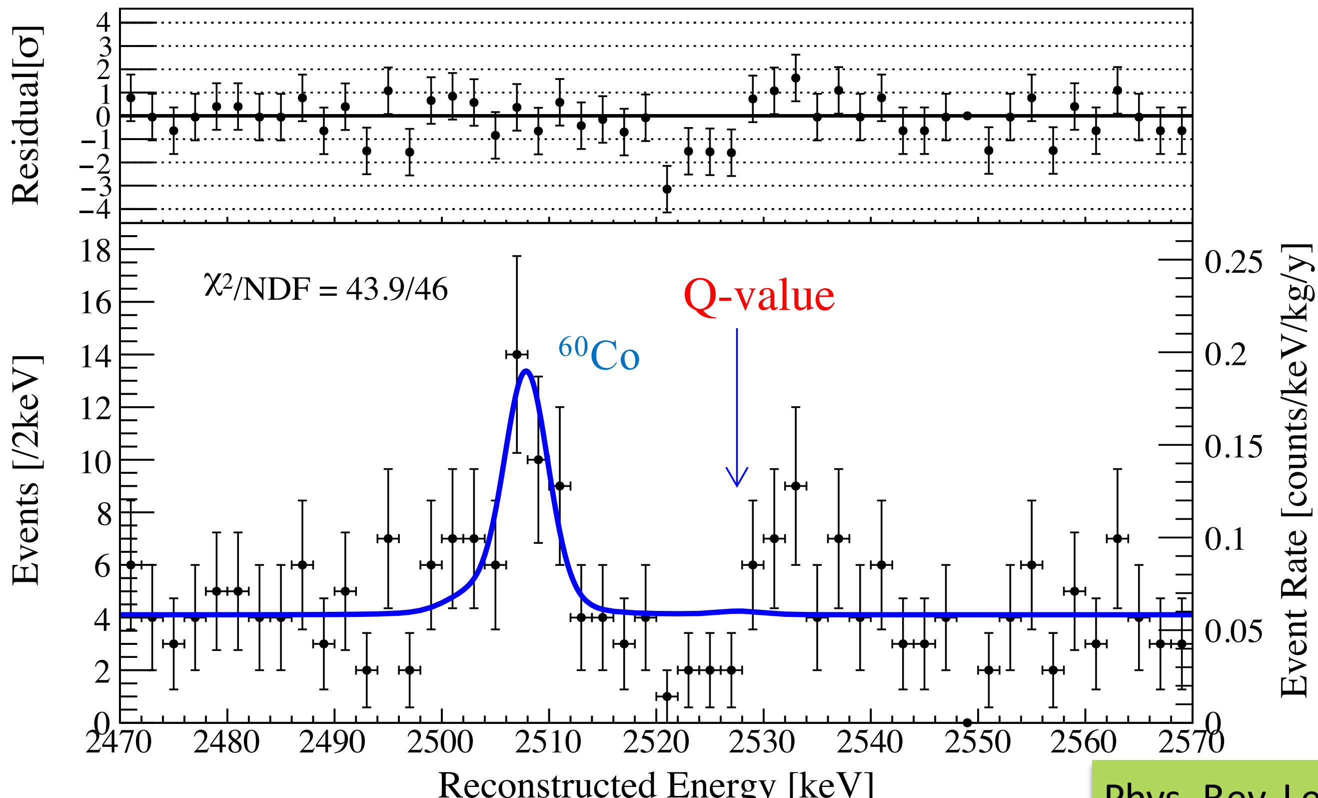
~ ×6 reduction in the alpha continuum region

CUORE-0 results

- We find no evidence for $0\nu\beta\beta$ decay of ^{130}Te: $T_{1/2} > 2.7 \times 10^{24}$ yr (90% C.L.)

