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Results from the CUORE experiment

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Summary. — The Cryogenic Underground Observatory for Rare Events (CUORE) is the first bolometric experiment searching for neutrinoless double beta decay that has been able to reach the 1-ton scale. In this talk we present the neutrinoless doube beta decay results of CUORE from examining a total TeO_2 exposure of 86.3 kg yr, characterized by an effective energy resolution of 7.7 keV FWHM and a background in the region of interest of 0.014 counts/(keV kg yr). In this physics run, CUORE placed a lower limit on the decay half-life of ^{130}Te $> 1.3\times10^{25}$ yr (90% C.L.). We then discuss the additional improvements in the detector performance achieved in 2018 and the latest update on the evaluation of the background budget.

1. – The CUORE experiment

The *Cryogenic Underground Observatory for Rare Events* (CUORE [1]) is an experiment focused on the search for the neutrinoless double beta decay ($0\nu\beta\beta$), a lepton number violating process $(Z, A) \rightarrow (Z+2, A)+2e^-$ with emission of (only) two electrons in the final state. Such process may be regarded as one of the most sensitive probes to physics beyond the Standard Model. The experimental signature is given by a peak in the spectrum of the summed electron energy at Q-value ($Q_{\beta\beta}$) of the isotope.

CUORE is based on the cryogenic bolometric technique: the energy released by the final state electrons is converted into lattice vibrations of an absorbing crystal inducing a temperature rise. The $0\nu\beta\beta$ emitter is ^{130}Te with $Q_{\beta\beta}$=2527.5 keV and isotopic abundance $\simeq$34%. The detector is composed of 988 cubic crystals of TeO_2 operated as independent bolometers that act both as source and detector. This approach gives a high signal efficiency (~90%) and excellent energy resolution. The total mass is 742 kg, or 206 kg of ^{130}Te. Each crystal is glued to a neutron transmutation doped thermistor to read the energy deposition. The bolometers are arranged in 19 copper structures (towers) of 13 floors each (the copper serving also as heath bath) and cooled down to ~10 mK inside a dilution-refrigerator custom made cryostat.

The sensitivity may be expressed as $\propto \sqrt{M \cdot t/b \cdot \Delta E}$, where M is the total mass, t the time exposure, b the background in counts/(kg·keV·y) and ΔE the energy resolution. The expected sensitivity in 5 years is $\mathrm{Te}^{0\nu}_{1/2} > 9\times 10^{25}$ y [2].

The underground location at L.N.G.S. (3600 m water equivalent depth) and passive shields both outside and inside the cryostat reduce the environmental radioactivity. Great efforts have been made to meet the strict radiopurity requirements of all the parts used to build the cryostat and the detector [3], including: careful selection of all materials, dedicated cleaning procedures, assembly and temporary storage in N_2 atmosphere.

The assembly of the detector was completed in summer 2016 followed by the installation inside the cryostat and cooldown. Base temperature was reached in January 2017. Overall 984/988 bolometers are operational. After a commissioning and optimisation period, two datasets were collected during summer 2017 for a total of 86.3 kg ·y of TeO_2 or 24.0 kg·y of ^{130}Te. These datasets are characterised by an exposure weighted energy resolution of 7.7±0.5 keV FWHM [4].

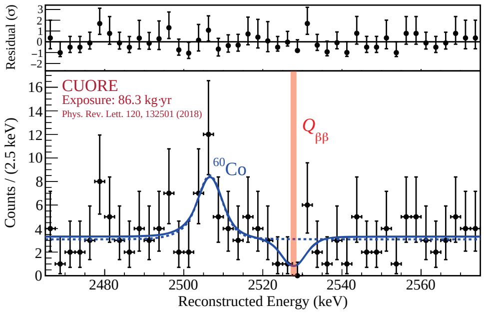

Fig. 1. – The best-fit model in the ROI. The normalized residuals of this model and the binned data are shown in the top panel. The vertical band is centered at $Q_{\beta\beta}$; the width of the band reflects the systematic uncertainty on the reconstructed energy.

