LOW
RADIOACTIVITY
TECHNIQUES

CUORE

Latest results from CUORE

Searching for 0νββ with a tonne-scale bolometric array

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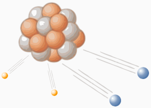
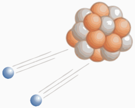
IX Workshop on Low Radioactivity Techniques

October 1 – 4, 2024 - Kraków, Poland



$$(A,Z) \to (A,Z+2) + 2e^- + 2\bar{\nu}_e \quad (2\nu\beta\beta)$$

$$(A,Z) \to (A,Z+2) + 2e^- \quad (0\nu\beta\beta)$$

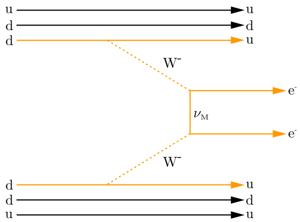


- *L*-violation: creation of a pair of electrons
  - discovery of 0νββ
    - ⇒ *L* is not a symmetry of the universe
    - ⇒ link to baryon asymmetry in Universe (?)
- assuming the ν mass mechanism

→ 0νββ key tool for studying neutrinos

  - Majorana or Dirac nature
  - mass scale and ordering

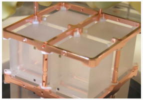
A possible diagram



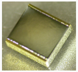
A powerful search aims to optimize **isotope + detector technique** combination

Thermal detectors

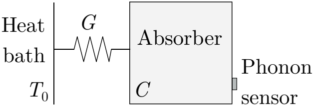
- bolometers detect the **phonon** contribution of the energy release
  - large fraction of the total energy
  - ionization/excitation $\rightarrow \cdots \rightarrow$ phonons
  - measured via **temperature variation**



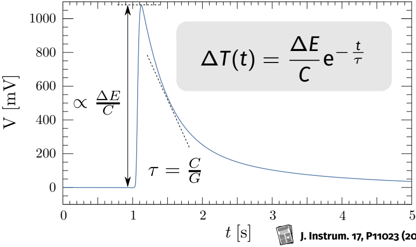
- $\Delta T = \Delta E / C$
  - **low *C***: $C \downarrow \;\; \Rightarrow \;\; \Delta T \uparrow$
  - **very low *T***
    - Debye law: $C \propto (T/\Theta_D)^3$
    - thermal fluctuations $\propto \sqrt{T^2\, C}$
- temporal evolution: $\tau = C/G$
- Neutron Transmutation Doped Ge thermistor
  - $R = R_* \; \exp\left(T_*/T\right)^{1/2}$



Simplified thermal model



- an absorber with heat capacity C
- (connected to) a heat bath @ constant T_0
- (through) a thermal conductance G

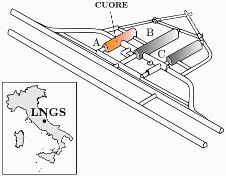


J. Instrum. 17, P11023 (2022)

CUORE: Cryogenic Underground Observatory for Rare Events

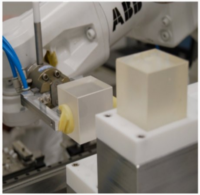
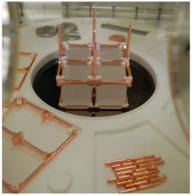
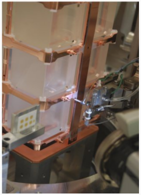
- search for $0\nu\beta\beta$ of ^{130}Te
- largest bolometric detector ever built
  - 19 towers $\times$ 13 floors $\times$ 4 crystals = 988 bolometers
  - 1 tonne detector mass: 327 kg Cu + 742 kg TeO_2

    $\rightarrow$ 206 kg of ^{130}Te
- at the Laboratori Nazionali del Gran Sasso
  - $\sim$ 3600 m w. e. (μ: $3 \cdot 10^{-8}$ cm^{-2} s^{-1})
  - 30-year-long history of measurements



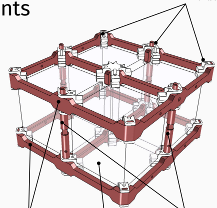
CUORE required a **dedicated protocol** for the detector construction
+ design of custom **cryogenic system** for its operation

Industrial-scale assembly of a rare-event detector

J. Instrum. 11, P07009 (2016)

- strict **material selection**
- high-standard **surface cleaning protocols** for detector components
  - crystal etching + lapping @ SICCAS (China)
  - magnetron plasma cleaning for Cu frames @ LNL of INFN
- semi-automatic system for sensor gluing
  - highly-reproducible
- contact-less approach in tower assembly & bonding
- **Rn exposure minimized** $\rightarrow$ avoid surface re-contamination
  - all operations performed in N_2 sealed glove boxes



