

UC Berkeley

UC Berkeley Previously Published Works

Title

First neutrinoless double beta decay results from CUORE-0

Permalink

<https://escholarship.org/uc/item/99q7p65m>

Journal

AIP Conference Proceedings, 1686(1)

ISSN

0094-243X

ISBN

9780735413337

Authors

Gironi, L
Alduino, C
Alfonso, K
et al.

Publication Date

2015-10-28

DOI

10.1063/1.4934900

Peer reviewed

First neutrinoless double beta decay results from CUORE-0

L. Gironi^{1,2,a)}, C. Alduino³, K. Alfonso⁴, D. R. Artusa^{3,5}, F. T. Avignone III³, O. Azzolini⁶, M. Balata⁵, T. I. Banks^{7,8}, G. Bari⁹, J.W. Beeman¹⁰, F. Bellini^{11,12}, A. Bersani¹³, M. Biassoni^{1,2}, C. Brofferio^{1,2}, C. Bucci⁵, A. Camacho⁶, A. Caminata¹³, L. Canonica⁵, X. G. Cao¹⁴, S. Capelli^{1,2}, L. Cappelli^{13,5,15}, L. Carbone², L. Cardani^{11,12}, P. Carniti^{1,2}, N. Casali^{11,12}, L. Cassina^{1,2}, D. Chiesa^{1,2}, N. Chott³, M. Clemenza^{1,2}, S. Copello¹⁶, C. Cosmelli^{11,12}, O. Cremonesi², R. J. Creswick³, J. S. Cushman¹⁷, I. Dafinei¹², A. Dally¹⁸, C. J. Davis¹⁷, S. Dell'Oro^{5,19}, M. M. Deninno⁹, S. Di Domizio^{16,13}, M. L. Di Vacri^{5,20}, A. Drobizhev^{7,8}, D. Q. Fang¹⁴, M. Faverezani^{1,2}, G. Fernandes^{16,13}, E. Ferri^{1,2}, F. Ferroni^{11,12}, E. Fiorini^{2,1}, M. A. Franceschi²¹, S. J. Freedman^{8,7}, B. K. Fujikawa⁸, A. Giachero^{2,1}, A. Giuliani²², P. Gorla⁵, C. Gotti^{1,2}, T. D. Gutierrez²³, E. E. Haller^{10,24}, K. Han^{17,8}, E. Hansen^{25,4}, K. M. Heeger¹⁷, R. Hennings-Yeomans^{7,8}, K. P. Hickerson⁴, H. Z. Huang⁴, R. Kadel²⁶, G. Keppel⁶, Yu. G. Kolomensky^{7,26}, C. Ligi²¹, K. E. Lim¹⁷, X. Liu⁴, Y. G. Ma¹⁴, M. Maino^{1,2}, M. Martinez^{11,12,27}, R. H. Maruyama¹⁷, Y. Mei⁸, N. Moggi^{28,9}, S. Morganti¹², T. Napolitano²¹, S. Nisi⁵, C. Nones²⁹, E. B. Norman^{30,31}, A. Nucciotti^{1,2}, T. O'Donnell^{7,8}, F. Orio¹², D. Orlandi⁵, J. L. Ouellet^{25,7,8}, C. E. Pagliarone^{5,15}, M. Pallavicini^{16,13}, V. Palmieri⁶, L. Pattavina⁵, M. Pavan^{1,2}, G. Pessina², V. Pettinacci¹², G. Piperno^{11,12}, C. Pira⁶, S. Pirro⁵, S. Pozzi^{1,2}, E. Previtali², C. Rosenfeld³, C. Rusconi², E. Sala^{1,2}, S. Sangiorgio³⁰, D. Santone^{5,20}, N. D. Scielzo³⁰, M. Sisti^{1,2}, A. R. Smith⁸, L. Taffarello³², M. Tenconi²², F. Terranova^{1,2}, C. Tomei¹², S. Trentalange⁴, G. Ventura^{33,34}, M. Vignati¹², S. L. Wagaarachchi^{7,8}, B. S. Wang^{30,31}, H. W. Wang¹⁴, L. Wielgus¹⁸, J. Wilson³, L. A. Winslow²⁵, T. Wise^{17,18}, A. Woodcraft³⁵, L. Zanotti^{1,2}, C. Zarra⁵, G. Q. Zhang¹⁴, B. X. Zhu⁴, S. Zimmermann³⁶ and S. Zucchelli^{37,9}

¹ Dipartimento di Fisica, Università di Milano-Bicocca, Milano I-20126 - Italy

² INFN - Sezione di Milano Bicocca, Milano I-20126 - Italy

³ Department of Physics and Astronomy, University of South Carolina, Columbia, SC 29208 - USA