Fitted background: 0.058 ± 0.004 (stat.) ± 0.002 (syst.) counts/keV/kg/yr

Best-fit decay rate: $\Gamma^{0\nu\beta\beta}(^{130}\mathrm{Te}) = 0.007 \pm 0.123\ (\mathrm{stat.}) \pm 0.012\ (\mathrm{syst.}) \times 10^{-24}\ \mathrm{yr}^{-1}$



Phys. Rev. Lett. 115, 102502

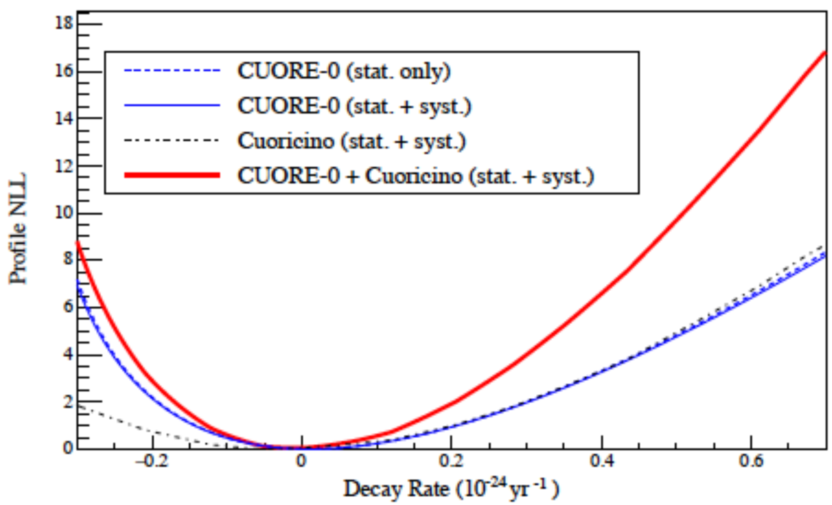
Combining CUORE-0 and Cuoricino

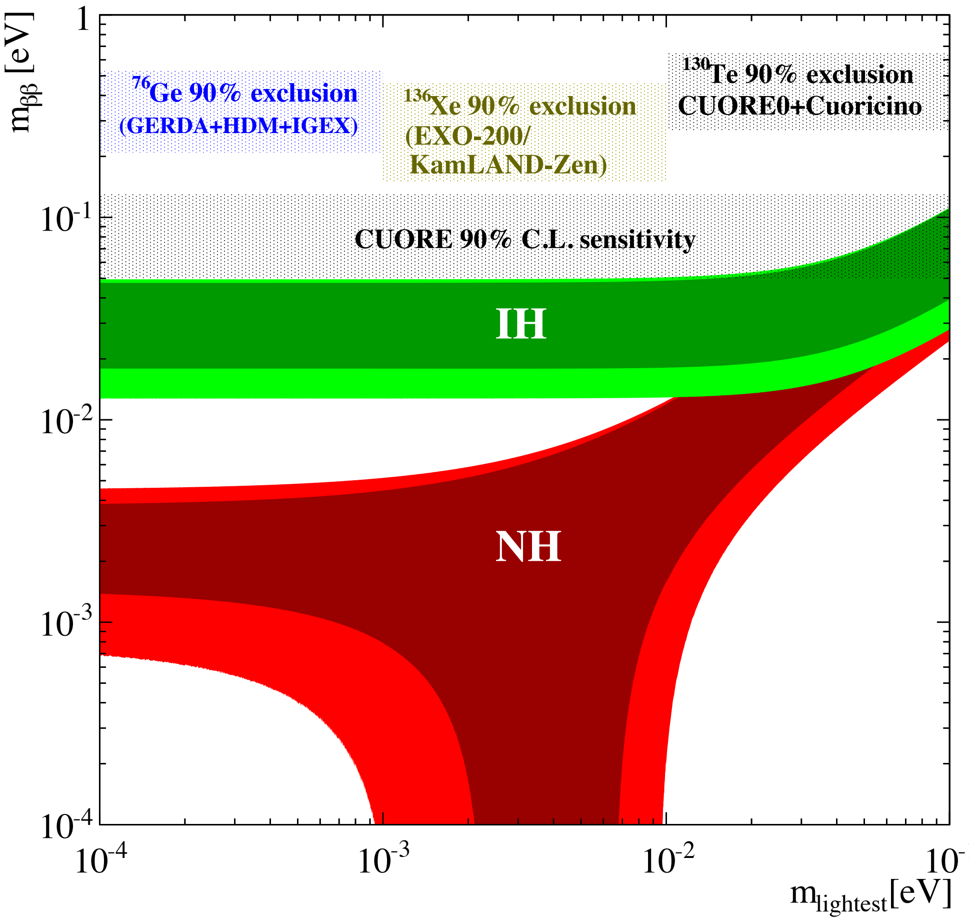
- Combination of the CUORE-0 result with the existing 19.75 kg · yr of ^{130}Te exposure from Cuoricino
- The combined half-life limit is

