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First results of the CUORICINO experiment

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Preliminary results on double beta decay (DBD) of ^{130}Te, obtained in the first run of the CUORICINO experiment are presented. The set-up consists of an array of 62 crystals of TeO_2 operating as bolometers in a deep underground dilution unit at a temperature of about 10 mK. Due to a total mass of about 41 kg, CUORICINO represents by far the most massive running cryogenic mass to search for rare events. The achieved lower limit on the neutrinoless DBD is $5.5 \cdot 10^{23}$ years, that corresponds to a limit on the Majorana effective mass between 0.37 and 1.9 eV. Performances of the detectors together with the sensitivity estimation are discussed.

1. INTRODUCTION

The evidence of a neutrino rest mass represents one of the most exciting discoveries in the field of particle physics.

Measurement of this tiny mass [1], however, represents a big challenge from an experimental point of view. Oscillation experiments provide only *differences* between squared neutrino

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masses. Double beta decay is a rare radioactive transition from an even nucleus (A, Z) to its isobar $(A, Z+2)$, with the simultaneous emission of two electrons. The discovery of the neutrinoless DBD (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 few meV [2]. 0ν-DBD searches actually measure the effective neutrino mass $|m_{ee}|=\sum_k m_{\nu_k}|U_{ek}|^2 e^{i\alpha_k}$. Therefore 0$\nu$-DBD does not measure the electron neutrino mass directly, but it can set the absolute scale for the neutrino mass eigenstates ν_k, using the neutrino mixing matrix U_{ek} and some hypotheses on the Majorana CP phases $e^{i\alpha_k}$.

In the experimental approach, the detector contains, or is made of, the isotope candidate to DBD, and the signature of the decay will be the appearance of a monochromatic line in the background spectrum, corresponding to the transition energy of the decay, shared by the two electrons. Using thermal detectors, a search on a wide choice of 0ν-DBD isotopes is possible.

The study of ^{130}Te is one of the most promising approaches for new-generation DBD experiments. In fact, considering the reasonably high transition energy (2.528 MeV, in the Compton edge of the highest γ line due to natural radioactivity) and the nuclear matrix elements, ^{130}Te DBD rate is predicted to be about four/five times faster than for ^{76}Ge [3], and it is one of the fastest among the most interesting candidates. In large mass DBD experiments, the availability of the isotope nuclide is a critical point. The natural isotopic abundance of ^{130}Te is 34 %, much higher than those of the other interesting DBD candidates. Therefore, a significant ^{130}Te experiment can be performed, even without isotopic enrichment, which is often economically prohibitive in large quantities.

2. EXPERIMENTAL SET-UP

The array of CUORICINO consists in a tower with 13 planes containing 62 TeO_2 crystals operating in the Gran Sasso Underground Laboratory, in the same dilution refrigerator used in our previous experiment [4]. As shown in Fig. 1, the

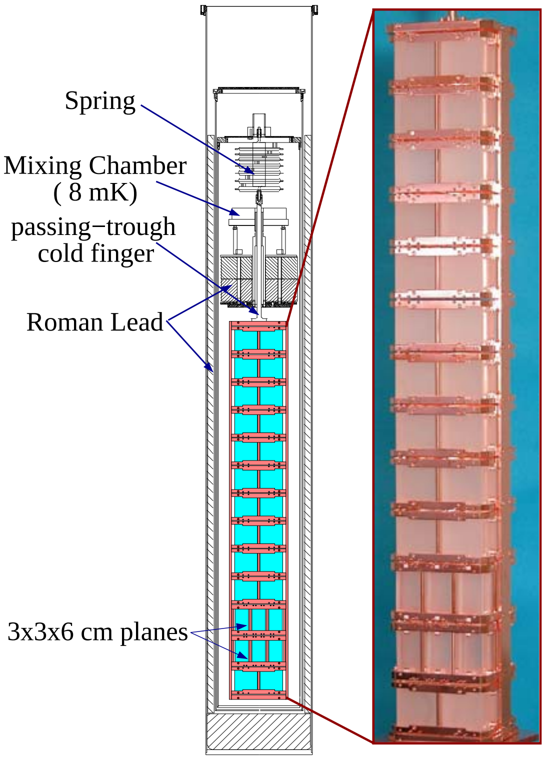

Figure 1. CUORICINO set-up.

