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## CUORICINO status and CUORE prospects

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CUORE is a proposed experiment, already partially funded, to search for  $0\nu$ -DBD of  $^{130}\text{Te}$  using 988  $\text{TeO}_2$  bolometers. It aims at reaching a sensitivity on the effective neutrino mass of the order of few tens of meV. The crucial parameter on which this expectation is based is background. Different strategies are under development to reduce as much as possible its value, among which the comprehension of CUORICINO background, a single CUORE tower running since 2003, plays an important role. Present results already achieved and studies that are underway are here presented and discussed.

### 1. INTRODUCTION

The recent observation of neutrino oscillations in atmospheric neutrinos and in solar neutrinos

has renewed the interest on neutrinoless double beta decay ( $0\nu$ -DBD) as a fundamental, and unique, probe for the neutrino nature, that could

also fix the neutrino absolute mass scale through the measurement of the effective Majorana mass of the electron neutrino,  $|\langle m_\nu \rangle|$ . CUORICINO is the most sensitive experiment presently running to search for  $0\nu$ -DBD, while CUORE is the natural expansion of CUORICINO toward the 1-ton detector scale, that should test the quasi-degenerate and inverted neutrino mass hierarchies.

### 1.1. First Results with CUORICINO

CUORICINO is a running experiment on  $0\nu$ -DBD of  $^{130}\text{Te}$  using 62  $\text{TeO}_2$  bolometers, for a total crystal mass of 40.7 kg. It consists of a single tower of 13 planes, operating in Hall A of the Gran Sasso Underground Laboratory, in the same dilution refrigerator previously used in the MI-DBD experiment with 20 crystals [1]. The CUORICINO structure is as follows: the upper 10 planes and the lowest one consists of 4 natural crystals of  $5 \times 5 \times 5 \text{ cm}^3$  (790 g each), while the 11th and 12th planes have  $9 \times 3 \times 3 \times 6 \text{ cm}^3$  crystals (330 g each). In these planes the central crystal is fully surrounded by the nearest neighbors. All the crystals are of natural tellurium (33.8 %  $^{130}\text{Te}$ ) except for four small ones. Two of them are enriched in  $^{128}\text{Te}$  and two in  $^{130}\text{Te}$ , with isotopic abundances of 82.3% and 75%, respectively.

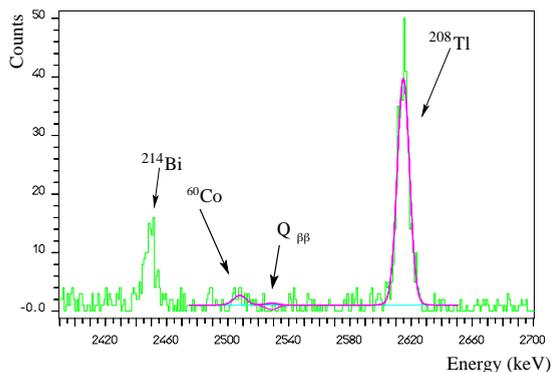


Figure 1. CUORICINO  $0\nu$ -DBD region

All crystals were grown with pre-tested low radioactivity material by the Shanghai Institute of Ceramics and shipped to Italy by sea to minimize the activation due to cosmic rays. They were lapped with specially selected low contamination abrasives to reduce the radioactive contamination on the surface. CUORICINO was first cooled in spring 2003, but some read-out wires broke inside the cryostat, reducing the total mass under study to 26.5 kg. Before warming up to cure the problem some data were collected, up to 3.75 kg-y statistics and the first preliminary results were released [2]. The experiment was stopped from autumn 2003 until spring 2004, unfortunately not only to solve the read-out problem but also because of some restrictions in the Gran Sasso Lab required by the Italian authorities for safety reasons. The second run started in March 2004, with all the crystals working, except for 2 big ones. The background level in the DBD-region is  $0.18 \pm 0.01$  counts/(keV·kg·y) and the energy resolution in the sum spectrum is 9.3 keV. The analysis of the very first weeks of data collected increased the statistics to 5.3 kg·y, giving a 90% C.L. limit on the half-life for  $0\nu$ -DBD of  $^{130}\text{Te}$  of  $1.0 \times 10^{24}$  y (see Fig. 1). This corresponds to a limit on  $|\langle m_\nu \rangle|$  between 0.28 and 2.41 eV, depending on the different evaluations of the nuclear matrix elements (NME). Using the Staudt et al. [3] evaluation, which is often used to make comparisons among different isotopes, the limit is 0.7 eV. This constraint is the most restrictive one except those obtained with Ge diodes, and is comparable to them.