A 10-mK infrastructure for large bolometric arrays

- the design of the CUORE cryostat had to satisfy very tight requirements
  - large **experimental volume** for detector + shielding of $\sim$ 1 m^3
  - **base temperature** for optimal operation of NTDs, i. e. down to about 10 mK
  - **low radioactive background** from the cryogenic apparatus,

    compatible with goal of 0.01 c keV^{-1} kg^{-1} yr^{-1} at $Q_{\beta\beta}$
  - **high system reliability** to guarantee long-term operation
  - **response to seismic events**

    (LNGS are located in a seismic sensitive area)

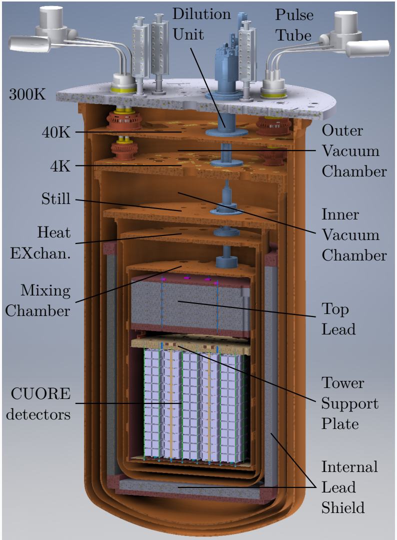
- custom cryogen-free cryostat
- only a few construction materials acceptable
  - use of Cu OFE/Cu NOSV for plates and vessels
  - more than 6.5 t of lead shielding integrated in the structure

CUORE cryostat

- 6+1 thermal stages
  - 300 K @ ambient temperature
  - 40 K @ PT first stage temperature
  - 4 K @ PT second stage temperature
  - Still @ 800 mK
  - HEX @ 50 mK
  - MC @ base $T < 10$ mK
  - TSP @ stabilized working T
- 2 vacuum chambers
- Fast Cooling System +

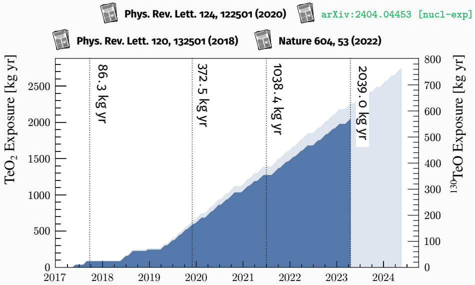
  5 Pulse Tubes + custom Dilution Unit
- 2 internal lead shields
  - use of ancient **Roman lead**
  - Spanish ingots from I century BCE
  - ^{210}Pb activity $<$ **715 uBq kg^{-1}**

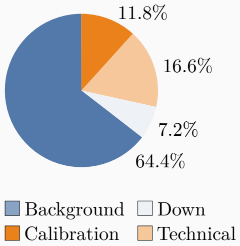
Cryogenics 102, 9 (2019)



CURE data-taking

- start of data-taking in April 2017
  - initial detector optimization
- *full-speed* data collection since 2019
  - exposure rate $\sim$ 50 kg yr per month
- accumulated **2.74 t yr** of TeO_2 to date
- goal is to reach 1 t yr of ^{130}Te
- beyond: upgrade cryogenic system





Operational performance

- operating $T = 11 - 15$ mK
  - year-long **cryogenic stability**
- uptime $>$**90%**
- 99.5% of channels active (984/988)
- resolution at $Q_{\beta\beta}$ of **7.3 keV** FWHM

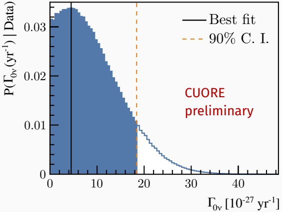
Results on the search for 0νββ

- **no peak** found at $Q_{\beta\beta}$ of ^{130}Te
  - 2039.0 kg yr of TeO_2 / 567.0 kg yr of ^{130}Te
- **bkg index** (BI) in line with expectations:

  $(1.42 \pm 0.02) \times 10^{-2}$ c keV^{-1} kg^{-1} yr^{-1}
- **limit** on decay half-life:

  $\Gamma_{0\nu}^{best} = 4.5^{+6.9}_{-4.5} \times 10^{-27}$ yr^{-1}

  $t_{1/2}^{0\nu} > 3.8 \times 10^{25}$ yr @ 90% C. I.

