RESULTS FROM CUORICINO AND PROSPECTS FOR CUORE

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CUORE will be an observatory for rare events consisting of a tightly packed array of TeO_2 bolometers, with a total mass of ∼740 kg, operating in the underground Gran Sasso laboratory. A first step towards CUORE is CUORICINO, a running experiment with 40.7 kg of TeO_2. Present results from CUORICINO for the neutrinoless double beta decay of ^{130}Te will be presented here ($T^{0\nu}_{1/2} \geq 1.0\times10^{24}$ y, $\langle m_\nu \rangle \leq$0.26-1.4 eV at 90% C.L.). The status of CUORE preparation and its physics potential, including dark matter searches, will be shown.

1. Introduction

Experiments searching for neutrinoless Double Beta Decay (DBD) can prove the Majorana character of neutrinos and determine the scale of the neutrino mass. CUORE (Cryogenic Underground Observatory for Rare Events)[1,2] is a proposed next generation experiment with almost 1000 bolometers of TeO_2 and a total mass of ∼740 kg to operate at the Labora-

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tori Nazionali del Gran Sasso (LNGS) in Italy. It is intended to investigate mainly double beta decay but searches for other rare events like the direct detection of WIMPs are also envisaged[3]. The first step towards CUORE is CUORICINO[4], running in Gran Sasso since the beginning of 2003 with 40.7 kg of TeO_2. In this paper, status and present results for CUORICINO will be presented and preparation and physics potential for CUORE will be described.

2. CUORICINO results

The CUORICINO detector consists of a tower of TeO_2 crystals with 13 planes (see Fig. 1)[4]. Eleven of these planes are 4-crystal modules like those foreseen for CUORE. Two additional planes are made of 9-crystal modules. CUORICINO contains therefore 44 $5{\times}5{\times}5$ cm^3 crystals (average mass 790 g) and 18 $3{\times}3{\times}6$ cm^3 crystals (average mass 330 g, previously used in the MiDBD experiment[5]). The same dilution refrigerator used in MiDBD at Hall A of LNGS is being used to operate at ∼10 mK.

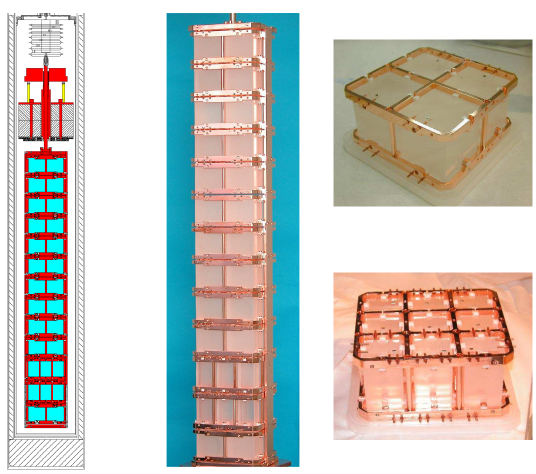

Figure 1. The CUORICINO detector: scheme of the tower and internal roman lead shields (left), the 13 planes tower (center), the 4-crystal module (top right) and the 9-crystal module (bottom right).

CUORICINO was cooled for the first time at the beginning of 2003. Unfortunately during the cooling procedure some of the signal wires disconnected so that only 32 of the large crystals and 16 of the small ones could be read. Nevertheless, in April 2003 the first background measurement started and went on up to October 2003, when data taking was stopped to solve the wiring problem. CUORICINO was cooled again in March 2004, losing only two of the electrical contacts this time. Data taking was resumed and is progressing.

Up to June 2004, the total collected statistics are of 52785 h$\times$crystal for the $5\times5\times5$ cm^3 detectors and 14115 h$\times$crystal for the $3\times3\times6$ cm^3 ones. Preliminary analysis indicates that $\sim$70% of the events in the neutrinoles DBD region can be due to surface contaminations on crystals and copper detector holders. By comparing Monte Carlo simulations with measured data in CUORICINO 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 supporters having a density profile decaying exponentially with constants between 0.1 and 10 μm and being from 2 to 3 orders of magnitude greater than the bulk contaminations[6].

The present background in the neutrinoless DBD region is 0.17 ± 0.04 c/keV/kg/y. Since no peak appears in the anticoincidence background spectrum at the DBD transition energy (2529 keV) a 90% C.L. lower limit on the ^{130}Te $\beta\beta(0\nu)$ half-life of 1.0×10^{24} years has been derived. The corresponding constraint on the effective neutrino mass ranges from 0.26 to 1.4 eV according to the various evaluations of nuclear matrix elements.

3. Prospects for CUORE

CUORE[1,2,3] will be a high granularity detector consisting of an array of 19 towers, containing each 13 CUORICINO-like modules (with 4 5x5x5 cm^3 TeO_2 crystals). The total mass will be of $\sim$740 kg. A new dilution refrigerator is being built to operate at $\sim$10 mK.