### 1.2. CUORICINO prospects

After a first claim in 2001, a report of evidence of the direct observation of the  $0\nu$ -DBD of  $^{76}\text{Ge}$  with a half-life of  $1.19 \times 10^{25}$  y at  $4.2\sigma$  C.L. was published recently [4]. Since much literature pro and con on this issue appeared during the last years, an experimental confirmation or confutation of the claim is strongly demanded, and CUORICINO is at the moment the only running experiment that could do the job. In fact, a minimum  $2\sigma$  level signal should be seen in 3 y, if the half-life for  $^{76}\text{Ge}$  is the claimed one, even if the less favourable NME is considered. On the other

side, due to the NME uncertainties, a null experiment on  $^{130}\text{Te}$  will not invalidate the claimed evidence. That is why the measurement of the  $0\nu\text{-DBD}$  in different nuclei is in any case invaluable: because it could reduce the NME uncertainties. Therefore CUORE must be considered as one of the future experiments on DBD, that will help in resolving the neutrino nature puzzle.

## 2. FROM CUORICINO TO CUORE

CUORE will be a tightly packed cylindrical array of 19 towers made of 13 planes of  $4.5 \times 5 \times 5 \text{ cm}^3$  crystals each. The total mass will therefore be 741 kg, corresponding to  $\sim 200 \text{ kg}$  of  $^{130}\text{Te}$ . The experiment has been approved by the Scientific Committee of Gran Sasso Lab and the special dilution refrigerator that is intended to house the detector has been funded. CUORE should start data-taking in 2010.

### 2.1. Background analysis

The crucial parameter, on which the success (or failure) of the CUORE experiment lies, is background. The comprehension of CUORICINO background origin will therefore lead the choices in the final CUORE design and assembly. With this aim, a Monte Carlo code has been developed in order to simulate decay processes occurring in the bulk and on the surfaces of the various parts of the experimental setup, in order to disentangle the sources responsible of measured background by comparing the simulated data with the experimental ones. The agreement between data above 3 MeV and Monte Carlo simulation of surface contaminations of crystals and Cu frames is excellent (see Fig. 2), provided you take into account the presence of a tiny bulk contamination of  $^{210}\text{Po}$  and  $^{190}\text{Pt}$  in the crystals. To explain also the gamma region, sources of background far away from the detectors must be taken into account.

The informations thus extracted are used to evaluate the CUORE background in the  $0\nu\text{-DBD}$  region. For instance, with the already available materials and without any optimization in the geometrical structure of the detector and shielding, the background in the  $0\nu\text{-DBD}$  region due

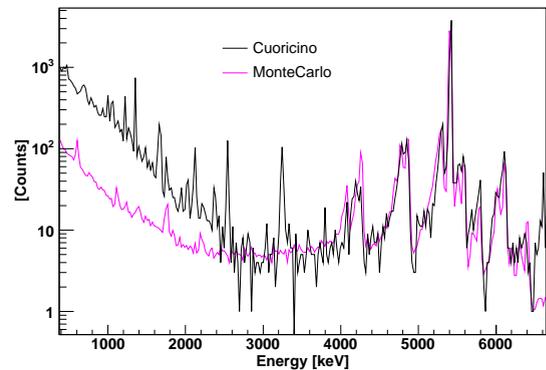


Figure 2. Comparison between CUORICINO spectrum and Monte Carlo simulation of surface contaminations on crystals and Cu.