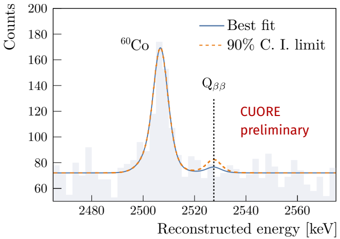


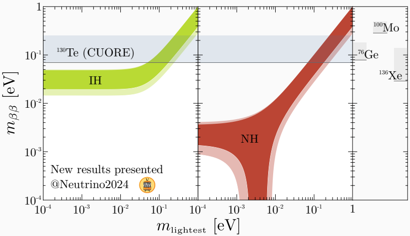
- bound on effective Majorana mass:

  $m_{\beta\beta} < (70 - 240)$ meV

arXiv:2404.04453 [nucl-exp]

ROI spectrum

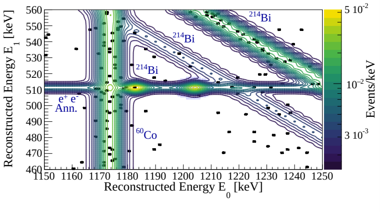




Investigations of Te isotopes

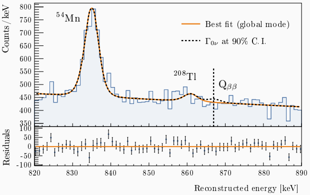
- $0\nu\beta^+EC$ of ^{120}Te $\quad (Q_{\beta\beta} = 1714.8$ keV)
  - $^{120}\text{Te} + e^-_b \rightarrow {}^{120}\text{Sn}^* + \beta^+$
    $\rightarrow {}^{120}\text{Sn} + X + \beta^+$
    $\rightarrow {}^{120}\text{Sn} + X + 2\,\gamma_{511}$
  - multiple signatures in M1, M2 and M3
  - limit: $t^{0\nu}_{1/2} > 2.9 \times 10^{22}$ yr @ 90% C. I.
    - 0.2405 kg yr of ^{120}Te $\quad (^{120}\text{Te}/^{\text{nat}}\text{Te} = 0.09\%)$

Phys. Rev. C 105, 065504 (2022)

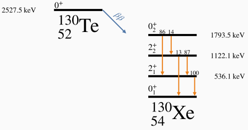


- $0\nu\beta\beta$ of ^{128}Te $\quad (Q_{\beta\beta} = 866.7$ keV)
  - limit: $t^{0\nu}_{1/2} > 3.6 \times 10^{24}$ yr @ 90% C. I.

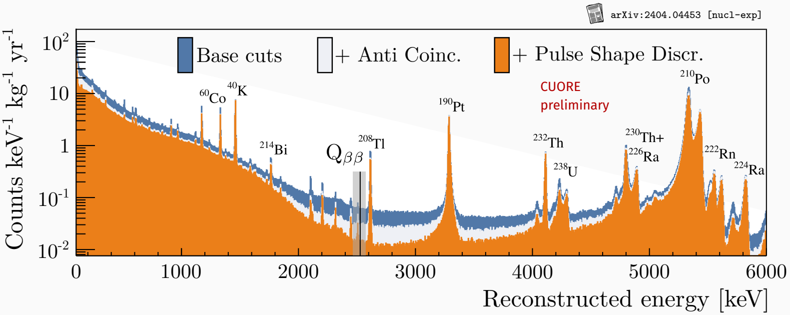
Phys. Rev. Lett. 129, 222501 (2022)



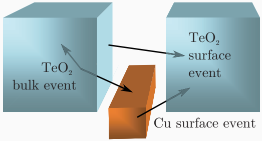
- $\beta\beta$ excited states of ^{130}Te to excited states of ^{130}Xe
  - search for de-excitation γ's
  - limits: $(t_{1/2})^{0\nu}_{0^+_2} > 5.9 \times 10^{24}$ yr @ 90% C. I.
  - $(t_{1/2})^{2\nu}_{0^+_2} > 1.3 \times 10^{24}$ yr @ 90% C. I.



Eur. Phys. J. C 81, 567 (2021)



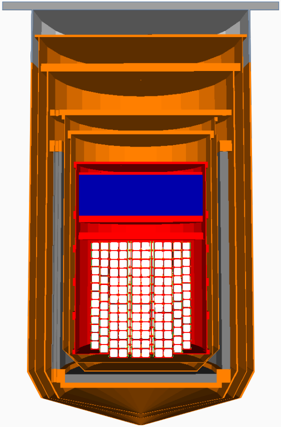
- different contributions in different regions of the energy spectrum
  - γ continuum + peaks up to 2.7 MeV
  - degraded α's in $(2.7 - 3.9)$ MeV
  - α region from 4 MeV
- construction of an extensive **background model**
  - large effort ongoing since predecessors of CUORE
  - ultimate validation by CUORE data



Modeling the background

- Geant4 simulation of contamination from different cryostat components
- background sources identified/ascribed to different locations in experimental setup
- **data-driven** Monte Carlo $\rightarrow$ inputs from
  - radio-assay measurements (HPGe, NAA, α spectroscopy)
  - modeling of CUORE-0 detector (single tower) **Eur. Phys. J. C 77, 13 (2017)**
  - CUORE data: α & γ peaks, time coincidences, event topologies
    - multiplicities ($\mathcal{M}$): exploit detector granularity

...

