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CUORICINO: a new large bolometer array for astroparticle physics

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Abstract

After 3 years of project study and development, a 40 kg, 62-crystal, thermal detector array CUORICINO started last February. It is supposed to test the two claimed, but still not confirmed, evidences in Dark Matter and in Double Beta Decay (DBD) reported in the last few years and it will have a first glance on Solar Axion. The technical goals that were forseen for this experiment would be the confirmation on the feasibility of the CUORE experiment, a 1 ton multipurpose experiment with bolometers, that could open a new era in DBD physics.

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1. CUORICINO detector

CUORE (Cryogenic Underground Observatory for Rare Events) is a segmented, 1000-channel, cryogenic detector for a 1 ton scale experiment [1]. The physical topics of CUORE are: search of Double Beta Decay (DBD), study of Dark Matter (DM), measurement of Solar Axion (SA). CUORE project has the realization of a smaller scale experiment named CUORICINO as the first step. This detector is designed to simulate a CUORE tower with 11 planes made with four $5 \times 5 \times 5\ cm^3$ crystals and two planes made with nine $3 \times 3 \times 6\ cm^3$ crystals of TeO_2; the total mass is around 40 kg.

TeO_2 crystals are suitable for studying the DBD of ^{130}Te. This isotope presents some peculiar characteristics: high natural isotopic abundance (33%) and high DBD transition energy (2528 keV). The presence of the two neutrinos DBD was reported by some geochemical experiments [2] and confirmed by the 20-crystal array detector (MiDBD) operated by the Milano group in the last few years [3].

Using TeO_2 crystals as absorbers CUORICINO takes advantage of the MiDBD experience. In particular, we know that such crystals can be produced very clean and with considerable mass (around 1 kg). The manipulation of the TeO_2 crystals was studied with special attention to surface lapping and cleaning to remove radioactive contaminations from crystal surfaces. Moreover, the crystal mounting design was optimized for obtaining the best detector performances. The cryogenic apparatus for CUORICINO is the dilution refrigerator installed by the Milano group in the hall A of Gran Sasso Underground Laboratory in which all the DBD and DM experiments of the group were realized since 1989. To reduce the effect of environmental radioactivity on the detector two lead shields are installed: one outside the cryostat and another placed inside, this one is made with ancient roman lead. Around the external shield a Plexiglas box filled with nitrogen is placed to minimize the radon contribution, and outside this box a layer of boron-doped polyethylene is mounted to reduce the neutron background contribution. The entire apparatus is enclosed in a Faraday cage to minimize local electromagnetic interference; the walls of the cage were covered with a phonon-adsorbing material to reduce the microphonic noise.

The CUORICINO tower is built with high-purity copper and crystals are held in the correct position by Teflon spacers screwed on the copper tower. Thermal signals are read out using Nuclear Transmutation-Doped (NTD) thermistors glued on TeO_2 crystals with epoxy glue. Silicon chip resistances are also glued on crystals to supply calibrated energy pulses that can be used to stabilize the detector during the long running time measurement [4]. Signals produced at the thermistor contact are amplified using a differential voltage-sensitive pre-amplifier operated at room temperature [5]. The amplified signals are digitalized with a 16-bit ADC

At the beginning of 2003 CUORICINO was cooled down and it became the biggest cryogenic thermal detector ever realized.

2. CUORICINO performances and background

During the cool-down we had lost same channels due to problems with the sapphire pads used for thermalizing the connecting wires. At the end of the cooling procedure CUORICINO showed 32 channels of $5 \times 5 \times 5\ cm^3$ crystals and 12 channels of $3 \times 3 \times 6\ cm^3$ crystals, the total active mass is around 30 kg. The performances of the working channels are quite good: at 2615 keV energy γ line of ^{208}Tl mean FWHM energy resolutions of 8 keV for "big" crystals and 11 keV for "small" ones were obtained. The lower energy resolution of smaller crystals is probably due to no proper optimized mounting structure for these configurations. At low energy the resolution is better but with large dispersion due to low-frequency noise.

Under present conditions the thresholds are not so low and normally, during analysis, we use a mean value around 100 keV to optimize the optimum filter procedure. So we cannot carry out at the moment, a DM or SA search. For the near future we are working towards optimizing

Table 1
Background of CUORICINO at various energy intervals

		1.0–2.0 MeV (c/keV/kg/yr)	2.0–3.0 MeV (c/keV/kg/yr)	3.0–4.0 MeV (c/keV/kg/yr)	4.0–5.0 MeV (c/keV/kg/yr)
MiDBD II	T	3.96 ± 0.12	0.753 ± 0.005	0.408 ± 0.004	2.15 ± 0.008
$3 \times 3 \times 6$ cm^3	S	3.07 ± 0.10	0.533 ± 0.004	0.243 ± 0.003	1.84 ± 0.008
CUORICINO	T	4.09 ± 0.06	0.47 ± 0.02	0.25 ± 0.02	—
$5 \times 5 \times 5$ cm^3	S	3.39 ± 0.05	0.38 ± 0.02	0.23 ± 0.02	0.55 ± 0.02
CUORICINO	T	4.36 ± 0.15	0.36 ± 0.05	0.34 ± 0.04	1.40 ± 0.09
$3 \times 3 \times 6$ cm^3	S	3.16 ± 0.13	0.29 ± 0.04	0.28 ± 0.04	1.17 ± 0.08

this part of the experiment in order to reach the values obtained in MiDBD runs with thresholds around 10 keV.

An important item for CUORICINO is the evaluation of the radioactive background. In Table 1 the background integrals of different energy regions are reported in comparison with the second run of MiDBD experiment (T indicates the total spectrum and S the spectrum obtained with crystals in anticoincidence). It is clear that we have a strong reduction in the α energy region, probably due to a better contamination removal from the crystal surfaces, and in the γ energy region CUORICINO shows a background comparable with MiDBD II. If we look at the neutrinoless DBD energy region we obtain a value of $0.26 \pm 0.06c$/keV/kg/yr that is compatible with our prediction of $0.22c$/keV/kg/yr reported at the Gran Sasso Scientific Committee in 2001. This data are obviously preliminary but probably overestimate the real background of CUORICINO. In fact, the anticoincidence rejection analysis does not work very well now due to a high energy threshold and broken channels present inside the CUORICINO tower. We cannot obviously evaluate the final reduction obtainable but we are planning all the technical improvements that can optimize the background rejection. Using this data we calculate a new lower limit on half-lifetime of neutrinoless DBD of ^{130}Te equal to 2.34×10^{23} years at 90% c.l.

3. Conclusions

CUORICINO is working since February but we have still obtained some important goals on the road towards the CUORE experiment. The CUORICINO tower works pretty well and it shows a good energy resolution. The background at neutrino-less DBD energy for ^{130}Te is compatible with our prevision and probably, when the working condition of the detector will be optimized, the background can be better. We again need to do a lot of work but these preliminary results are very encouraging and push us in the direction to present, as soon as possible, the official proposal for the realization of the CUORE experiment.

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