structure is as follows: the upper ten planes and the lowest one are made of 4 crystals of 5×5×5 cm^3, while the 11th and 12th ones are made of nine 3×3×6 cm^3 crystals. In these two planes, the central crystal is fully surrounded by the nearby ones. It will be useful to investigate the effect of surface contamination of the crystals and of the copper frame using coincidence and anticoincidence analysis. Four of this small crystals are isotopically enriched (two 75% of ^{130}Te and two 82% of ^{128}Te) in order to search for the 2νDBD decay mode with the method of background subtraction. The temperature sensors are neutron transmutation doped Ge thermistors of 3×3×1 mm^3, specifically prepared in order to present similar thermal characteristics, and thermally coupled to each crystal with nine ∼0.6 mm diameter epoxy glue spots. A resistor of ∼50 kΩ, realized with a heavily doped meander on a 1 mm^3 silicon chip, is attached to each absorber and acts as a heater to stabilize the gain of bolometer [5]. The tower is mechanically decoupled from the cryostat in order to avoid vibration from the cryogenic facility, which will induce noise on the detectors [6]. The tower is, therefore, connected, through a 25 cm copper bar passing through the mixing chamber, to a steel spring fixed at the 50 mK plate (see Fig.1). The longitudinal oscillation frequency of the system is $\sim$ 1.8 Hz. The thermal link is ensured by four $40\times10\times0.05$ mm^3 copper foils connected from the MC to the tower.

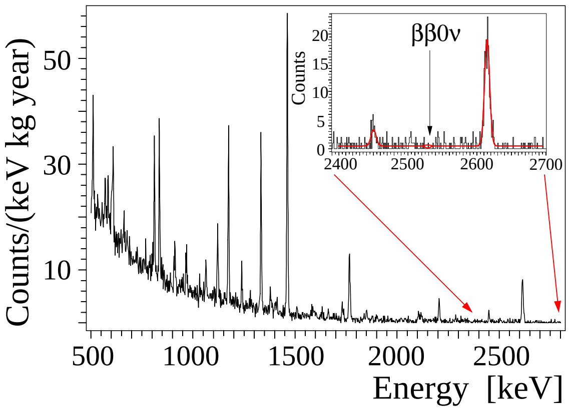

Figure 2. Background sum spectrum corresponding to a statistic of 3.1 kg×year.

3. PHYSICS RESULTS

CUORICINO was cooled down at the beginning of 2003; unfortunately during the cooling procedure some of the contacts of the read out wires inside the cryostat were lost, so that only 32 of the large crystal and 16 of the small ones could be read. The performances of the remaining detectors are quite good: the average FWHM energy resolution measured on the ^{208}Tl γ line at 2615 keV (near the expected 0ν-DBD region) is $\sim$7 keV for the large crystal and $\sim$9 keV for the small ones.

The results reported here refer to the first run, totalling effective statistics corresponding to $\sim$2.9 kg y^{-1} for the large crystals and $\sim$0.26 kg y^{-1} for the small ones. The background counting rates in the region of 0ν-DBD are, respectively, $0.20\pm.03$ and $0.20\pm.1$ c kg^{-1} y^{-1} for the large and small crystals. The *sum* of all the background spectra, reported in Fig. 2, shows the γ lines due to ^{60}Co, ^{40}K, and those due to the ^{238}U and ^{232}Th chains. Also visible are the activation lines of ^{57}Co, ^{58}Co, ^{60}Co and ^{54}Mn; as can be seen from the inset, no peaks appear in the region of interest. A maximum likelihood procedure used to establish the maximum number of 0ν-DBD events, compatible with the measured background, allows setting an upper limit of $5.5\cdot10^{23}$ years for neutrinoless DBD of ^{130}Te at 90% CL. The corresponding limit of the effective Majorana mass ranges between 0.37 and 1.9 eV, due to the uncertainties on the nuclear matrix elements. The sources of background in the region of interest are mainly due to degraded α's from the copper surfaces facing the detector (50$\pm$20 %), ^{232}Th γ's from the cryostat (30$\pm$10 %) and α's from the surfaces of crystals (20$\pm$10 %).

4. CONCLUSIONS

The first run of CUORICINO, lasting only three months, is now temporarily stopped. We replaced all the wires in order to have the full mass sensitivity. The next run is foreseen to start data taking in January 2004. With the first run, we already partially covered the corresponding span of the experiments on neutrinoless DBD of ^{76}Ge. The expected three years of sensitivity for the full mass of CUORICINO is $\sim1\cdot10^{25}$ years, corresponding to a sensitivity on the Majorana mass between 0.1 and 0.45 eV.

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