$T_{1/2} > 4.0 \times 10^{24}$ yr (90% CL)

Effective Majorana Mass

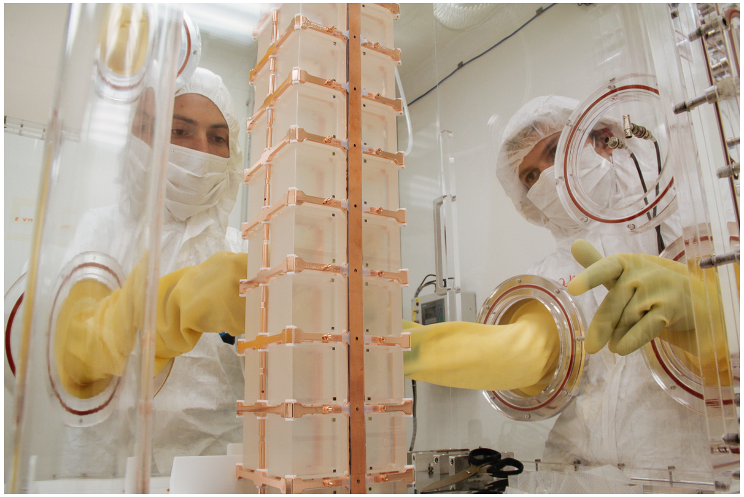
$m_{\beta\beta}$ <(270-650) meV



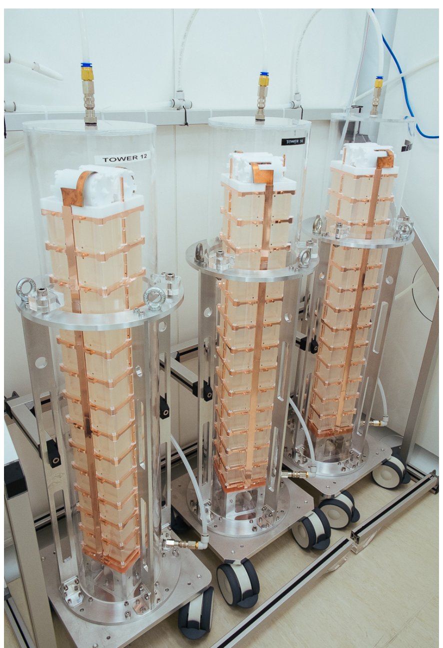


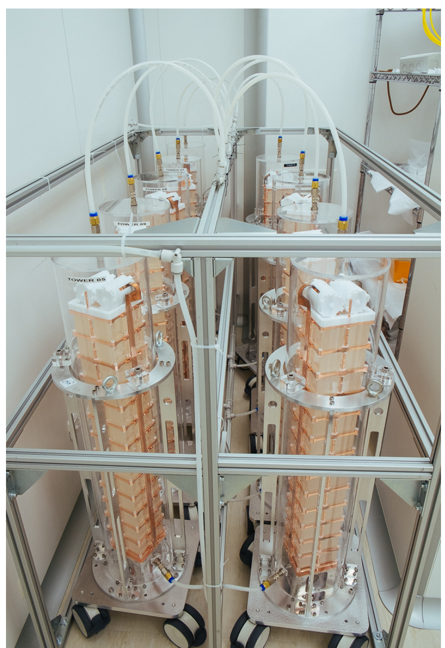
IBM-2 Phys. Rev. C 91, 034304 (2015)
QRPA-TU Phys. Rev. C 87, 045501 (2013)
pnQRPA Phys. Rev. C 91, 024613 (2015)
ISM Nucl. Phys. A 818, 139 (2009)
EDF Phys. Rev. Lett. 105, 252503 (2010)

