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CUORE and CUORE-0 experiments

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Summary. — Neutrino oscillation experiments proved that neutrinos have mass and this enhanced the interest in neutrinoless double-beta decay ($0\nu\beta\beta$). The observation of this very rare hypothetical decay would prove the leptonic number violation and would give us indications about neutrinos mass hierarchy and absolute mass scale. CUORE (Cryogenic Underground Observatory for Rare Events) is an array of 988 crystals of TeO_2, for a total sensitive mass of 741 kg. Its goal is the observation of $0\nu\beta\beta$ of ^{130}Te. The crystals, placed into the a dilution cryostat, are operated as bolometers at a temperature close to 10 mK. CUORE commissioning phase has been concluded recently in Gran Sasso National Laboratory, Italy, and data taking is expected to start in spring 2017. If target background rate is reached (0.01counts/day/keV/kg), the sensibility of CUORE will be, in five years of data taking, $T_{1/2} \simeq 10^{26}$years (1σ CL). In order to test the quality of materials and optimize the construction procedures, the collaboration realized CUORE-0, that took data from spring of 2013 to summer 2015. Here, after a brief description of CUORE, I report its commissioning status and CUORE-0 results.

1. – Introduction

Neutrinoless double-beta decay ($0\nu\beta\beta$) is a hypothetical decay in which a nucleus changes its atomic number by two units, emitting only two beta particles and violating leptonic number [1]. Its observation would confirm that neutrinos are Majorana particles (*i.e.*, neutrinos are their own antiparticles) and would give us important indications regarding neutrino mass scale and hierarchy.

The CUORE experiment, in Gran Sasso National Laboratory (Italy), is aimed to search $0\nu\beta\beta$ decay of ^{130}Te ($Q_{\beta\beta} = 2526$ keV) using 988 crystals of TeO_2, for a total ^{130}Te mass of 206 kg. Every crystal is a cube of $5 \times 5 \times 5\,\text{cm}^3$, of 750 g, and is equipped with a neutron transmutation doped germanium semiconductor (NTD). The crystals are arranged in 19 towers of 13 floors each, inside a dilution cryostat that brings them to a temperature close to 10 mK. In this way each crystal acts both as source and detector, since the emitted electrons cause a heat deposition that can be evaluated by means of NTDs. To reach a reasonable signal to noise ratio a lead shield is placed around the towers, outside and inside the cryostat. The expected background upper limit is 10^{-2} counts/keV/kg/year.

2. – CUORE cryostat

The CUORE cryostat (fig. 1) [2] is composed of six coaxial vessels, each one operating at a different temperature, from outside to inside they are 300, 40, 4 K and 600, 50, 10 mK. The 300 K and the 4 K vessels are vacuum tight and define two separated volumes, respectively, called Outer and Inner Vacuum Chamber (OVC and IVC). In order to minimize vibrations transmission the cryostat is suspended from above to a structure called Main Support Plate (MSP). For the same reason the detectors array is suspended, inside 10 mK vessel, by means of dumping suspensions.

The cooling procedure is carried out in three steps. The first one is performed by the so-called Fast Cooling System (FCS) that uses gaseous helium to cool down a mass

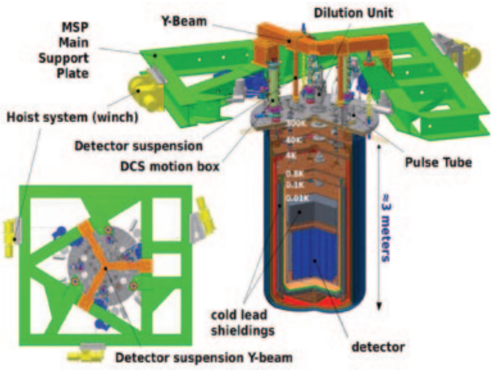

Fig. 1. – Section view of CUORE cryostats.

of about 15 tons. The Fast Cooling System will bring the apparatus to 30 K in about two weeks. When this temperature is reached, five Pulse Tubes (PT) are used to cool to 4 K. The nominal cooling power of each PT is 1.5 W at 4.2 K. Four of them are enough for cryostat operation so maintenance operations of a PT are allowed without warming up. Rotating motors of PT's are mounted on 300 K vessel upper plate and cause a significant vibration injection. For this reason the phases of the motors are remotely driven, mechanical connection with 300 K plate are made of rubber and thermal connections are made of flexible metal wires. The base temperature of 10 mK is reached via a customized Dilution Refrigerator (DR) which nominal cooling power is 5 μW at 12 mK. The DR works with ^{3}He -^{4}He mixture that flows through two condensing lines, thermalized with PT's, and reaches the mixing chamber placed on 10 mK plate.