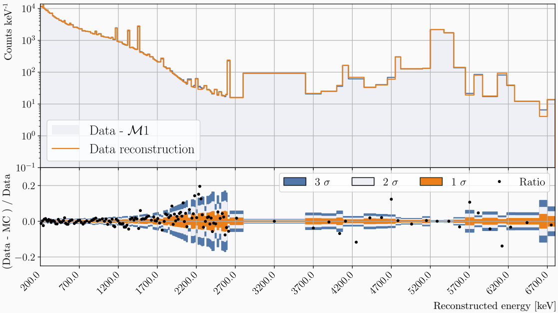


- raw Monte Carlo converted into CUORE-like data
  - include resolution, efficiencies, ...

Fit to CUORE data

- validation dataset: 1038.4 kg yr of TeO_2
- simultaneous **Bayesian fit** to $\mathcal{M}1$, $\mathcal{M}2$ energy spectra
  - $\sim$ **80 parameters** to describe contamination sources
    - bulk and surface (different depths)
  - Gaussian / expontial prior distributions from input values / limits
  - energy range from 200 keV to 6.8 MeV

See poster by S. Ghislandi



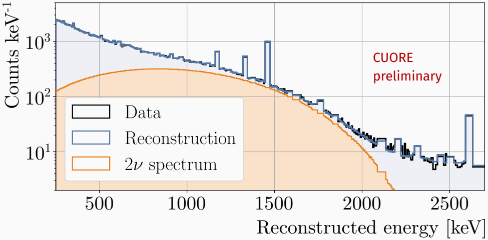
Sensitivity down to 10 nBq kg^{-1} and 0.1 nBq cm^{-2} for bulk and surface contamination level

Phys. Rev. D 110, 052003 (2024)

Results from the background model

Measurement of the ^{130}Te 2νββ decay

work in preparation

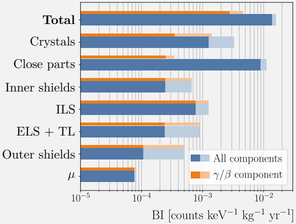


- 2νββ component isolated from total spectrum
- most precise measurement to date
  - $t^{2\nu}_{1/2} = 9.323\,^{+0.052}_{-0.037}\,\text{(stat.)} \times 10^{20}$ yr (systematics ∼ 1% under finalization)
- test of different nuclear models

See talk by P. Loaiza

Source decomposition

Phys. Rev. D 110, 052003 (2024)



- reconstruction of BI
- benchmark for CUORE
- projections for CUPID
  - CUORE Upgrade with Particle IDentification
  - next-gen. 0νββ experiment

Next challenges

- continue data collection for 0νββ search
- extend field of investigations
  - DM, axions, other rare decays
- lower the E threshold
  - noise investigation & mitigation Eur. Phys. J. C 84, 243 (2024)
  - spcific channel+run selection
  - dedicated analysis

See talk by A. Ressa

CUORE run-II

- new pulse tubes & thermalizations
  - lower vibrational noise
- benchmark improvements + extend sensitivity to low-E studies
- ...preparation in view of CUPID

Summary & Outlook

- CUORE represents a milestone for bolometric experiments searching for rare events
- CUORE has been collecting data since 2017
  - the current limit on the $0\nu\beta\beta$ of ^{130}Te is: $t^{0\nu}_{1/2} > 3.8 \times 10^{25}$ yr @ 90% C. I.
  - the goal is to collect 1 t yr of ^{130}Te
- a complete description of the CUORE background has been constructed and validated
- multiple analyses are ongoing $\rightarrow$ a large effort is devoted to lowering the *E* threshold

Looking ahead...

- CUORE run-II will extend the sensitivity thanks to an improved cryogenic system
- CUORE is paving the way to the next-generation $0\nu\beta\beta$ bolometric experiment
  - CUPID = CUORE Upgrade with Particle IDentification

Thank you!

