Abstract

Aiming to discover neutrinoless double beta decay from ^{130}Te, the Cryogenic Underground Observatory for Rare Events (CUORE) experiment continues to make progress at Laboratori Nazionali del Gran Sasso (LNGS). CUORE-0, a 1/19 mass replica of CUORE, is a 52 bolometer array that continues to take data providing validation for the methods and strategies undertaken for CUORE. We will present the latest results from CUORE-0 and milestones achieved by the ongoing commissioning of CUORE. I will also summarize R&D with bolometers for future generation double-beta decay experiments.

Latest results from CUORE-0 and status of CUORE

Dr. Kevin Peter Hickerson
on behalf of the CUORE collaboration

University of California Los Angeles

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Outline

Neutrinoless double beta decay

Double-beta decay is a rare allowed transition when single beta decay is energetically forbidden

$$(Z, A) \longrightarrow (Z+2, A) + 2e^- + 2\nu_e$$

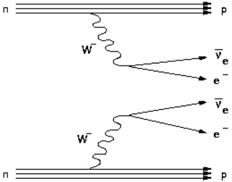


Figure 1: Standard double-beta decay ($2\nu\beta\beta$).

$$(Z, A) \longrightarrow (Z+2, A) + 2e^-$$

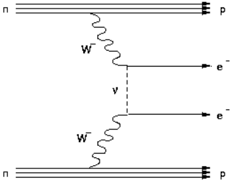


Figure 2: Neutrinoless double-beta decay ($0\nu\beta\beta$).

$0\nu\beta\beta$ decay rate

The $0\nu\beta\beta$ decay rate depends on the Majorana mass $\langle m_{\beta\beta}\rangle$ as in:

$$\frac{1}{T_{1/2}^{0\nu}} = G^{0\nu}(Q,Z)\left|M^{0\nu}\right|^2 \frac{\left|\langle m_{\beta\beta}\rangle\right|^2}{m_e^2}. \tag{1}$$

where

- $G^{0\nu}(Q,Z)$ is the phase-space factor;
- $M^{0\nu}$ is nuclear matrix element [1]
- $\langle m_{\beta\beta}\rangle$ depends on neutrino mixture:

$$f(\theta_{12},\theta_{23},\theta_{13},\Delta m_{12},\pm\Delta m_{23},m_0) \tag{2}$$

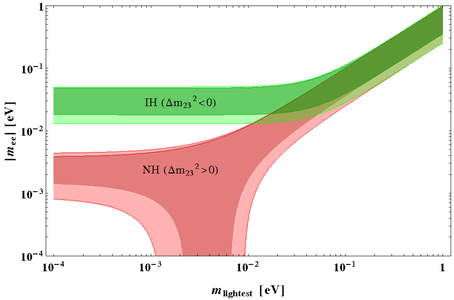
[1] This can be calculated but different models differ by $2\times$ or $3\times$ (Bilenky and Giunti, 2012a)

Neutrino mass hierarchy

It is possible to examine the neutrino mass hierarchy, $\Delta m_{12} \pm \Delta m_{23}$, and the absolute mass scale m_0. Present data from neutrino oscillation experiments favor

$$10 \text{ meV} < \langle m_{\beta\beta} \rangle < 50 \text{ meV}$$

for an inverted hierarchy and 10 times smaller for normal hierarchy (Strumia and Vissani, 2010; Bilenky and Giunti, 2012b).



Experimental signature of $0\nu\beta\beta$

The $0\nu\beta\beta$ signature is a monoenergetic line at Q-value

$$T^{0\nu}_{1/2} = \ln(2)\, T\, \varepsilon\, \frac{N_{\beta\beta}}{N_{\text{peak}}} \qquad (3)$$

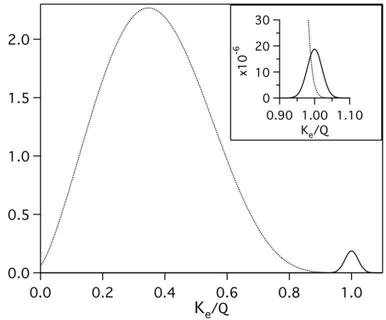


Figure 3: Electron spectrum for $2\nu\beta\beta$ and $0\nu\beta\beta$. Not to scale; the peak is very exaggerated height and width.

Large bolometers

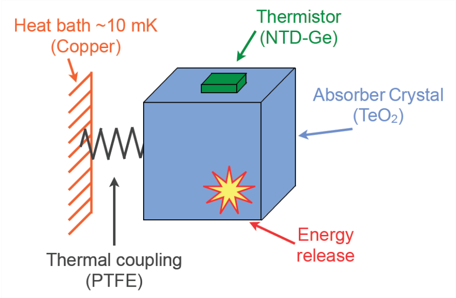


Figure 4: Schematic of a single CUORE-0 bolometer.