Building CUORE: Detector array assembly



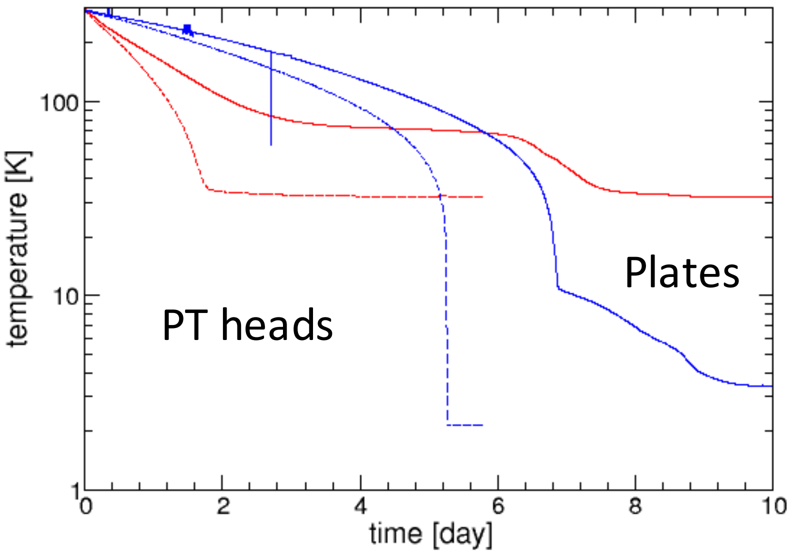
- All 19 ultraclean towers assembled by summer 2014.
- From ~10000 components
- Inside 5 glove boxes
- 988/988 thermistors
- 988/988 heaters

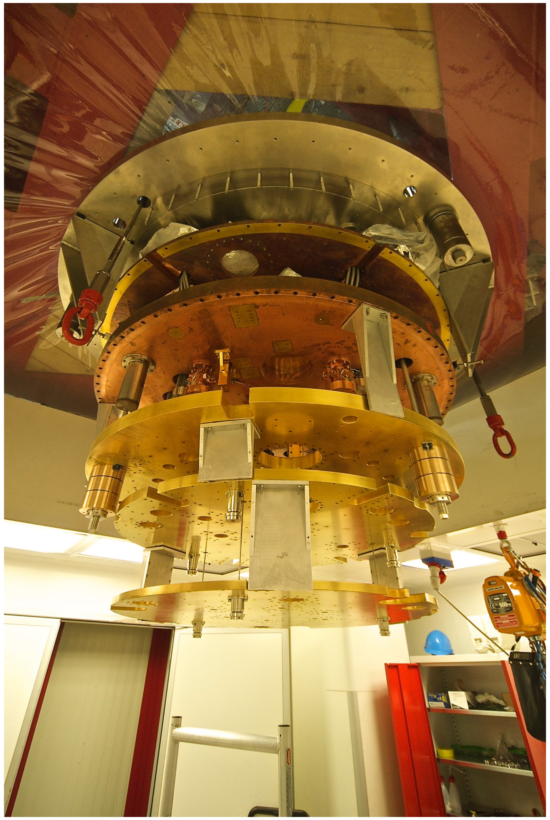




Cryogenic system commissioning phase 1: individual systems test

- Outer/Inner vacuum chamber
- Cryostat
  - 32 K at the 40K stage
  - 3.3 K at the 4K stage
- Dilution Unit
  - Lowest temperature: 4.95 mK