CUORE Collaboration – LNGS (Italy), May 2024

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CUORE bulk contamination (I) [Phys. Rev. D 110, 052003 (2024)]

Volume	Contaminant	Prior [Bq kg^{-1}]		Mode/Limit [Bq kg^{-1}]	Systematic
Crystals					
	^{130}Te $2\nu\beta\beta$			$(3.03 \pm 0.01) \times 10^{-5}$	$^{+0.11}_{-0.17}$
	^{232}Th	$< 1.2 \times 10^{-7}$	CUORE-0	$(2.75 \pm 0.05) \times 10^{-7}$	$^{+0.85}_{-1.47}$
	^{228}Ra $\rightarrow$ ^{208}Pb	$< 7.5 \times 10^{-8}$	CUORE-0	$(1.19 \pm 0.04) \times 10^{-7}$	$^{+0.2}_{-1.16}$
	^{238}U $\rightarrow$ ^{230}Th	$< 3.6 \times 10^{-8}$	CUORE-0	$< 6.36 \times 10^{-10}$	
	^{230}Th	$(2.8 \pm 0.3) \times 10^{-7}$	CUORE-0	$(3.85 \pm 0.06) \times 10^{-7}$	$^{+0.26}_{-1.3}$
	^{226}Ra $\rightarrow$ ^{210}Pb	$< 2.2 \times 10^{-8}$	CUORE-0	$< 4.63 \times 10^{-10}$	
	^{210}Pb	$(1.37 \pm 0.83) \times 10^{-6}$	CUORE-0	$(1.55 \pm 0.02) \times 10^{-6}$	$^{+0.44}_{-1.48}$
	^{235}U $\rightarrow$ ^{231}Pa			$< 2.92 \times 10^{-11}$	
	^{231}Pa $\rightarrow$ ^{207}Pb			$< 9.06 \times 10^{-10}$	
	^{190}Pt	$(1.95 \pm 0.05) \times 10^{-6}$	CUORE-0	$(1.93 \pm 0.01) \times 10^{-6}$	$^{+0.29}_{-0.3}$
	^{147}Sm			$(1.09 \pm 0.12) \times 10^{-8}$	$^{+0.67}_{-0.58}$
	^{125}Sb			$(2.93 \pm 0.11) \times 10^{-6}$	$^{+2.42}_{-1.44}$
	^{110m}Ag			$(9.06 \pm 2.44) \times 10^{-8}$	$^{+62.58}_{-2.45}$
	^{108m}Ag			$(6.02 \pm 1.08) \times 10^{-8}$	$^{+2.61}_{-2.66}$
	^{60}Co	$(3.0 \pm 1.4) \times 10^{-7}$	CUORE-0	$(1.86 \pm 1.22) \times 10^{-8}$	$+4.21$
	^{40}K (no Tower 12)	$< 8.2 \times 10^{-6}$	CUORE-0	$(4.30 \pm 0.12) \times 10^{-6}$	$^{+2.62}_{-1.11}$
	^{40}K (Tower 12)			$(2.45 \pm 0.68) \times 10^{-5}$	$^{+1.49}_{-0.63}$
Close parts					
	^{232}Th	$< 2.1 \times 10^{-6}$	CUORE-0	$< 3.88 \times 10^{-7}$	
	^{238}U	$< 2.2 \times 10^{-5}$	CUORE-0	$< 4.73 \times 10^{-7}$	
	^{235}U			$< 2.17 \times 10^{-8}$	
	^{137}Cs	$< 2.2 \times 10^{-5}$	HPGe	$(1.25 \pm 0.24) \times 10^{-6}$	-0.71
	^{60}Co	$< 2.5 \times 10^{-5}$	HPGe	$(2.04 \pm 0.03) \times 10^{-5}$	$^{+0.32}_{-0.39}$
	^{54}Mn	$< 3.1 \times 10^{-5}$	HPGe	$(2.29 \pm 0.33) \times 10^{-6}$	$^{+2.63}_{-1.93}$
	^{40}K			$(4.42 \pm 0.06) \times 10^{-4}$	-1.06

CUORE bulk contamination (II) [Phys. Rev. D 110, 052003 (2024)]