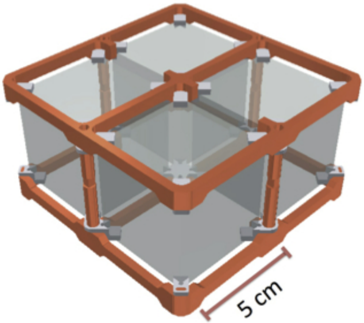
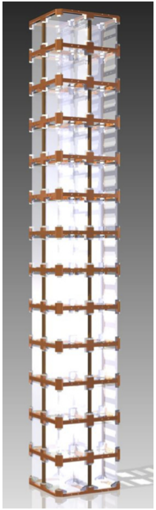


Figure 5: CAD model of a CUOER-0 floor with 4 bolometers.

Overview of TeO_2 bolometers for CUORE



CUORE (Cryogenic Underground Observatory for Rare Events)

- proposed by E. Fiorini and T.O. Niinikoski in 1984 .
- Searching for $0\nu\beta\beta$ decay of ^{130}Te.
- ^{130}Te has high natural isotopic abundance (34.2%)(Fehr, 2004).
- TeO_2 crystals are used as bolometers.
- β energy converted into phonons that raises T.
- The base temperature is $T = 10$ mK where heat capacity C is small.
- $\Delta T = \Delta E/C = \Delta$E$\sim$10-20 μK/MeV (Artusa, 2014b).
- TeO_2 crystal bolometers can be large (5$\times$5$\times$5 cm^3)!

Sensitivity

The expected number of $0\nu\beta\beta$ events, in a period T of time, is (Alessandria, 2014).

$$S \propto (i.a.)\, M\, \varepsilon\, \frac{T}{T^{0\nu}_{1/2}} \tag{4}$$

If there is a background, the rate is approximately

$$B \approx b\, M\, T\, \Delta E \tag{5}$$

The sensitivity is in terms of the $0\nu\beta\beta$ half-life,

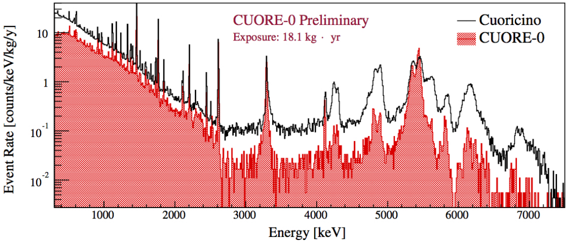
$$\widehat{T^{0\nu}_{1/2}} \propto \frac{(i.a.)\,\varepsilon}{n_\sigma}\sqrt{\frac{M\,T}{b\,\Delta E}} \sim \sqrt{\frac{\text{detector scale}}{\text{performance}}} \tag{6}$$

in the limit of zero background, the sensitivity becomes

$$\widehat{T^{0\nu}_{1/2}} \propto (i.a.)\,\varepsilon\, T\, M \tag{7}$$

Backgrounds

Improvement from Cuoricino



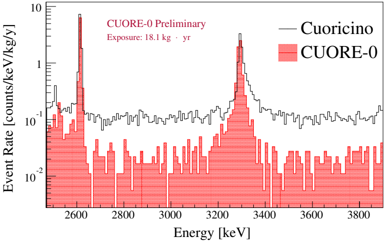


Figure 6: Background energy spectrum in Cuoricino and CUORE-0

- main sources of background identified with Cuoricino.
- (50±20)% in ROI near Q is from αs from ^{238}U, ^{232}Th, ^{210}Pb
- (30±10)% due to γ from ^{208}Tl in the decay chain of the ^{232}Th contamination in the cryostat materials.

The CUORE design background is 0.01 counts/(kev kg yr). The overall backgrounds in ROI is reported in table 1.

Table 1: Total background in ROI in counts/(keV kg y). For CUORE we report the predicted value.

	$0\nu\beta\beta$	2700-3900 keV
Cuoricino	0.153±0.006	0.110±0.001
CUORE-0	0.063±0.006	0.020±0.001
CUORE	0.01	

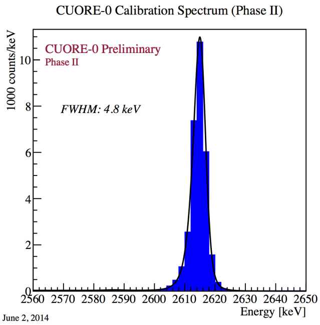


Figure 7: The ^{208}Tl line used to estimate the energy resolution.

- photo peak originated by the ^{208}Tl decay (which is close to the Q-value of 2527.5 keV).
- detector resolution was found to be 5.7 keV (FWHM) (Artusa, 2014a,b).
- phase II of CUORE-0 reached 4.8 keV (FWHM).
- Design goal 5 keV expected.
- detection efficiency of CUORE-0 is estimated to be (77.6$\pm$1.3)

- Initial CUORE-0 started taking data in March 2013 (Artusa, 2014a).
- Phase II started November 2013
- accumulated TeO_2 exposure on 49 fully active channels is 18.06 kg·year for a ^{130}Te isotopic exposure of 5.02 kg·year.

