The CUORE cryostat

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Abstract. The CUORE experiment (Cryogenic Underground Observatory for Rare Events) is a ton-scale detector, operating at a cryogenic temperature around 10 mK, searching for neutrinoless double-beta decay in ^{130}Te and other rare events. The experiment cryogenic infrastructure, its subsystems and the cool-down procedure that allowed CUORE to obtained the first physics results will be presented.

1. Introduction

The Cryogenic Underground Observatory for Rare Events (CUORE) experiment aims to investigate of the $0\nu\beta\beta$ decay of ^{130}Te [2, 3]. It is a ton-scale cryogenic experiment hosted at the underground laboratories of LNGS (Laboratori Nazionali del Gran Sasso). The CUORE detector is composed by 988 TeO_2 crystals arranged in a structure of 19 towers. The main goal of the experiment is the investigation of the $0\nu\beta\beta$ decay of ^{130}Te . The CUORE experiment employs a calorimetric phonon energy detection method. In order to be sensitive to the small increase in temperature due to particle interactions, the CUORE crystals must be kept at a stable cryogenic temperature around 10 mK. This is possible thanks to the CUORE cryostat which has been specifically designed for the experiment.

2. The CUORE cryogenic infrastructure

The cryogenic system implemented in CUORE has to cool down the detectors, the cryostat components and the Pb shields and to maintain the detector volume stably at a temperature around 10 mK for at least 5 years [4, 5]. The infrastructure consists in a multistage cryostat made by nested vessels at decreasing temperature (see Fig.1).

A cryogen free refrigerator system is utilized for the cooling of the detector; it consists of three subsystem: the Fast Cooling System (FCS), five Pulse Tube cryocoolers (PTs), and a powerful custom $^3He/^4He$ dilution refrigerator (DU). Five PTs (Cryomech PT415) cool-down the system in two stages to 40 K (40 W cooling power) and 4 K (1.2 W cooling power) respectively. The cooling power is provided by means of ^{4}He gas iso-enthalpic expansions. The advantage of using this technology is that they allow a shorter down-time with respect to conventional LHe bath, since there are no cryogens to refill. However, they induce a slight increase of noise contributions due to vibrations, which is monitored and reduced by applying the PTs active noise cancellation technique [6]. A continuous-cycle $^3He/^4He$ Dilution Refrigerator (Joule-Thomson custom DU by Leiden Cryogenics) allows to reach the base temperature, with a cooling power of 2 mW at 100 mK, 4 μW at 10 mK. The working principle of a DU is based on the phase diagram of the $^3He/^4He$ mixture a low temperatures.

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The CUORE cryostat, thanks to its cooling power, a total mass of 12 tons and an experimental volume $1\,m^3$ is the biggest and most powerful dilution cryostat in the world. A dedicated mechanical vibration isolation system is implemented to reduce the energy dissipation by vibrations. In addition to its underground location, the CUORE cryostat also satisfies strict constraints in terms of radio-purity of the materials in order to preserve the low radioactivity environment necessary to reach the experimental goals.

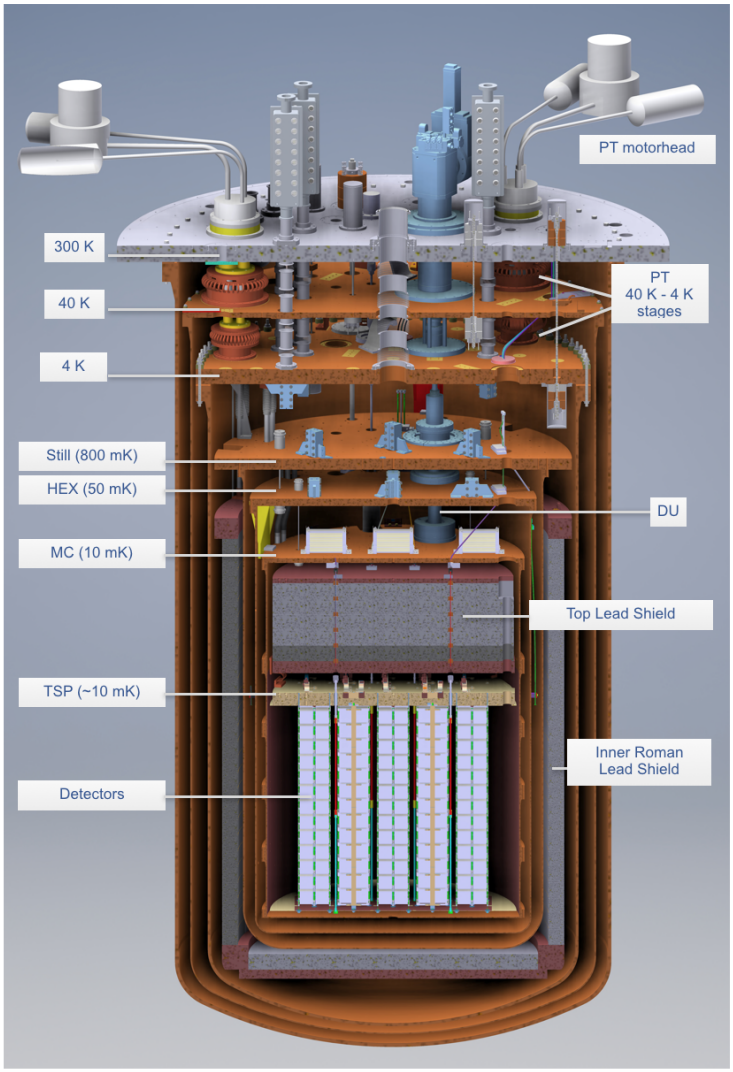

Figure 1. Rendering of the CUORE cryostat.

3. CUORE cooldown and data-taking

The cool-down of the CUORE experimental volume is subdivided in mainly two steps. The cool-down to 4K is performed by the PTs (assisted by FCS) and takes $\sim$ 20 days. Then the He exchange gas is pumped out from the vacuum tight volume hosting the detectors; this procedure takes $\sim$ 10 days. The detector volume is then cooled-down from 4K to 8 mK via the DU and it takes $\sim$ 3 days. In conclusion, given the large masses involved and consequently the thermal inertia, the total detector cool-down time from 300K to 10 mK takes almost 1 month.

The CUORE first science runs were carried out by mid-2017 at 15 mK temperature. After the initial CUORE physics data taking, dedicated runs devoted to further characterization and optimization of the detector were performed in late 2017. Multiple warm-ups (at 100 K) and maintenance of the cryogenic system had to be performed in 2018 and early 2019. The mentioned activities were necessary in order to ensure a stable and long-term operation of the cryostat and detectors. The data-taking restarted in March 2019 at 11.8 mK temperature and it is ongoing. Only short ordinary maintenance operations are performed at the closure of a dataset (collection of science runs and calibration) every two months and are followed by checks on the detectors for noise and thermal response consistency. CUORE now has reached a stable data-taking with high duty cycle (for physics data).

4. Conclusion

The CUORE cryogenic infrastructure is a complex system, which allows to operate the TeO_2 crystals at $\sim$ 10 mK. Given the optimized performance of the cryogenic system, the detector is increasing significantly its exposure and it is currently underway to collect 5 years of run time.

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