Volume	Contaminant	Prior [Bq kg^{-1}]		Mode/Limit [Bq kg^{-1}]	Systematic
Inner shields					
	^{232}Th	$< 6.4 \times 10^{-5}$	HPGe	$(4.10 \pm 0.39) \times 10^{-5}$	$^{+1.92}_{-2.54}$
	^{238}U	$< 5.4 \times 10^{-5}$	HPGe	$(7.71 \pm 5.03) \times 10^{-6}$	$+16.51$
	^{137}Cs			$< 1.92 \times 10^{-6}$	
	^{60}Co	$< 2.4 \times 10^{-5}$	HPGe	$(1.46 \pm 0.19) \times 10^{-5}$	$^{+4.89}_{-1.44}$
	^{54}Mn			$< 3.71 \times 10^{-6}$	
	^{40}K	$< 6.7 \times 10^{-4}$	HPGe	$< 3.48 \times 10^{-5}$	
Outer shields					
	^{232}Th			$< 2.45 \times 10^{-5}$	
	^{238}U			$< 4.02 \times 10^{-5}$	
	^{137}Cs			$< 7.33 \times 10^{-4}$	
	^{60}Co			$(1.45 \pm 0.04) \times 10^{-3}$	$^{+0.29}_{-0.87}$
	^{54}Mn			$< 2.14 \times 10^{-4}$	
	^{40}K			$< 8.61 \times 10^{-4}$	
ILS					
	^{232}Th	$(3.9 \pm 2.2) \times 10^{-5}$	CUORE-0	$(1.70 \pm 0.22) \times 10^{-5}$	$^{+0.62}_{-0.8}$
	^{238}U	$(2.7 \pm 1.0) \times 10^{-5}$	CUORE-0	$< 1.61 \times 10^{-6}$	< 11.44
	^{108m}Ag			$(7.99 \pm 0.78) \times 10^{-6}$	$^{+2.62}_{-3.72}$
	^{40}K			$< 3.87 \times 10^{-5}$	< 18.58
TL					
	^{232}Th			$(3.06 \pm 1.47) \times 10^{-4}$	$^{+22.95}_{-2.74}$
	^{238}U	$< 1.1 \times 10^{-3}$	HPGe	$(3.45 \pm 0.36) \times 10^{-3}$	-3.44
	^{210}Bi $\rightarrow$ ^{206}Pb			$(1.61 \pm 0.02) \times 10^{+2}$	$^{+0.51}_{-0.41}$
	^{40}K	$< 7.6 \times 10^{-3}$	HPGe	$(3.74 \pm 2.64) \times 10^{-3}$	$^{+7.49}_{-3.01}$
ELS					
	^{210}Bi			$(3.31 \pm 0.14) \times 10^{+2}$	$^{+1.35}_{-1.86}$
	^{207}Bi			$(2.29 \pm 0.20) \times 10^{-3}$	$^{+1.21}_{-1.47}$

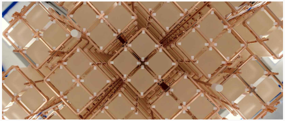
Volume	Contaminant	Depth [μm]	Mode/Limit [Bq cm^{-2}]	Systematic
Crystals				
	^{210}Pb	0.001	$(7.32 \pm 0.02) \times 10^{-8}$	$^{+4.98}_{-3.23}$
	^{232}Th	0.01	$(3.10 \pm 0.14) \times 10^{-10}$	$^{+0.2}_{-2.98}$
	^{228}Ra $\rightarrow$ ^{208}Pb	0.01	$(1.10 \pm 0.03) \times 10^{-9}$	$^{+0.69}_{-0.19}$
	^{238}U $\rightarrow$ ^{230}Th	0.01	$(1.90 \pm 0.03) \times 10^{-9}$	-1.08
	^{230}Th	0.01	$(8.22 \pm 0.32) \times 10^{-10}$	$^{+13.51}_{-0.4}$
	^{226}Ra $\rightarrow$ ^{210}Pb	0.01	$(2.56 \pm 0.04) \times 10^{-9}$	$^{+1.52}_{-1.12}$
	^{235}U $\rightarrow$ ^{231}Pa	0.01	$(8.74 \pm 0.01) \times 10^{-10}$	-0.50
	^{231}Pa $\rightarrow$ ^{207}Pb	0.01	$(1.05 \pm 0.34) \times 10^{-10}$	$^{+1.07}_{-0.66}$
	^{232}Th	0.1	$(3.21 \pm 1.52) \times 10^{-11}$	$+3.21$
	^{228}Ra $\rightarrow$ ^{208}Pb	0.1	$(5.34 \pm 0.34) \times 10^{-10}$	-5.27
	^{238}U $\rightarrow$ ^{230}Th	0.1	$(9.15 \pm 2.65) \times 10^{-11}$	$^{+36.50}_{-8.35}$
	^{230}Th	0.1	$(8.64 \pm 2.56) \times 10^{-11}$	$^{+7.75}_{-3.98}$
	^{226}Ra $\rightarrow$ ^{210}Pb	0.1	$(9.10 \pm 0.40) \times 10^{-10}$	$^{+1.31}_{-8.71}$
	^{210}Pb	0.1	$(1.31 \pm 0.01) \times 10^{-8}$	$^{+0.29}_{-0.17}$
	^{235}U $\rightarrow$ ^{231}Pa	0.1	$(4.21 \pm 1.22) \times 10^{-12}$	$^{+16.78}_{-3.84}$
	^{231}Pa $\rightarrow$ ^{207}Pb	0.1	$< 6.06 \times 10^{-11}$	
	^{232}Th	1	$(7.77 \pm 1.74) \times 10^{-11}$	-3.81
	^{228}Ra $\rightarrow$ ^{208}Pb	1	$(1.86 \pm 0.19) \times 10^{-10}$	$^{+10.17}_{-1.06}$
	^{238}U $\rightarrow$ ^{230}Th	1	$(2.84 \pm 0.14) \times 10^{-10}$	$^{+0.51}_{-1.11}$
	^{230}Th	1	$(9.32 \pm 1.84) \times 10^{-11}$	$^{+18.73}_{-5.25}$
	^{226}Ra $\rightarrow$ ^{210}Pb	1	$(3.08 \pm 0.15) \times 10^{-10}$	$^{+1.41}_{-2.58}$
	^{210}Pb	1	$(5.15 \pm 0.10) \times 10^{-9}$	$^{+0.7}_{-0.94}$