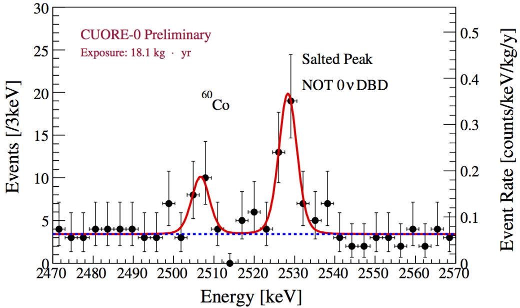
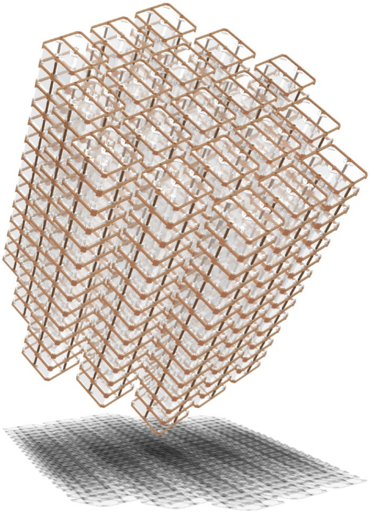
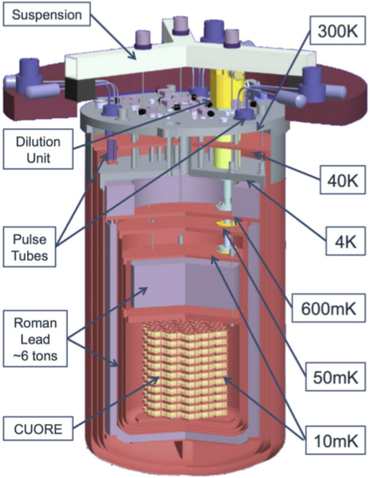


Figure 8: Preliminary results of the CUORE-0 first data taking phase.

CUORE will consist of

- 988 crystals arranged in 19 towers.
- detector mass is 741 kg
- isotope mass of ^{130}Te s 206 kg.
- All 19 towers have been assembled, instrumented, and stored in nitrogen-flushed atmosphere





Current ongoing commissioning tasks are

- detector integration,
- commissioning of the new cryostat,
- the installation of the calibration system
- data acquisition system,
- Faraday cage and other auxiliary systems like
- the slow control and monitoring system.

CUORE-0 has demonstrated that the CUORE design parameters of equation 6 reported in table 2,

Table 2: Experimental parameter values used for the sensitivity of CUORE-0 and CUORE. Symbols are defined in equation 6.

	i.a. [%]	ε [%]	M [kg]	ΔE [keV]	b [keV kg y]$^{-1}$
CUORE-0	34.167	87.4	39	5	0.063
CUORE	34.167	87.4	741	5	0.01

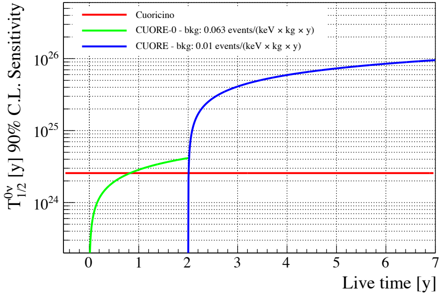


Figure 9: 90% C.L. sensitivity for CUORE-0 and CUORE using data in table 2.

- Cuoricino run completed (2003–2008) (Coll.), 2011).
- CUORE-0 demonstrates feasibility large-scale bolometric (2012)
- CUORE-0 is running (2012–now)
- A half-life sensitivity close to 10^{25} years is expected for a 2 years live-time of CUORE-0 (est. 2015)
- CUORE will begin data taking (est. 2015)

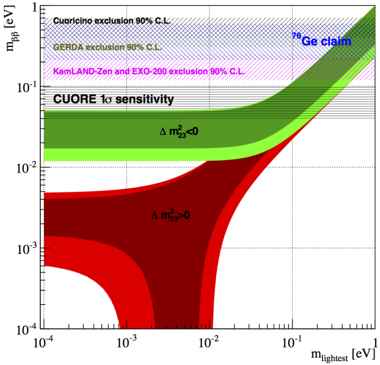


Figure 10: CUORE sensitivity to Majorana mass

Sensitivity in terms of effective Majorana mass for 5 years live time computed using the experimental parameters given in table 2. The band corresponds to the maximum and minimum $\langle m_{\beta\beta} \rangle$ values obtained from different nuclear matrix elements.

CUORE-0

- at present the most sensitive experiment $0\nu\beta\beta$ in ^{130}Te.
- currently taking data.
- validated that design parameters of full CUORE, can be reached.
- validating energy resolution and the background rate goals.

Conclusions

CUORE

- under construction and expected to take data in 2015.
- excellent energy resolution and large isotope mass.
- one of the most competitive upcoming $0\nu\beta\beta$ experiments.
- target background of 0.01 counts/(keV kg y) and seems within reach.
- in 5 years expected 1σ sensitivity to ^{130}Te

$$1.6 \times 10^{26} \text{ years } (9.5 \times 10^{25} \text{ years at 90\% C.L.}).$$

- Majorana mass 1σ sensitivity of

$$\text{40–100 meV (50–130 meV at 90\% C.L.).}$$

Acknowledgments

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