The surface contaminations on crystals and copper holders detected in CUORICINO are a serious problem for the CUORE sensitivity; different R&D works are being devoted to solve it. A direct measurement of the ^{238}U and ^{232}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. A preliminary result for a sample of the CUORICINO copper shows that the contamination quickly decreases with depth, in good agreement with our background model. If the elimination of the surface contaminations was not possible, an active rejection of surface events could be the solution. This technique has been proved using composite bolometers made covering the TeO_2 crystal with very thin Ge/Si detectors; pulse amplitudes from the Ge/Si thermistor are much higher for surface events allowing their identification[7].

The sensitivity of CUORE will strongly depend on the final background levels achieved. CUORE background predictions are based on Monte Carlo simulations and data from CUORICINO (see the CUORE Proposal[1]). Assuming for surface contaminations a reduction of a factor of 10 with respect to CUORICINO, the CUORE background could be of ∼0.007 c/keV/kg/y in the neutrinoless DBD region and of ∼0.05 c/keV/kg/d near the threshold.

The physics potential of CUORE has been studied in detail in Ref.[3]. Regarding the search for neutrinoless DBD of ^{130}Te, assuming five years of data, in a conservative (optimistic) situation with background b=0.01 (0.001) c/keV/kg/y and energy resolution Γ=10 (5) keV, the expected sensitivity is of 1.5 (6.5) $\times 10^{26}$ y for the half-life. The corresponding regions explored for the neutrino effective mass are 23-118 (11-57) meV, depending on the nuclear matrix elements considered.

Figure 2 shows the expected exclusion plots for the direct detection of WIMPs calculated assuming an energy threshold of 10 keV, an exposure of one year and two different background levels in the low energy region, 0.05 and 0.01 c/keV/kg/d[3]. As a reference, the limit obtained in the previous MiDBD experiment is also shown[8].

Since CUORE will be a very massive experiment, a search for the annual modulation in the WIMP signal might be possible provided a good stability was achieved. Following the method from Ref.[9], the sensitivity of CUORE has been evaluated in Fig. 3 assuming an energy threshold of 10 keV, an exposure of two years and background levels of 0.05 and 0.01 c/keV/kg/d. The more optimistic case of a 5 keV threshold with the lowest background has been also plotted. The regions of WIMPs above the curves would give a positive annual modulation signal at 90% C.L. with a 50% probability.

Acknowledgments

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References

1. CUORE Proposal, January 2004, http://crio.mib.infn.it/wig.
2. C. Arnaboldi *et al.*, *Nucl. Instrum. Meth.* **A518**, 775 (2004).

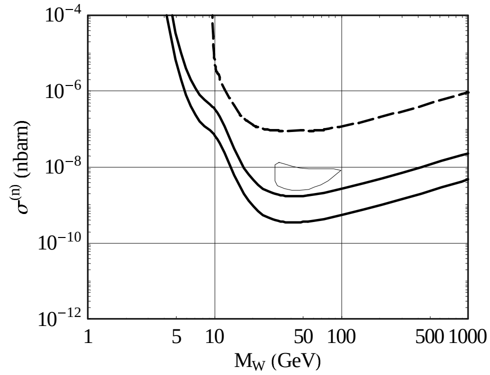

Figure 2. Expected exclusion plots for WIMP direct detection in CUORE (solid lines) and MiDBD result (dashed line). See text for details.

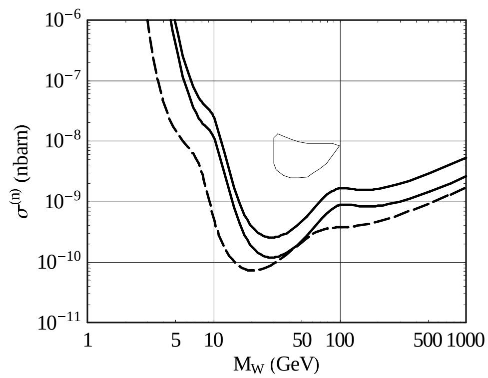

Figure 3. Sensitivity plots for the annual modulation effect in the WIMP signal for CUORE with threshold of 10 keV (thick solid lines) and 5 keV (dashed line). See text for details.

3. C. Arnaboldi *et al.*, *Astrop. Phys.* **20**, 91 (2003).
4. C. Arnaboldi *et al.*, *Phys. Lett.* **B584**, 260 (2004).
5. C. Arnaboldi *et al.*, *Phys.Lett.* **B557**, 167 (2003).
6. S. Capelli, Poster Session at Neutrino 2004, Paris, June 2004. To appear in *Nucl. Phys. B (Proc. Suppl.)*.
7. M. Pedretti, Poster Session at Neutrino 2004, Paris, June 2004. To appear in *Nucl. Phys. B (Proc. Suppl.)*.
8. A. Giuliani *et al.*, *Nucl. Phys. (Proc. Suppl.)* **B110**, 64 (2002).
9. S. Cebrián *et al.*, *Astrop. Phys.* **14**, 339 (2001).