only to the bulk contaminations is expected to be  $\leq 4 \times 10^{-3} \text{ counts}/(\text{keV}\cdot\text{kg}\cdot\text{y})$ , as evaluated from CUORICINO data. Unfortunately, preliminary analysis of CUORICINO data indicates that roughly 60% of the events in the  $0\nu\text{-DBD}$  region can be due to surface contaminations on crystals and copper detector holders. By comparing Monte Carlo simulations with measured data it has been deduced that the shapes and rates of the observed degraded alpha peaks are well reproduced assuming surface contaminations on the crystals and copper holders having a density profile decaying exponentially with characteristic length between 0.1 and  $10 \mu\text{m}$  and being from 2 to 3 orders of magnitude greater than the bulk contaminations. A direct measurement of the  $^{238}\text{U}$  and  $^{232}\text{Th}$  surface contaminations on copper, attacking samples with acid during different times and analyzing the obtained solutions with ICPMS (Inductive Coupled Plasma Mass Spectroscopy), is being attempted and the preliminary results already obtained have confirmed the Monte Carlo simulation. If this level of surface contaminations should remain also in CUORE, then a contribution equal to  $0.07 \text{ counts}/(\text{keV}\cdot\text{kg}\cdot\text{y})$  should be expected, mostly ( $\sim 80\%$ ) coming from the Cu structure surface. The minimal goal for CUORE

is therefore a reduction by a factor 20 of the surface background contribution to the  $0\nu$ -DBD region. A factor 2 can be obtained very easily, only by changing the CUORE structure design, reducing the Cu surfaces facing the crystals. Preliminary studies on crystals lapping show that a factor 5 reduction on crystal surface contamination can be obtained using new abrasives and chemical attack, while for Cu several different strategies are at the moment pursued. Anyhow, if the elimination of the surface contaminations would not be possible, an active rejection of surface events could be the solution.

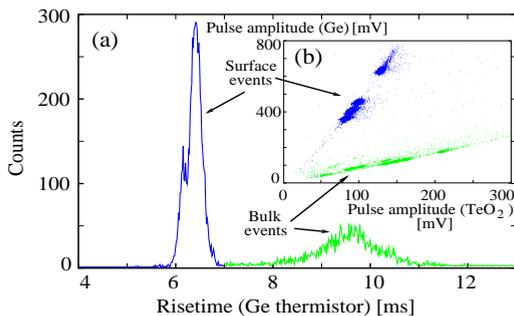


Figure 3. Surface-sensitive bolometer: different risetimes in the Ge auxiliary bolometer for different origins of the event. In the inset: scatter plot of the  $\text{TeO}_2$  vs Ge bolometer response

The basic idea consists in the realization of active shields in the form of thin, large-area, ultra-pure Ge or Si bolometers, by which the  $\text{TeO}_2$  crystal is surrounded. The Ge or Si auxiliary bolometers are attached at the main crystal, providing almost complete coverage. In this way, a composite bolometer is realized with multiple read-out, capable to distinguish the origin of the event (see Fig. 3). A degraded alpha coming from outside or from the Ge itself generates a much higher and faster thermal pulse in the shield bolometer than the corresponding pulse generated by the same energy released directly in the main  $\text{TeO}_2$  crystal. A prototype composite bolometer has al-

ready been realized with very good results and the optimization of the detector is underway [5].

## 2.2. CUORE prospects

The “straightforward” prospect for CUORE ( $b=0.01$  counts/(keV·kg·y),  $\Gamma=10$  keV) is  $2.1 \times 10^{26}$  y in 10 years, which translates into an effective neutrino mass ranging between 19 and 167 meV, due to the NME uncertainties, while the “optimistic” (but realistic) prospect ( $b=0.001$  counts/(keV·kg·y),  $\Gamma=5$  keV) is  $9.2 \times 10^{26}$  y, corresponding to  $|\langle m_\nu \rangle| = (9\text{-}79$  meV). If we consider the opportunity to have an enriched core, or a complete enriched CUORE, then the sensitivity on the  $|\langle m_\nu \rangle|$  could even reach the few meV region, therefore spanning completely the region foreseen by the inverse hierarchy neutrino mass scale and attacking the normal hierarchy one.

## 3. CONCLUSIONS

CUORICINO is now running regularly and statistics is increasing nicely. This will allow to improve the understanding of the background sources suggesting therefore the best strategies for CUORE. In parallel passive and active methods to control surface background will proceed.

## 4. ACKNOWLEDGMENTS

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