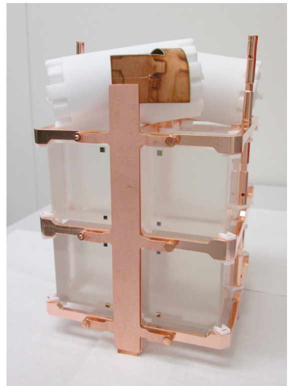


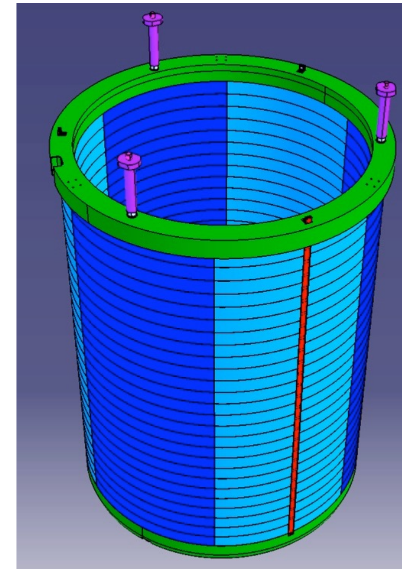


Flanges of CUORE cryostat

DU in a test cryostat

Cryogenic system commissioning phase 2: system integration

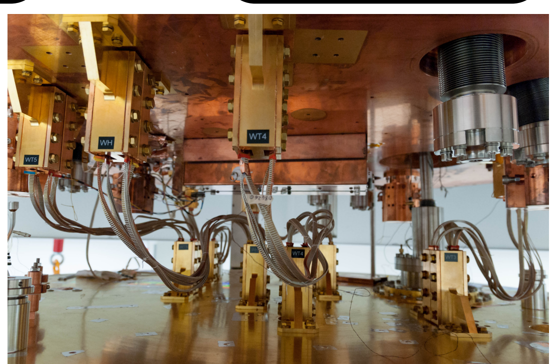


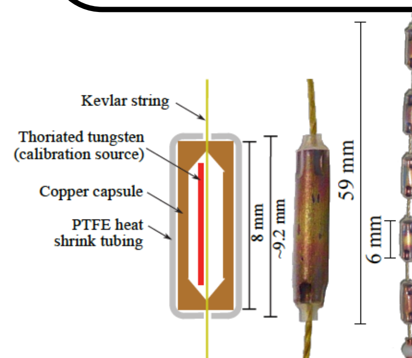


Attaching a mini-tower

↓

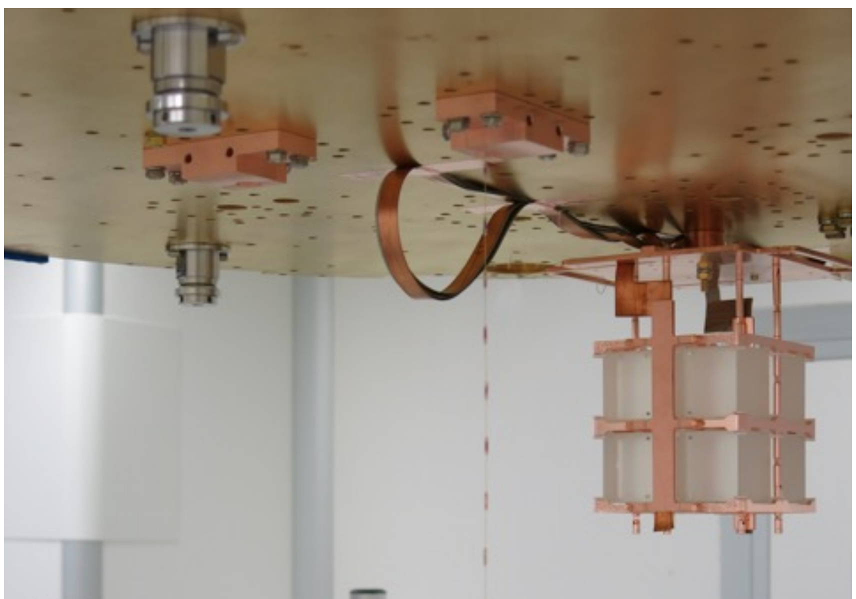
Cryostat + Dilution Unit → Wiring → Top Pb shield / Calibration System / Towers support plate / Fast Cooling System → Side roman Pb shield





