PROCEEDINGS OF SCIENCE

Latest results from the CUORE experiment

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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 one-tonne mass scale. The detector, located at the Laboratori Nazionali del Gran Sasso in Italy, consists of an array of 988 TeO_2 crystals arranged in a compact cylindrical structure of 19 towers. CUORE began its first physics data run in 2017 at a base temperature of about 10 mK and in April 2021 released its 3rd result of the search for neutrinoless double-beta decay, corresponding to a tonne-year of TeO_2 exposure. This is the largest amount of data ever acquired with a solid state detector and the most sensitive measurement of neutrinoless double-beta decay in ^{130}Te ever conducted, with a median exclusion sensitivity of 2.8×10^{25} yr. We find no evidence of neutrinoless double-beta decay and set a lower bound of 2.2×10^{25} yr at a 90% credibility interval on the ^{130}Te half-life for this process. In this talk, we presented the current status of CUORE search for neutrinoless double-beta decay with the updated statistics of one t yr; we also gave an update of the CUORE background model and of the measurement of the ^{130}Te two-neutrino double-beta decay decay half-life, study performed using an exposure of 300.7 kg yr.

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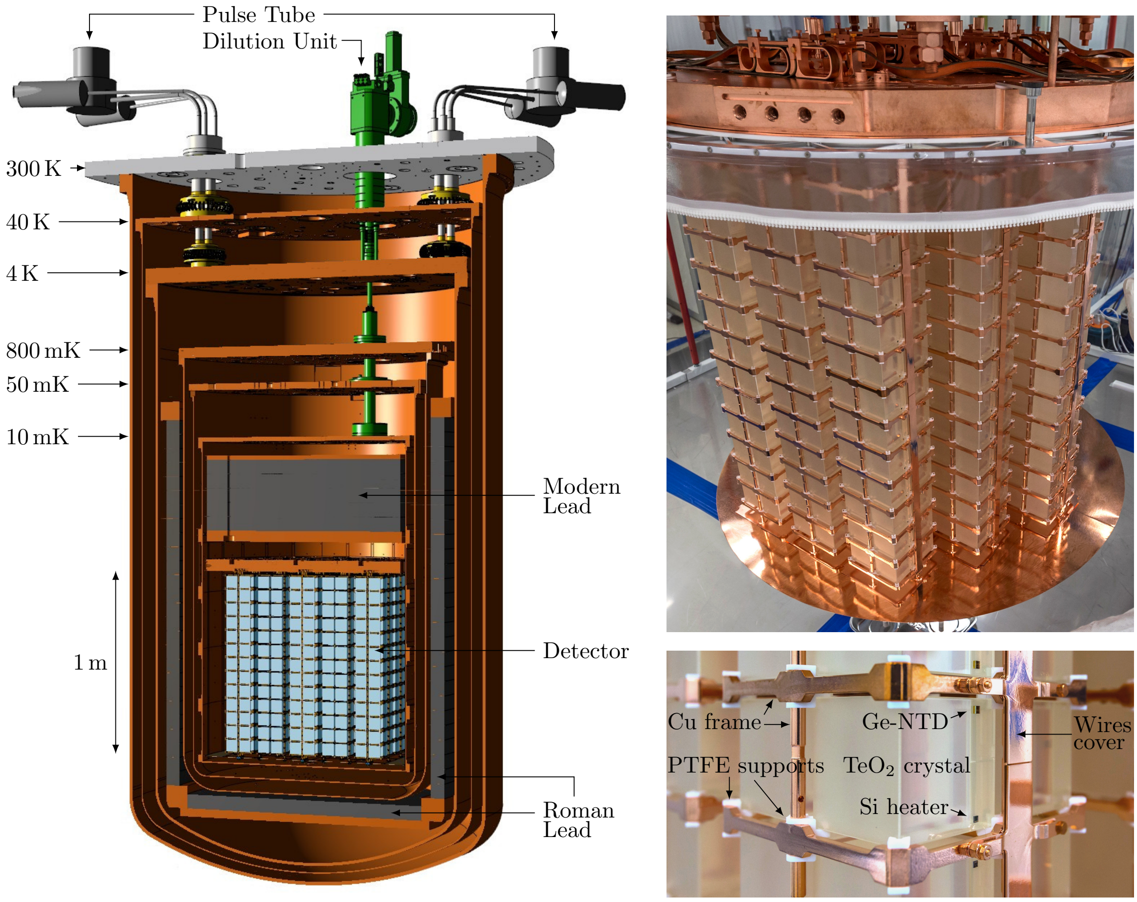

Figure 1: (Left) Rendering of the CUORE crysotat. The different thermal stages, vacuum chambers, cooling elements and lead shields are indicated. (Right) The detector after installation and a zoomed view on one of the calorimeters. Figure from Ref. [4].

