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New CUORICINO results on the way to CUORE

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Abstract
CUORE is a 0.75 ton experiment to search for neutrinoless double beta decay of Te^{130} using 988 TeO_2 bolometers. It aims at reaching a sensitivity on the effective neutrino mass of the order of few tens of meV. CUORICINO, a single CUORE tower running since 2003, plays an important role as a stand alone experiment and for developing the future CUORE setup. Present results already achieved and studies that are underway are here presented and discussed.

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(Some figures in this article are in colour only in the electronic version.)

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1. Introduction

The evidence of a neutrino rest mass represents one of the most exciting discoveries in the field of particle physics. The discovery of the neutrinoless double beta decay (0ν-DBD), however, will provide not only the ultimate answer about the nature (Dirac or Majorana) of the neutrino, but will also allow a sensitivity on the mass down to a few meV. The use of the bolometric technique offers the unique possibility to investigate different 0ν-DBD candidates with considerable high energy resolution, needed to separate the 2ν contribution from the 0ν peak. The CUORE experiment [1], to search 0ν-DBD of ^{130}Te, will start its assembling phase in 2007 and it aims to reach a sensitivity on Majorana mass better than 50 meV. CUORICINO represent not only the first stage of CUORE, but also the most massive 0ν-DBD experiment presently running.

2. CUORICINO setup

CUORICINO [2] is an array of 62 crystals of TeO_2 with a total active mass of 40.7 kg, that corresponds to a mass of ^{130}Te of ~11 kg. The tower is located inside the cryostat situated in Hall A of Laboratori Nazionali del Gran Sasso (LNGS) of INFN. CUORICINO's 62 crystals are arranged in a tower made by 13 planes (figure 1), 11 of them are filled with four cubes of 5 cm side while the other two with nine crystals $3 \times 3 \times 6\,\mathrm{cm}^3$ each. Four $3 \times 3 \times 6\,\mathrm{cm}^3$ crystals are enriched, two with ^{128}Te, 82.3% isotopic abundance, and the other two with ^{130}Te, isotopic abundance of 75%.

All the materials making up the detector were selected for low contamination with radioactive isotopes. To avoid external vibrations reaching the detectors the tower is mechanically decoupled from the cryostat through a steel spring. In order to shield the materials of the refrigerator from radioactive contaminants, a 1.2 cm shield of Roman lead with ^{210}Pb activity of $4\,\mathrm{mBq\,kg^{-1}}$ [3] is framed around the array to reduce the activity of the thermal shields. The cryostat is externally shielded by means of two layers of lead of 10 cm minimal thickness each. The background due to environmental neutrons is reduced by a layer of borated polyethylene of 10 cm minimum thickness. The refrigerator operates inside a Plexiglass anti-radon box flushed with clean N_2 and inside a Faraday cage to reduce electromagnetic interferences. Thermal pulses are recorded by neutron transmutation doped Ge thermistors thermally coupled to each crystal. CUORICINO is operated at a temperature of ~8 mK with a spread of ~1 mK. The energy calibration is performed before and after each subset of runs, which lasts about a month, by exposing the array to two thoriated tungsten wires inserted in the immediate vicinity of the refrigerator.

Figure 1. The CUORICINO tower inside a nitrogen-fluxed glove-box, during the final assembly of the detector.

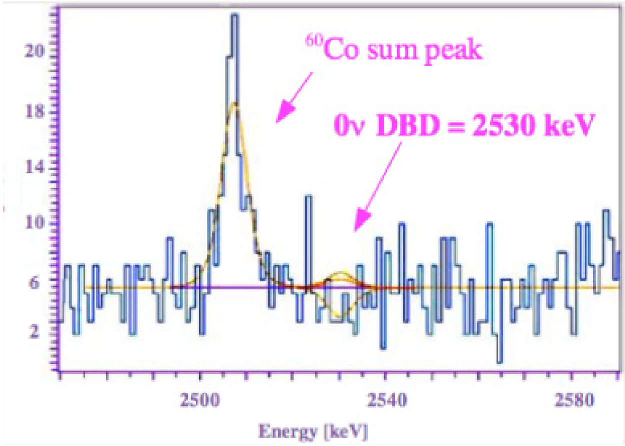

Figure 2. CUORICINO spectrum in the 0νDBD energy region.

