

From Cuoricino to CUORE: investigating the inverted hierarchy region of neutrino mass

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Abstract. Cuoricino is a Double Beta Decay experiment operating deep underground, in the Laboratori Nazionali del Gran Sasso (Italy) at a depth of about 3500 m.w.e. The search for the $0\nu\beta\beta$ of ^{130}Te is carried out with the bolometric technique and an upper limit of 3×10^{24} y (@ 90%C.L.) is set for this process. Cuoricino represents not only the most sensitive DBD Experiment presently operating but also a prototype for a next generation experiment, CUORE (Cryogenic Underground Observatory for Rare Events). The expected performance and sensitivity, based on Monte Carlo simulations and extrapolations of the present Cuoricino results, indicate that CUORE will be able to test the 0.02-0.05 eV region for the effective neutrino mass, having a high discovery potential in the inverted hierarchy region of the neutrino mass pattern.

1. Introduction

The search for the neutrino mass is one of the most relevant and exciting field in particle physics and cosmology, the neutrino mass scale being one of the key quantities in the new theories beyond the Standard Model.

A physical tool able to help in answering crucial questions about neutrinos is the nuclear process called neutrinoless double beta decay ($0\nu\beta\beta$) [1]. It is a rare nuclear transition that, if observed, would imply that the neutrino mass is different from zero and that neutrinos are Majorana particles.

To detect this process, the bolometric technique is very powerful. It requires very low temperatures to read appreciable thermal signals induced by the investigated decays.

Cuoricino, described in the following sections, is a $0\nu\beta\beta$ experiment looking for the decay of ^{130}Te and using the bolometric technique.

2. The Cuoricino detector

Cuoricino is an array of 62 bolometers of TeO_2 with an active mass of 40.7 kg. There are 44 bolometers with $5\times 5\times 5\text{ cm}^3$ crystals and 18 bolometers with $3\times 3\times 6\text{ cm}^3$ crystals. Of the small crystals, 2 are enriched in ^{128}Te and 2 in ^{130}Te . The array is cooled down to $\sim 8\text{ mK}$ in a dilution refrigerator, shielded from environmental radioactivity and energetic neutrons. It is running in the Laboratori Nazionali del Gran Sasso (LNGS), Italy, a location that guarantees a high degree of suppression of cosmic ray flux thanks to the $\sim 3500\text{ m.w.e.}$ depth.

To fulfill the background requirements typical of rare events physics, a particular care was dedicated to the selection and treatment of the materials used for the construction of the

Cuoricino array.

The mechanical structure of the array was made exclusively in OFHC copper and PTFE, due to their extremely low radioactive content. All the copper and PTFE parts of the mounting structure were separately treated with acids to remove surface contamination. Finally, the array was assembled in an underground clean room in a nitrogen atmosphere to avoid radon contamination, closed in a copper structure and hung in vacuum inside the Inner Vacuum Chamber of the refrigerator; it is surrounded by a ~ 1 cm thick roman lead cylindrical shield closed with bottom and top lead discs of thicknesses of 7.5 cm and 10 cm respectively. The refrigerator itself is shielded with low activity lead with 20 cm thickness and with borated PET with 10 cm thickness. Nitrogen is fluxed between the external lead shield and the cryostat to avoid any Rn contribution to the detector background; in addition the cryostat is placed inside a Faraday cage to reduce electromagnetic interferences. In order to prevent vibrations induced by the overall facility from reaching the detectors, the tower is mechanically decoupled from the cryostat through a stainless steel spring.

Thermal pulses are recorded by means of Neutron Transmutation Doped (NTD) Ge thermistors operated in the Variable Range Hopping (VRH) conduction regime. Electrical connections are made by two gold wires, ball bonded to metalized surfaces on the thermistor, which are then attached to each bolometer by 9 spots of two-component epoxy. The front-end electronics is at room temperature for most of the channels; some channels are read-out by a Si JFET in emitter-follower configuration operating in a 150 K environment placed at the 4 K plate of the dilution fridge.

3. Cuoricino results

Cuoricino is the most massive bolometric experiment taking data in the world. The present limit on the half life for the $0\nu\beta\beta$ decay of ^{130}Te is

$$T_{1/2}^{0\nu} > 3 \cdot 10^{24} \text{ y} \quad (90\%C.L.) \quad (1)$$

with an exposure of 11.83 kg.y of ^{130}Te . This translates into a limit on the effective neutrino mass of

$$m_\nu < 0.20 - 0.98 \text{ eV} \quad (2)$$

where the range for the limit is spanned by the most and the less favourable nuclear matrix elements. In the context of a number of nuclear models, these values fall within the range corresponding to the claim of evidence of decay by H.V. Klapdor-Kleingrothaus and his co-workers [2]. Cuoricino is still collecting data and the sensitivity to half life should be twice the present limit when it will be stopped in coincidence with the start-up of CUORE, its natural continuation.