⁴ Department of Physics and Astronomy, University of California, Los Angeles, CA 90095 - USA

⁵ INFN - Laboratori Nazionali del Gran Sasso, Assergi (L'Aquila) I-67010 - Italy

⁶ INFN - Laboratori Nazionali di Legnaro, Legnaro (Padova) I-35020 - Italy

⁷ Department of Physics, University of California, Berkeley, CA 94720 - USA

⁸ Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720 - USA

⁹ INFN - Sezione di Bologna, Bologna I-40127 - Italy

- ¹⁰ *Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720 - USA*
- ¹¹ *Dipartimento di Fisica, Sapienza Università di Roma, Roma I-00185 - Italy*
- ¹² *INFN - Sezione di Roma, Roma I-00185 - Italy*
- ¹³ *INFN - Sezione di Genova, Genova I-16146 - Italy*
- ¹⁴ *Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800 - China*
- ¹⁵ *Dipartimento di Ingegneria Civile e Meccanica, Università degli Studi di Cassino e del Lazio Meridionale, Cassino I-03043 - Italy*
- ¹⁶ *Dipartimento di Fisica, Università di Genova, Genova I-16146 - Italy*
- ¹⁷ *Department of Physics, Yale University, New Haven, CT 06520 - USA*
- ¹⁸ *Department of Physics, University of Wisconsin, Madison, WI 53706 - USA*
- ¹⁹ *INFN - Gran Sasso Science Institute, L'Aquila I-67100 - Italy*
- ²⁰ *Dipartimento di Scienze Fisiche e Chimiche, Università dell'Aquila, L'Aquila I-67100 - Italy*
- ²¹ *INFN - Laboratori Nazionali di Frascati, Frascati (Roma) I-00044 - Italy*
- ²² *Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, 91405 Orsay Campus - France*
- ²³ *Physics Department, California Polytechnic State University, San Luis Obispo, CA 93407 - USA*
- ²⁴ *Department of Materials Science and Engineering, University of California, Berkeley, CA 94720 - USA*
- ²⁵ *Massachusetts Institute of Technology, Cambridge, MA 02139 - USA*
- ²⁶ *Physics Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720 - USA*
- ²⁷ *Laboratorio de Física Nuclear y Astroparticulas, Universidad de Zaragoza, Zaragoza 50009 - Spain*
- ²⁸ *Dipartimento di Scienze per la Qualità della Vita, Alma Mater Studiorum - Università di Bologna, Bologna I-47921 - Italy*
- ²⁹ *Service de Physique des Particules, CEA / Saclay, 91191 Gif-sur-Yvette - France*
- ³⁰ *Lawrence Livermore National Laboratory, Livermore, CA 94550 - USA*
- ³¹ *Department of Nuclear Engineering, University of California, Berkeley, CA 94720 - USA*
- ³² *INFN - Sezione di Padova, Padova I-35131 - Italy*
- ³³ *Dipartimento di Fisica, Università di Firenze, Firenze I-50125 - Italy*
- ³⁴ *INFN - Sezione di Firenze, Firenze I-50125 - Italy*
- ³⁵ *SUPA, Institute for Astronomy, University of Edinburgh, Blackford Hill, Edinburgh EH9 3HJ - UK*
- ³⁶ *Engineering Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720 - USA*
- ³⁷ *Dipartimento di Fisica e Astronomia, Alma Mater Studiorum - Università di Bologna, Bologna I-40127 - Italy*

^{a)}Corresponding author: luca.gironi@mib.infn.it

Abstract. The CUORE-0 experiment, a 52 bolometer array searching for neutrinoless double beta decay from ^{130}Te , has started taking data in spring 2013 underground at the Laboratori Nazionali del Gran Sasso (LNGS). The excellent results obtained in terms of energy resolution and background level allowed this experiment to reach the sensitivity of Cuoricino in approximately half the runtime. Combining CUORE-0 data (9.8 kg-yr exposure of ^{130}Te) with the 19.75 kg-yr exposure of the Cuoricino experiment, we obtain the most stringent limit to date on the half-life of this isotope ($T_{1/2} > 4.0 \times 10^{24}$ yr). In this article, we review the results from CUORE-0 and discuss the status and the physics potential of CUORE, a 19 times larger bolometer array that plans to begin operations by end of this year.