The cryostat is also equipped with a Detector Calibration System (DCS) that allows to slide γ-sources from outside 300 K vessel to detector level.

3. – CUORE status

After some separated pre-tests of Dilution Refrigerator and Pulse Tubes, in the beginning of 2014, the cryostat was assembled in its final configuration and several test runs were performed. The aim of the first set of runs was to characterize the dilution refrigerator: the 10 mK plate reached a base temperature of 5.9 mK. We encountered an issue due to vibration injection from PTs to cold stages that caused a low-frequency modulation of base temperature. It was fixed by stiffening the connection between 300 K plate and MSP. Other issues came from the variable flow impedance of a condensing line that resulted quite unstable. Then two runs were done to check thermal conduction and thermalization of wiring. The CUORE wiring consists in 2600, 0.1 mm thick, NbTi wires which bring thermistors signals from detectors (10 mK) to Front End electronics (300 K). Because of the large temperature gradient, their thermalization required special care. To test bolometer functionality a mini-tower of 8 crystals was also prepared and mounted inside the cryostat. A final run was done to check lead shielding cooling-down. At the time of writing, the test phase has been succesfully completed and we moved toward the detector installation phase.

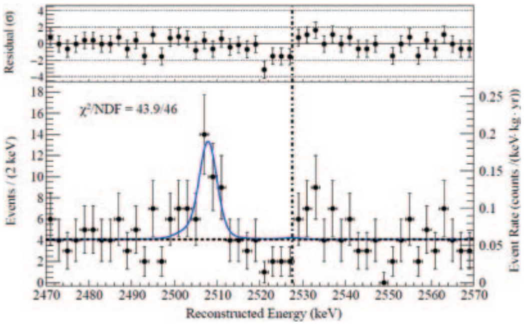

Fig. 2. – Bottom: The best-fit (solid blue line) overlaid on the spectrum of $0\nu\beta\beta$ decay candidates in CUORE-0. Top: the normalized residuals. The vertical line indicates the position of $Q_{\beta\beta}$.

4. – CUORE-0

In order to test the CUORE construction procedure and that materials satisfy the required standard, in terms of background and energy resolution, the collaboration designed and built a prototype called CUORE-0. CUORE-0 is a single CUORE-like tower placed in a 25-years-old cryostat. Its ^{130}Te total mass is 10.9 kg and it took data from beginning of 2013 to middle 2015 for a total exposure of 9.8 kg·yr. Each detector signal is amplified, filtered and analog-to-digital converted. Then a trigger algorithm selects pulse windows of about 5 seconds. Pulses need to be stabilized because thermal gain of bolometers is not constant over time. To do that each crystal is equipped with a resistor used to inject a known energy at regular intervals during data taking. Calibrations are performed by placing thoriated wires next to the cryostat. Data quality is improved rejecting periods in which detector presents instability, excluding events with pileup, and comparing each pulse with an average pulse to remove noise events. Furthermore we remove pulses in time coincidence (within 5 ms) with signals on the other crystals. The total selection efficiency is $(81.3 \pm 0.6)\%$. As fitting algorithm the unbinned extended maximum-likelihood method is used in the region 2470–2570 keV. The fit components are: the signal peak at $Q_{\beta\beta}$, the peak at 2507 keV from ^{60}Co, and the background attributed to multiscatter Compton events from ^{208}Tl and surface decays. Both peaks are modeled using a lineshape made of the sum of two Gaussians (fig. 2). We found no evidence for $0\nu\beta\beta$ decay [3] and set a 90% CL Bayesian upper limit at e $\Gamma_{0\nu} < 0.25 \cdot 10^{-24}$ yr^{-1} or $T^{0\nu}_{1/2} > 2.7 \cdot 10^{24}$ yr, including systematic uncertainties. In addition, if we combine our data with the 19.75 kg·yr exposure of ^{130}Te from Cuoricino (a previous prototype), we obtain $T^{0\nu}_{1/2} > 4.0 \cdot 10^{24}$ yr (90% CL), which is the most stringent limit to date on this quantity.

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