More from Jeremy Cushman: FD.00006 : Calibration of CUORE-0 and CUORE

Cryogenics milestones

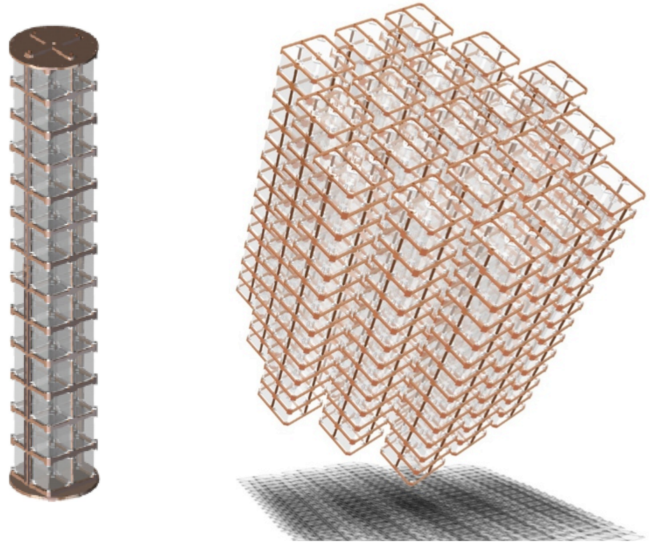


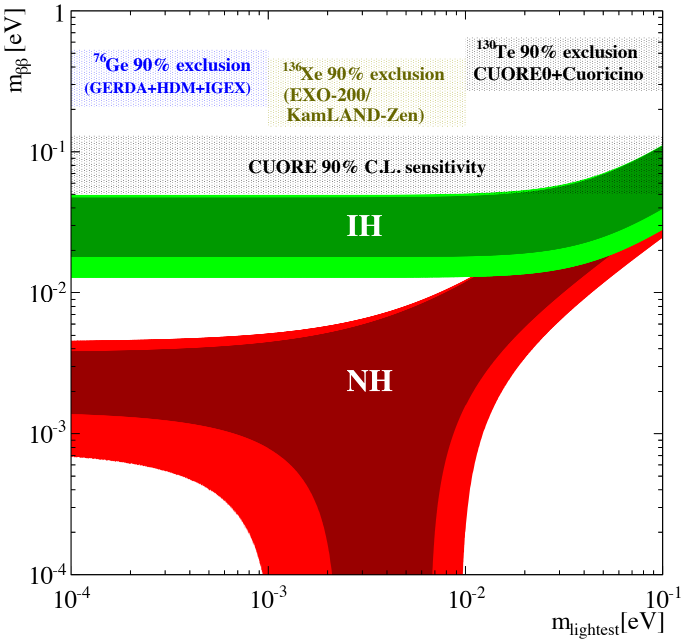
Summary and outlook

- CUORE-0 reached energy resolution and background rate requirement.
- Null $0\nu\beta\beta$ result published in PRL.
- $2\nu\beta\beta$ analysis, instrumentation, and dark matter search papers in the pipeline.

- CUORE, with 206 kg of ^{130}Te and 5 keV resolution, is able to reach 50-130 meV effective Majorana mass.
- All detectors were assembled successfully.
- CUORE cryostat reached base temperature of ~ 6 mK.
- CUORE operation expected in early 2016.

- CUPID, CUORE upgrade with particle ID will cover the inverted hiearchy band.