Volume	Contaminant	Depth [μm]	Mode/Limit [Bq cm^{-2}]	Systematic
Crystals				
	$^{235}U \rightarrow {}^{231}Pa$	1	$(1.31 \pm 0.06) \times 10^{-11}$	$^{+0.23}_{-0.51}$
	$^{231}Pa \rightarrow {}^{207}Pb$	1	$< 2.23 \times 10^{-11}$	
	^{232}Th	10	$(1.18 \pm 0.28) \times 10^{-10}$	$+7.12$
	$^{228}Ra \rightarrow {}^{208}Pb$	10	$(3.29 \pm 1.27) \times 10^{-11}$	$+61.54$
	$^{238}U \rightarrow {}^{230}Th$	10	$< 1.99 \times 10^{-11}$	
	^{230}Th	10	$(2.17 \pm 0.25) \times 10^{-10}$	$^{+5.95}_{-0.78}$
	$^{226}Ra \rightarrow {}^{210}Pb$	10	$(1.82 \pm 0.86) \times 10^{-11}$	$^{+10.24}_{-1.46}$
	^{210}Pb	10	$(2.23 \pm 0.09) \times 10^{-9}$	$^{+2.48}_{-2.18}$
	$^{235}U \rightarrow {}^{231}Pa$	10	$< 9.15 \times 10^{-12}$	
	$^{231}Pa \rightarrow {}^{207}Pb$	10	$< 1.37 \times 10^{-11}$	
Close parts				
	^{232}Th	0 .01	$(1.35 \pm 0.06) \times 10^{-9}$	$^{+0.51}_{-0.51}$
	^{238}U	0 .01	$(1.24 \pm 0.07) \times 10^{-9}$	$^{+0.44}_{-0.68}$
	^{210}Pb	0 .01	$(3.40 \pm 0.02) \times 10^{-7}$	$^{+1.22}_{-0.96}$
	^{210}Pb	0 .1	$(6.48 \pm 0.25) \times 10^{-8}$	-3.55
	^{235}U	0 .01	$(5.71 \pm 0.03) \times 10^{-10}$	$^{+0.20}_{-0.31}$
	^{210}Pb	1	$(5.23 \pm 0.19) \times 10^{-8}$	$^{+3.15}_{-0.69}$
	^{232}Th	10	$(1.15 \pm 0.05) \times 10^{-8}$	$^{+0.34}_{-0.64}$
	^{238}U	10	$(8.35 \pm 0.68) \times 10^{-9}$	-3.96
	^{210}Pb	10	$(6.85 \pm 0.69) \times 10^{-8}$	$^{+4.88}_{-4.23}$
	^{235}U	10	$(3.84 \pm 0.31) \times 10^{-10}$	-1.82

Volume	Contaminant	Depth [μm]	Mode/Limit [Bq cm^{-2}]	Systematic
MC				
	^{232}Th	0 .01	$< 4.36 \times 10^{-9}$	
	^{238}U	0 .01	$(6.79 \pm 1.32) \times 10^{-8}$	-6.42
	^{210}Pb	0 .01	$< 2.05 \times 10^{-5}$	< 17.11
	^{235}U	0 .01	$(3.12 \pm 0.61) \times 10^{-9}$	-2.95
HEX				
	^{210}Pb		$(8.23 \pm 0.20) \times 10^{-4}$	$^{+6.43}_{-6.43}$