Introduction

The discovery of the neutrinoless double beta decay ($0\nu\text{DBD}$) would demonstrate that lepton number is not a symmetry of nature, establish that neutrinos are Majorana fermions and possibly constrain the absolute neutrino mass scale. Current limits on the half life of the $0\nu\text{DBD}$ are of the order of 10^{25} years, therefore the search for this process sets stringent requirements on the features of the detectors. Devices with large mass and good energy resolution are particularly appealing. A good energy resolution strongly reduces the natural background produced by $2\nu\text{DBD}$, the ultimate limit to the background in the energy region of the decay, while a large number of isotopes that can undergo $0\nu\text{DBD}$ is needed to increase the sensitivity. Bolometers are therefore almost ideal detectors for $0\nu\text{DBD}$ searches because they can achieve excellent energy resolution, high detection efficiency and good radio-purity levels. Moreover, the Cuoricino experiment [1], other than set the current limit on the $0\nu\text{DBD}$ of ^{130}Te , gave fundamental informations about long term operation of an array of 62 bolometers and allowed to characterize the sources of background in bolometric experiments for $0\nu\text{DBD}$ searches. The dominant source of background in the region of interest (ROI) was attributed to

α surface contaminations of the materials facing the detector, namely the copper mechanical structure. For this reason a new design for the support structure that reduces the inert surfaces facing the detector has been studied for CUORE and several surfaces cleaning techniques were tested [2].

CUORE-0

CUORE-0 is a CUORE-style tower (52 TeO₂ crystals, 39 kg of TeO₂ mass and 10.9 kg of ¹³⁰Te) built using the same materials, assembly devices and procedures developed for CUORE. Actually, given the sizable mass and the low background level reached in CUORE-0, it operated also as an independent 0 ν DBD experiment while CUORE is under construction.

All the CUORE-0 assembly procedure operations were conducted in glove boxes under nitrogen atmosphere to minimize oxidization and contamination of radon. The process started with the gluing of thermistors and heaters to crystals with a robotic system to gain high uniformity among detectors. It was followed by the mechanical assembly of the instrumented crystals, cleaned copper parts, and PTFE spacers into a tower. Two sets of flexible readout cables were then attached on opposite sides of the tower, and a wire bonder was used to bond the thermistors to the bonding pads on the readout boards.

CUORE-0 was operated in the same cryostat that previously hosted Cuoricino, in the Hall A of LNGS and maintained an operating temperature of ~ 10 mK. The analog read-out of the thermistor was performed using the same electronics that was used for Cuoricino.

CUORE-0 data taking started in March 2013. A CUORE-0 dataset consisted of 3–4 weeks of low background data taking preceded and followed by 2–3 days of calibration runs. The total TeO₂ background exposure amounts to 35.2 kg·y (9.8 kg·y of ¹³⁰Te).

Each thermistor voltage was continuously acquired at a rate of 125 Hz. Events were identified using a software trigger. Once triggered, we analyzed a 5-s-long window consisting of 1 s before and 4 s after the trigger. The pre-trigger voltage allowed to determine the bolometer temperature before the event, the pulse amplitude established the energy. In the analysis we have applied two parallel pulse filtering techniques, denoted optimal filter and decorrelated optimal filter, as well as two thermal gain stabilization techniques [3].

During the offline analysis, noisy pulses were identified and discarded as a result of the comparison with a set of template signals. Calibration spectra were analyzed to extract the correct calibration function of each detector. Finally, the time coincidences between events on different crystals was evaluated to be used in the anti-coincident analysis. Since the majority of 0 ν DBD events are expected to be fully contained in a single crystal, only single crystal events were selected for the 0 ν DBD search.

The overall detection efficiency in this analysis is 81.3 ± 0.6 %, which includes the shape, anti-coincidence, trigger and containment efficiencies. The 0 ν DBD ROI was blinded to avoid biasing in the subsequent analysis and allowed to test the fitting algorithms used after unblinding [4].

The measured exposure-weighted harmonic mean of the FWHM energy resolution at the 2615 keV line of ²⁰⁸Tl is 4.9 keV on calibration runs.

The comparison of the Cuoricino background spectrum and the CUORE-0 one is reported in Fig. 1. The continuum from 2.7 to 3.9 MeV is attributed to degraded α particles from surface contaminations. This α continuum extends down into the ROI and was 0.110 ± 0.001 counts/keV/kg/y in Cuoricino. The value measured in CUORE-0 is 0.016 ± 0.001 counts/keV/kg/yr. The factor of ~ 7 reduction from Cuoricino proves the success of the radio-purity protocols that were implemented for the CUORE production and assembly.

The best-fit value of the background index in the ROI is 0.058 ± 0.004 (stat.) ± 0.002 (syst.) counts/keV/kg/yr and it is dominated by residual environmental γ and from Th cryostat contaminations. This contribution will be greatly reduced in CUORE thanks to the newly designed dilution refrigerator made of low radioactivity materials and to the thicker shielding.