The CUORE Collaboration

CSNSM

Università degli Studi di Cassino e del Lazio Meridionale

Universitas Studii Paduani

Università degli Studi di Milano Bicocca

INFN Istituto Nazionale di Fisica Nucleare

Yale — Lux et Veritas

Alma Mater Studiorum Università di Bologna A.D. 1088

UCLA

SINAP

University of South Carolina

CUORE

The University of California 1868

Berkeley Lab

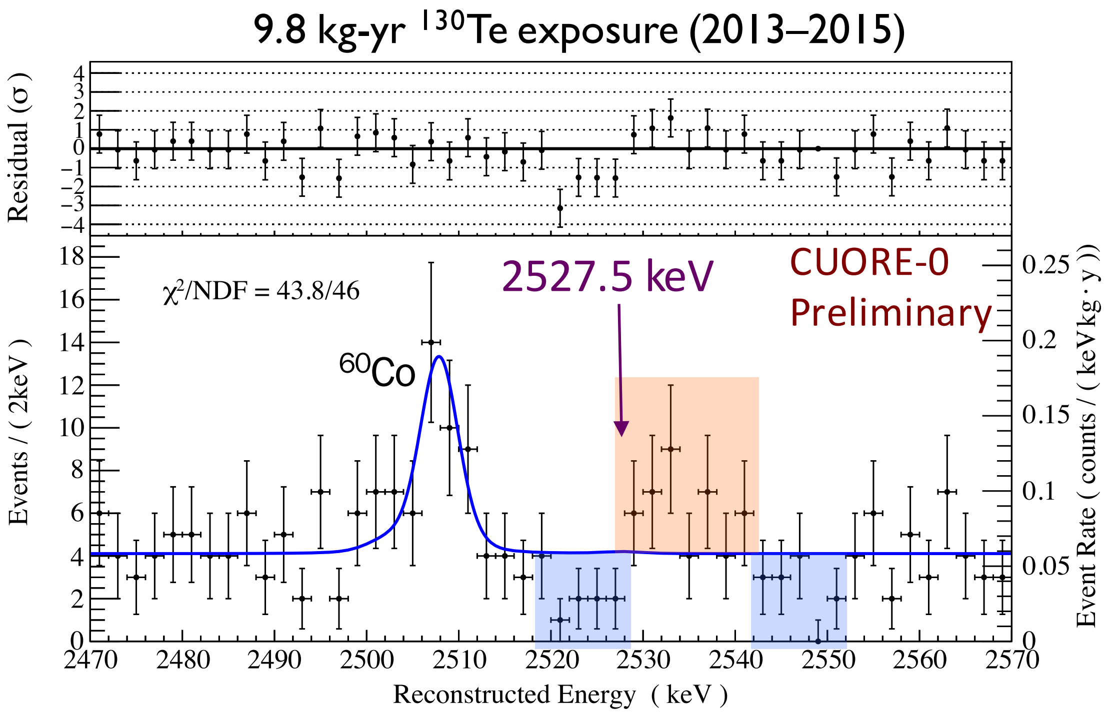
Massachusetts Institute of Technology

Lawrence Livermore National Laboratory

Sapienza Università di Roma

Cal Poly San Luis Obispo

Background fluctuations



- ▶ We evaluated the statistical likelihood of observed excess and deficits in data
- ▶ Kolmogorov-Smirnov test shows data are consistent with zero-rate hypothesis
- ▶ None of the positive or negative fluctuations have signal significance > 3σ
- ▶ Probability to observe a fluctuation anywhere in the ROI as big as largest is ~ 10% (i.e., accounting for trials factor)

Systematics

TABLE I. Systematic uncertainties on $\Gamma_{0\nu}$ in the limit of zero signal (Additive) and as a percentage of nonzero signal (Scaling).

	Additive (10^{-24} y^{-1})	Scaling (%)
Lineshape	0.007	1.3
Energy resolution	0.006	2.3
Fit bias	0.006	0.15
Energy scale	0.005	0.4
Bkg function	0.004	0.8
Signal normalization	0.7%	

- For each systematic, we run toy MC expts to evaluate bias on fitted $0\nu\beta\beta$ decay rate
- Bias is parameterized as p0 + p1×Γ, where p0="additive" and p1="scaling"
- Signal lineshape: Used variety of different lineshapes to model signal
- Energy resolution: Apply 1.05±0.05 correction to calibration-derived resolution
- Fit bias: Effect of using unbinned extended ML fit to extract values
- Energy scale: Assign 0.12 keV uncertainty derived from peak residuals in physics spectrum
- Bkg function: Treated choice of 0-, 1-, 2-order polynomial as discrete nuisance parameter