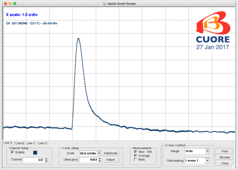
- tower assembly (Sep 2012 – Jul 2014)
- cryostat commissioning

  (Aug 2012 – Mar 2016)
- detector installation (Jul – Aug 2016)



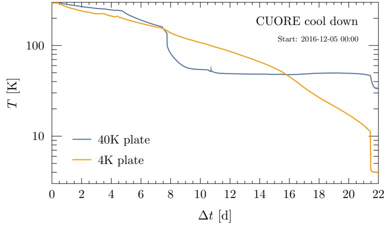
- cool down: T_{MC} = 6.8 mK

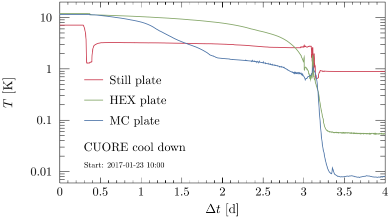
First events @ Jan 2017



CUORE cool down

Cryogenics 102, 9 (2019)

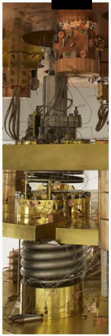




Some pictures from the CUORE cryostat

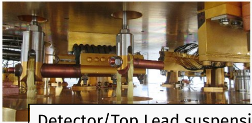
Plates + Top Lead

DU



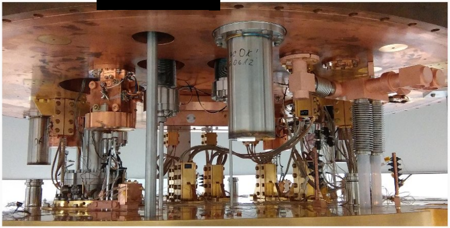
PT

Superinsulation

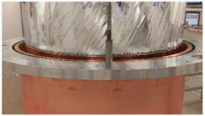


Detector/Top Lead suspensions

Inside the IVC



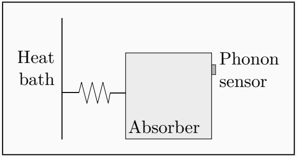
Vessels



From CUORE to CUPID

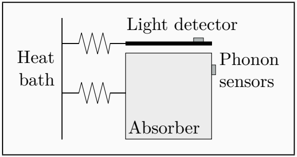
- experimental search for 0νββ: $t^{0\nu}_{1/2} \propto \sqrt{M\,T/B\,\Delta}$
- when $M\,T\,B\,\Delta = \mathcal{O}(1)$, i. e. no event expected in ROI: $t^{0\nu}_{1/2} \propto M\,T$

$\rightarrow$ crucial to achieve zero background, so that sensitivity scales linearly with exposure



CUORE

- ^{130}Te ($Q_{\beta\beta}$= 2527.5 keV)
  - below ^{208}Tl @2615 keV
- only heat channel
  - pure thermal detector
  - no particle identification

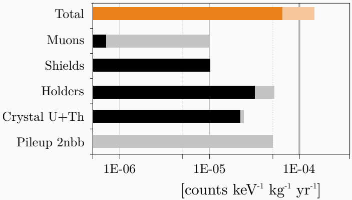


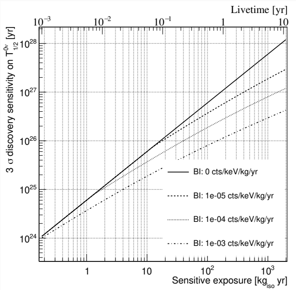
Next generation

- ^{100}Mo ($Q_{\beta\beta}$= 3034.4 keV)
  - reduced γ contribution
- heat + light
  - scintillating bolometer
  - α vs. β/γ discrimination

CUPID physics potential

- mass: 450 kg, i. e. $\sim$ 240 kg of ^{100}Mo
  - 1596 $Li_2{}^{100}MoO_4$ crystals
  - 57 towers of 14 floors of 2 crystals
  - each $45 \times 45 \times 45\,mm^3$, with a mass of 280 g
- live time: 10 yr
- resolution: 5 keV at $Q_{\beta\beta}$
- bkg: 10^{-4} c $keV^{-1}\,kg^{-1}\,yr^{-1}$ in ROI
- sensitivity on 0νββ: $t^{0\nu}_{1/2} > 10^{27}$ yr
  - $m_{\beta\beta} < (15 - 20)$ meV
  - full coverage of Inverted-Hierachy region
- other searches
  - rare decays: 2νββ, excited states
  - spectral-shape study: CPT-violation, Majorons
  - low-E searches: DM, axions, CEνNS





arXiv:1907.09376 [physics.ins-det]