After the unblinding, we found no evidence for neutrinoless double-beta decay of ¹³⁰Te and placed a Bayesian lower bound on the decay half-life, $T_{1/2} > 2.7 \times 10^{24}$ yr at 90% C.L.. Combining CUORE-0 data with the 19.75 kg·yr exposure of ¹³⁰Te from the Cuoricino experiment we obtained $T_{1/2} > 4.0 \times 10^{24}$ yr at 90% C.L., the most stringent limit to date on this half-life [3].

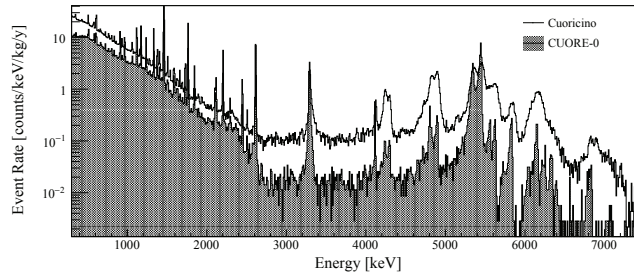


FIGURE 1. Cuoricino (line) and CUORE 0 (shaded) background spectra comparison. Only events with a single crystal hit are considered (anti-coincidence mode).

CUORE and beyond

CUORE (Cryogenic Underground Observatory for Rare Events) [5] is a 741 kg array of 988 TeO_2 bolometers currently in an advanced construction phase at LNGS. If the target background of 0.01 counts/keV/kg/yr will be reached, in five years of data taking and with an energy resolution of 5 keV FWHM, CUORE will have a 90% half life sensitivity of 9.5×10^{25} yr.

To achieve this challenging background level, in addition to the effective cleaning and the assembly techniques used for CUORE-0, CUORE will have a much smaller detector surface facing inert materials. Moreover, the high granularity of the CUORE detector will allow to reduce the flat α background due to surface contaminations of the crystals and the residual γ background thanks to the analysis of the coincidences between the crystals.

The assembly of the detectors has been completed and the 19 towers of CUORE are now stored underground waiting for their installation into the cryostat. The cryostat is already assembled and passed the 4K commissioning test. The Dilution Unit has been installed in the main cryostat in 2014 and reached a temperature of ~ 6 mK. The final integration run is ongoing and we expect to deploy the array of crystals in the cryostat later this year.

Despite the considerable efforts devoted to CUORE, we are also looking forward on several R&Ds to design a future tonne-scale bolometric 0 ν DBD experiment with a background close to zero at the ton \times year exposure scale. In order to achieve this ambitious science goals, CUPID (CUORE Upgrade with Particle ID) aims to increase the source mass and dramatically reduce the backgrounds in the region of interest. This requires isotopic enrichment and new detector technologies with active background rejection capabilities [6].

ACKNOWLEDGMENTS

The CUORE Collaboration thanks the directors and staff of the Laboratori Nazionali del Gran Sasso and the technical staff of our laboratories. This work was supported by the Istituto Nazionale di Fisica Nucleare (INFN); the National Science Foundation under Grant Nos. NSF-PHY-0605119, NSF-PHY-0500337, NSF-PHY-0855314, NSF-PHY-0902171, NSF-PHY-0969852, NSF-PHY-1307204, and NSF-PHY-1404205; the Alfred P. Sloan Foundation; the University of Wisconsin Foundation; and Yale University. This material is also based upon work supported by the US Department of Energy (DOE) Office of Science under Contract Nos. DE-AC02-05CH11231 and DE-AC52-07NA27344; and by the DOE Office of Science, Office of Nuclear Physics under Contract Nos. DE-FG02-08ER41551 and DEFG03-00ER41138. This research used resources of the National Energy Research Scientific Computing Center (NERSC).

REFERENCES

- [1] E. Andreotti *et al.*, *Astropart. Phys.* **34**, 822 (2011).
- [2] F. Alessandria *et al.*, *Astropart. Phys.* **45**, 13-22 (2013).
- [3] D.R. Artusa *et al.*, Submitted to PRL, [arXiv:1504.02454](https://arxiv.org/abs/1504.02454).
- [4] D.R. Artusa *et al.*, *Eur. Phys. J. C* **74**, 2956 (2014).
- [5] D.R. Artusa *et al.*, *Adv. High Energy Phys.* 879871 (2015).
- [6] The CUPID Interest Group, [arXiv:1504.03612](https://arxiv.org/abs/1504.03612).