1. Introduction

Neutrinoless double beta decay ($0\nu\beta\beta$) is a key tool to address some of the major outstanding issues in particle physics: its discovery would demonstrate that the lepton number is not a conserved quantity and it would also provide precious information on the neutrino-mass nature (Majorana type) and values.

The Cryogenic Underground Observatory for Rare Events (CUORE) experiment is searching for the $0\nu\beta\beta$ of ^{130}Te with an array of 988 bolometers. Each bolometer consists in a 750 g $5 \times 5 \times 5\,\mathrm{cm}^3$ TeO_2 crystal, for a total mass of over 742 kg. The detector is operated at a cryogenic temperature of about 10 mK thanks to a custom cryostat, which is able to guarantee a year-long stable, low-noise, radio-pure environment (Fig. 1).

2. Search for $0\nu\beta\beta$ with CUORE

CUORE is located at the Laboratori Nazionali del Gran Sasso (LNGS) and has been collecting data since 2017. Up to date (summer 2022), more than 1 tonne yr of TeO_2 exposure has been

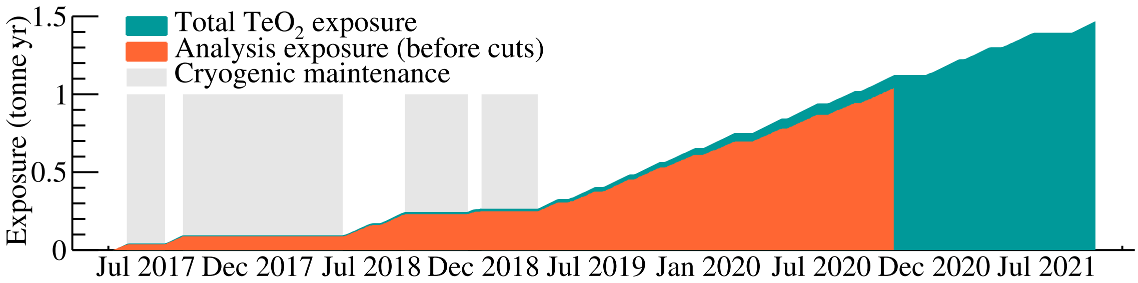

Figure 2: Exposure accumulated by CUORE (teal), along with the exposure used for this analysis (orange). Parts of 2017 and 2018 were dedicated to maintenance and optimization of the cryogenic set-up. Data releases on the search for $0\nu\beta\beta$ from the CUORE Collaboration are from 2017 [2], 2019 [3] and most recently 2022 [4]. Figure from Ref. [4].

analyzed and used in the search for $0\nu\beta\beta$ (Fig. 2).

The data processing begins by extracting a series of triggered waveforms from the continuous voltage data stream and computing the pulse amplitudes by applying optimum filters that maximize the frequency-dependent signal-to-noise ratio. We monitor and correct for possible drifts of the thermal gain of the detectors by exploiting stable heater pulses regularly injected onto the detectors; the stabilized amplitudes are then converted to energy by using source-calibration data, which are regularly acquired on a monthly base. We reject data from periods affected by high noise or failed data processing and apply a series of cuts to suppress background-like and low-quality events. An additional anti-coincidence cut excludes events depositing energy in more than one crystal, since we expect that these events will cover close to 90% of the $0\nu\beta\beta$ events, while a pulse shape discrimination rejects pile-up pulses ans pulses with a non-physical shape.

The final background spectrum is shown in Fig. 3, together with a zoomed inset on the region of interest, which contains only one background peak at 2505.7 keV from the simultaneous absorption of two coincident γ rays from ^{60}Co in the same crystal. After applying an unbinned Bayesian fit with uniform non-negative priors on the background and $0\nu\beta\beta$ decay rates, we find no evidence of $0\nu\beta\beta$ and we set a limit on the process half-life of $T^{0\nu}_{1/2} > 2.2 \times 10^{25}$ yr at 90% C. I. .