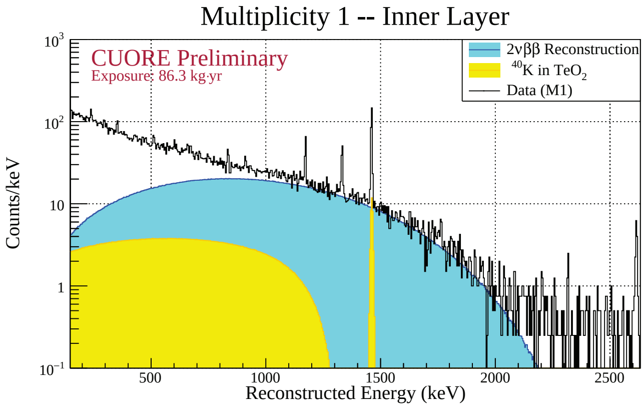

Fig. 2. – The $2\nu\beta\beta$ spectrum overlaid to the full physical spectrum. Only $M1$ events are used. For illustrative purposes the spectrum has been converted to 1keV binning with no uncertainty shown, and $2\nu\beta\beta$ and ^{40}K to smooth continua.

2. – Results

The energy-calibrated spectrum is obtained using six γ lines of the ^{232}Th decay chain from the calibration runs that bracket each dataset. The high statistics ^{208}Tl 2615 keV line is used also to characterise the energy resolution performance. Data quality cuts are then applied: events with energy deposit in more than one bolometer are rejected and a pulse shape consistent with signal-like events is required. The final spectrum shows no evidence of $0\nu\beta\beta$ decay. An unbinned extended maximum likelihood fit is performed in the range 2465-2575 keV (fig.1) to extract a limit on the half-life. The fit function include a signal peak at $Q_{\beta\beta}$m a peak at 2506 keV (^{60}Co) and a dataset-dependent flat background. Assuming zero signal, the 90% C.L. limit is Te$^{0\nu}_{1/2}$ >1.3×10^{25} y [4]. By combining this with Cuoricino and CUORE-0 results [5] we obtain Te$^{0\nu}_{1/2}$ >1.5× 10^{25} y which is the most stringent result to date. Interpreted as a limit on the Majorana mass this results may be expressed as $m_{\beta\beta}$ <110-520 eV at 90% C.L. depending on the nuclear matrix element used and assuming $g_A = 1.27$.

The fit yields a background index of 0.0014±0.002 counts/(kg·keV·y) at $Q_{\beta\beta}$ (average over datasets). Both energy resolution and background index improve in the second dataset. More improvements are expected with the understanding of the new cryostat performance and the implementation of all the data quality cuts. In order to understand the observed spectrum a background model was developed where all possible background sources are simulated following the method used in CUORE-0 [6]. About 60 parameters represent the source types, contamination levels and detector locations. Much information may be extracted directly from the CUORE data by splitting events into different type of spectra. “Multiplicity 1” ($M1$) contains events where energy os deposited in a single bolometer, “Multiplicity 2” ($M2$) events where the energy is shared between two bolometers and $M2sum$ events where energy of the $M2$ events is summed. $M1$ mostly contains signal, $M2$ and $M2sum$ mostly background. $M1$ may be further split geometrically into spectra from inner bolometers (more shielded) and outer bolometers (more exposed to external contaminations). By fitting the simulated spectra to the observed data all major features of the physical spectrum are reproduced. The dominant component of $M1$ in the region 1-2 MeV is due to the $2\nu\beta\beta$ decay of ^{130}Te (fig.2). Its contribution may be disentangled from other backgrounds and the half-life evaluated to be $T^{2\nu}_{1/2}$=(7.9±0.1$_{stat.}$±0.2$_{syst.}$)× 10^{20} y, consistent with previous measurements [7] and most precise to date.

Besides its potential also for dark matter searches and other $\beta\beta$ decays, CUORE will continue to be one of the most sensitive searches for $0\nu\beta\beta$ over the coming years.

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