3. Physics results

The first CUORICINO measurement started in March 2003 and ended in October 2003. After a substantial operation of maintenance in April 2004 the second run of CUORICINO started. The average pulse amplitude is $215\,\mu\mathrm{V\,MeV^{-1}}$ for the $5 \times 5 \times 5$ crystals and $430\,\mu\mathrm{V\,MeV^{-1}}$ for the $3 \times 3 \times 6\,\mathrm{cm}^3$ crystals. The average resolution FWHM is 7.5 ± 2.9 keV for the bigger size and 9.6 ± 3.5 keV for the small size crystals. The duty cycle of the experiment, since August 2004 is ~73%. Discarding the time needed for energy calibration measurement (3 days every 3–4 weeks) the total *background* live time is 63%. The total background spectra collected up to July 2005, corresponding to a total statistic of 8.38 kg (of ^{130}Te) year, is presented in figure 2. Apart from the ^{60}Co sum line and the ^{208}Tl line, no other unexpected peak is found near the 2528 keV 0νDBD region of ^{130}Te. The obtained lower limit on the 0νDBD of ^{130}Te is 2.4×10^{24}

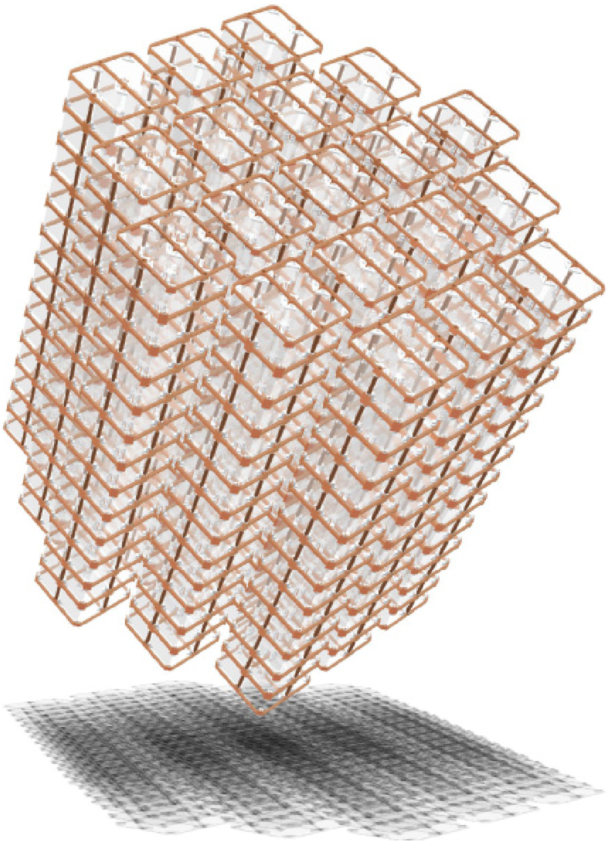

Figure 3. The CUORE detector (cylindrical-shaped) built of 19 CUORICINO-like tower.

year (90% CL). This limit leads to a constraint on the electron neutrino effective Majorana mass ranging from 0.18 to 0.97 eV, depending on the nuclear matrix elements considered in the computation.

4. The CUORE experiment

The CUORE detector will consist of an array of 988 TeO_2 bolometers arranged in a cylindrical configuration of 19 towers containing 52 crystals each (figure 3), for a total mass of $\sim$741 kg. Each of these towers is a CUORICINO-like detector consisting of 13 modules, four detectors each. Assuming a background of $B = 0.01\,\mathrm{c\,keV^{-1}\,kg^{-1}\,yr^{-1}}$, achievable with a slight improvement of the current available material selection and cleaning techniques, and an energy resolution $\Gamma(2.5\,\mathrm{MeV}) = 5\,\mathrm{keV}$, we get a sensitivity $S_{0\nu}$ on the half life (90% CL) of $5.8 \times 10^{25}\sqrt{t}$ years ($4.1 \times 10^{25}\sqrt{t}$ years for $\Gamma = 10\,\mathrm{keV}$), which in 5 years of statistics would provide $|\langle m_\nu \rangle|$ bounds in the range 0.024–0.13 eV. However, the R&D to be carried out in CUORE, if successful, would provide a value of $B \sim 0.001\,\mathrm{c\,keV^{-1}\,kg^{-1}\,yr^{-1}}$, i.e. a detection sensitivity of $S_{0\nu} \sim 1.86 \times 10^{26}\sqrt{t}$ years ($1.2 \times 10^{26}\sqrt{t}$ years for $\Gamma = 10\,\mathrm{keV}$), or $|\langle m_\nu \rangle|$ bounds in the range $\sim$0.016–0.085 eV in 5 years. TeO_2 crystals made with ^{130}Te enriched material have been already operated in MiDBD and CUORICINO, making an enriched CUORE a feasible option. Assuming a 95% enrichment in ^{130}Te and a background level of $B = 0.01\,\mathrm{c\,keV^{-1}\,kg^{-1}\,yr^{-1}}$, the sensitivity would become $S_{0\nu} \sim 8.32 \times 10^{26}\sqrt{t}$ years. For an exposure of 5 years, the corresponding $|\langle m_\nu \rangle|$ bounds would range from 8 to 45 meV depending on the nuclear matrix element calculations.

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