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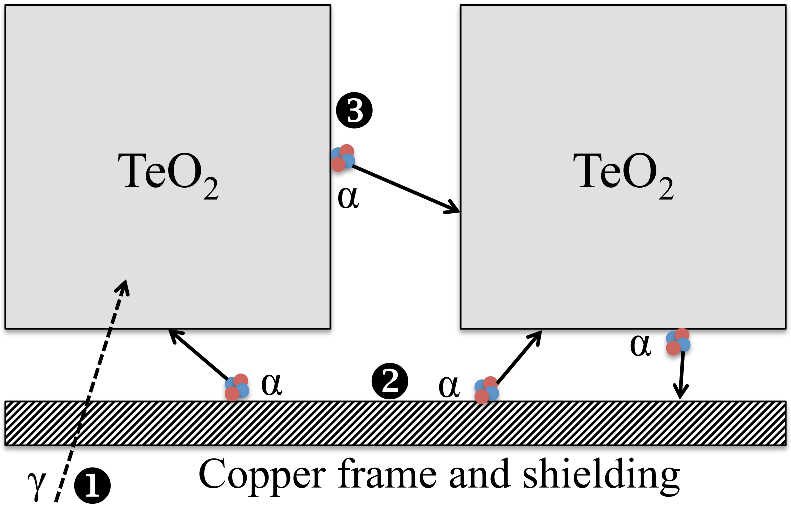
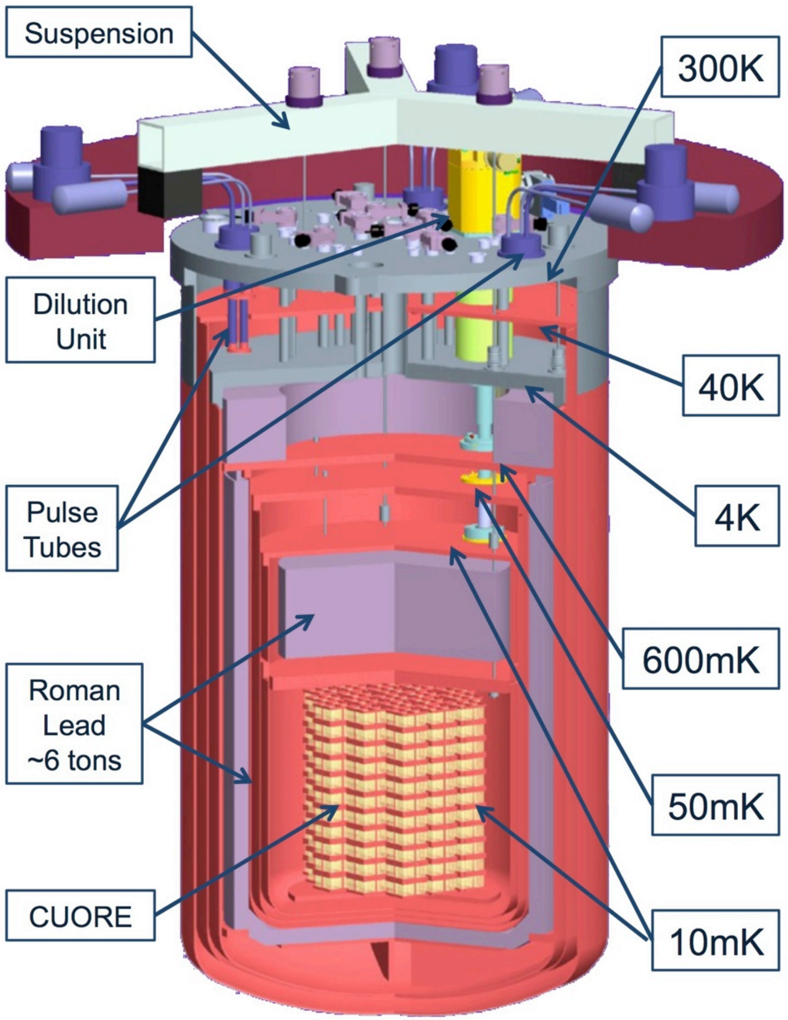
After accounting for systematic uncertainties we report the Bayesian limits:

$\Gamma^{0\nu\beta\beta}$ (^{130}Te) < 0.25 × 10^{-24} yr^{-1} (90% C.L., stat.+syst.)

$T_{1/2}^{0\nu\beta\beta}$(^{130}Te) > 2.7 × 10^{24} yr (90% C.L., stat. + syst.)

Background reduction: from CUORE-0 to CUORE





CUORE background in ROI

1. New cryostat with radio-pure materials
   → negligible gamma contributions
2. More effective self-shielding
   → Copper surface background can be reduced below background goal.
3. More effective anti-coincidence
   → negligible surface alpha from crystals.

Detection channels