Looking at the background energy spectrum in the region of interest for DBD summed over all the channels, no peak appears at the $0\nu\beta\beta$ Q value; the upper limit, obtained with a Maximum Likelihood procedure, is evaluated using anticoincidence sum spectra and considering separately the sum spectra of big, small and ^{130}Te enriched crystals and distinguishing two runs; to account for the spread in the detector energy resolutions, the response function used in the fit is the sum of N gaussian (N being the number of detectors summed in the considered spectrum) centered at the same energy but with different sigmas.

4. From Cuoricino to CUORE

CUORE is the natural extension of the Cuoricino experiment [4]. It will be also located in the Laboratori Nazionali del Gran Sasso. It is a proposed tightly packed array of 988 TeO_2 bolometers, each being a cube of 5 cm on a side with a mass of 760 g. The array will consist of

19 vertical towers, arranged in a cylindrical structure. CUORE is a funded project expected to take data during 2011.

The temperature sensors will be NTD Ge thermistors and proper resistive heaters will be used to calibrate and stabilize the gain of the bolometers over long running periods. CUORE crystals will be grouped in elementary modules of 4 elements held between two copper frames joined by copper columns. PTFE pieces are inserted between the copper and TeO_2 , as a heat impedance and to clamp the crystals. The bolometers will require an operational working point of $\sim 7\text{--}10$ mK that will imply an extremely powerful dilution refrigerator.

The background goal of CUORE is to achieve a counting rate in the range from 0.001 to 0.01 counts/keV/kg/y at the $0\nu\beta\beta$ transition energy of ^{130}Te (2530 keV). A low counting rate near threshold (that will be of the order of ~ 5 keV) is also foreseen and will allow to have results in the WIMP and solar axions research fields. Radioactive contaminations of individual construction materials, as well as the laboratory environment, were measured and the impact on detector performance determined by Monte Carlo computations.

Although background levels of the order of 0.001 counts/(keV kg y) seem to be viable thanks to an accurate selection of construction material and to the optimization of the surface treatment, a more conservative level of 0.01 counts/(keV kg y) can be also considered for CUORE sensitivity. A full Monte Carlo simulation of the CUORE background shows that all its sources are controlled at the level of 0.001 counts/(keV kg y), with the exception of *surface contamination*. The presently achieved level in the R&D tests for CUORE allows to predict a background level from 2 to 4 times higher than the conservative scenario of 0.01 counts/(keV kg y). Therefore some work is still to be done to reach even the *conservative* goal of CUORE, and this work regards solely the issue of surface contamination. The radical solution of this problem would have a dramatic impact on the physical reach of CUORE. In fact, a background level of 0.01 counts/(keV kg y) would allow just to touch the inverted hierarchy region of the neutrino mass pattern, while a factor 10 lower would allow to explore deeply this region, with an obvious increase of the CUORE discovery potential. This explains why the struggle against surface background is presently the central issue in the CUORE preparation work.

5. Conclusions

Cuoricino is the most sensitive running experiment on $0\nu\beta\beta$; while being a self consistent experiment, it is also a fundamental test for the next generation CUORE experiment for what concerns detector performances and background value in the $0\nu\beta\beta$ region. For a background value in the $0\nu\beta\beta$ region of the order of 0.001 c/keV/kg/y CUORE could reach a sensitivity for the effective neutrino mass in the range 15-50 meV in 5 years, just in the region favoured by current oscillation experiments for the inverted hierarchy.

Acknowledgments

The Cuoricino Collaboration owes many thanks to the Director and Staff of the Laboratori Nazionali del Gran Sasso. The experiment was supported by the Istituto Nazionale di Fisica Nucleare (INFN), the European Commission under Contract No. HPRN-CT-2002-00322 and Contract No. RII3-CT-2004-506222 (ILIAS Integrating Activity), by the U.S. Department of Energy under Contract No. DE-AC03-76-SF00098, and DOE W-7405-Eng-48, and by the National Science Foundation Grants Nos. PHY-0139294 and PHY-0500337.

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