3. Other physics results

Aside from the main $0\nu\beta\beta$ search, we performed different investigations on the CUORE data; smaller datasets of about 300 kg yr have bee used for searches on different nuclear decays of Te. In particular, we were able to set very the stringent limits:

- $T_{1/2} > 3.4 \times 10^{22}$ yr at 90% C. I. on the $0\nu\beta^+$EC of ^{120}Te [5]
- $T_{1/2} > 3.6 \times 10^{24}$ yr at 90% C. I. on the $0\nu\beta\beta$ of ^{128}Te [6]
- $(T_{1/2})^{0\nu}_{0^+_2} > 5.9 \times 10^{24}$ yr and $(T_{1/2})^{2\nu}_{0^+_2} > 1.3 \times 10^{24}$ at 90% C. I. on the $0\nu\beta\beta$ / $2\nu\beta\beta$ on the excited states of ^{130}Te [7]

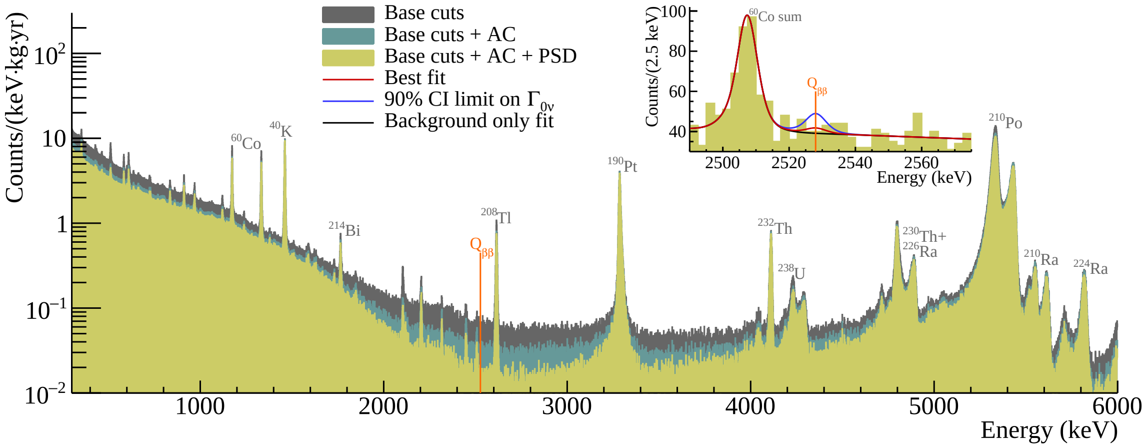

Figure 3: CUORE Physics spectrum for 1038.4 kg yr exposure of TeO_2 after application of the analysis cuts (base, anti-coincidence (AC) and pulse shape discrimination (PSD)). The most evident background peaks are highlighted, together with the expected position of the $0\nu\beta\beta$ peak. A zoom of the region of interest (after all selection cuts) with the best-fit curve (solid red), the best-fit curve ($0\nu\beta\beta$ rate fixed to the 90% CI limit (blue), background-only fit (black)) is shown in the inset. Figure from Ref. [4].

By performing a Bayesian analysis to fit simulated spectra to the experimental data, we have also been able to disentangle all the major background sources and precisely measure the two-neutrino contribution. We could thus make the most precise measurement to date on the $2\nu\beta\beta$ of ^{130}Te: $T^{2\nu}_{1/2} = 7.71\ ^{+0.08}_{-0.06}\ \text{(stat.)}\ ^{+0.12}_{-0.15}\ \text{(syst.)} \times 10^{20}$ yr [8].

4. Present status and outlook

The CUORE data-taking is ongoing; the experiment will continue acquiring data until about 3 t yr of ^{130}Te exposure will be collected. We are further developing our analysis tools in order to improve our current sensitivities with increased statistics, while enlarging the spectrum of possible investigations to other rare and exotic phenomena, like the study of the validity limits of the CPT/Lorentz invariance, the search for Tri-Nucleon decay and alternative forms of $0\nu\beta\beta$ involving the emission on other mediators (Majorons). At the same time, we are finalizing the construction of a background model of our detectors, extending from the low-energy γ region to high-energy α's.

Looking ahead, the experience acquired in running the first tonne-scale bolometric detector will serve as starting point for the next generation $0\nu\beta\beta$ experiment based on this technology. The CUORE Upgrade with Particle IDentification (CUPID) will search the $0\nu\beta\beta$ of ^{100}Mo with a sensitivity larger than 10^{27} yr [9].

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