

Particle discrimination in TeO₂ bolometers

N. CASALI⁽¹⁾⁽⁸⁾, J. W. BEEMAN⁽²⁾, F. BELLINI⁽³⁾⁽⁴⁾, L. CARDANI⁽³⁾⁽⁴⁾,
I. DAFINEI⁽⁴⁾, S. DI DOMIZIO⁽⁵⁾⁽⁶⁾, F. FERRONI⁽³⁾⁽⁴⁾, F. ORIO⁽⁴⁾, G. PESSINA⁽⁷⁾,
G. PIPERNO⁽³⁾⁽⁴⁾, S. PIRRO⁽⁷⁾⁽⁸⁾, C. TOMEI⁽⁴⁾ and M. VIGNATI⁽⁴⁾

⁽¹⁾ *Università dell'Aquila - L'Aquila, Italy*

⁽²⁾ *Lawrence Berkeley National Laboratory - Berkeley, CA 94720, USA*

⁽³⁾ *Dipartimento di Fisica, Sapienza Università di Roma - Roma I-00185, Italy*

⁽⁴⁾ *INFN, Sezione di Roma - Roma I-00185, Italy*

⁽⁵⁾ *Dipartimento di Fisica, Università di Genova - Genova I-16146, Italy*

⁽⁶⁾ *INFN, Sezione di Genova - Genova I-16146, Italy*

⁽⁷⁾ *INFN, Sezione di Milano-Bicocca - Milano I-20126, Italy*

⁽⁸⁾ *INFN, Laboratori Nazionali del Gran Sasso - Assergi, L'Aquila I-67010, Italy*

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Summary. — TeO₂ crystals are used as bolometric detectors in experiments searching for the neutrinoless double beta decay. The extreme rarity of the studied signal requires an ultra low background level. The natural radioactivity of the materials represents for these experiments the main background source, in particular the component due to α particles. In this work, we present a possibility for particle discrimination in TeO₂ bolometers using the Čerenkov radiation. The results show that we are able to measure the light produced by β/γ particles, which can be explained as due to Čerenkov emission. No light is detected from α particles, allowing the rejection of this background source.

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PACS 07.57.Kp – Bolometers; infrared, submillimeter wave, microwave, and radiowave receivers and detectors.

PACS 23.40.-s – β decay; double β decay; electron and muon capture.

PACS 29.40.Ka – Čerenkov detectors.

1. – Research for neutrinoless double beta decay with TeO₂ bolometers

The experiments that want to understand if the neutrino is a Majorana particle search for a nuclear reaction known as neutrinoless double beta decay ($0\nu\beta\beta$) [1]. In the $0\nu\beta\beta$ a nucleus decays into another nucleus emitting two electrons and no anti-neutrinos, thus violating the total lepton number. The decay is mediated by the exchange between two β vertexes of a neutrino, which controls the decay rate through its mass ($m_{\beta\beta}$). The

signature of this process is a monochromatic line at the Q -value of the decay in the sum energy spectrum of the two electrons.

The sensitivity of an experiment to the $0\nu\beta\beta$ half-life goes as

$$(1) \quad S \propto a \epsilon \sqrt{\frac{Mt}{B\Delta E}},$$

where a is the isotopic abundance, ϵ the efficiency of the signal, M the detector mass, t the observation time, B the background level and ΔE the energy resolution.

It is clear from eq. (1) that the experimental investigation of this process requires a large amount of $0\nu\beta\beta$ emitter and ultra-low background detectors. The bolometric technique can satisfy these requirements, as has been demonstrated by the CUORICINO [2] detector in such a convincing way that a 1-ton scale experiment, CUORE [3], is now under construction. A bolometer is a low-temperature-operated calorimeter able to fully thermalize the energy released by a particle, providing excellent energy resolution and low-energy thresholds.

The CUORE experiment will use 988 TeO_2 bolometers of 750 g each to study the $0\nu\beta\beta$ decay of ^{130}Te (34.2% isotopic abundance) featuring an energy resolution ΔE of 5 keV FWHM at the Q -value of the decay (2527.518 ± 0.013 keV [4]).

Although TeO_2 crystals are extremely good bolometers, they are unable to operate any discrimination between α particles and β/γ ones [5]; unfortunately, the radioactive contaminants, located on the surfaces of the detector or on passive elements facing them, produce α particles that can lose part of their energy in a few microns and deposit the rest in a bolometer. This leads to an essentially flat background that affects also the Region of Interest (ROI) around the $0\nu\beta\beta$ Q -value [6].

The advantages offered by this material in terms of bolometric performances and natural isotopic abundance are a strong motivation to pursue an extremely challenging option: the read-out of the Čerenkov light emitted in β/γ interactions (and not in α ones) to perform a particles discrimination, as has been pointed out in ref. [7].

2. – Search for Čerenkov light from TeO_2 bolometer

We operated as bolometer a $3.0 \times 2.4 \times 2.8$ cm³ TeO_2 crystal, whose weight was 116.65 g. The crystal was doped with natural samarium, which contains 15% of ^{147}Sm , a long living isotope ($T_{1/2} = 1.07 \times 10^{11}$ y) that undergoes α decay with a Q -value of 2310 ± 1 keV. This decay allows a direct analysis of the behavior of α 's in an energy region close to the $0\nu\beta\beta$ [8]. We faced to the TeO_2 crystal a high sensitivity dark bolometer acting as a light detector (LD) [9]. This consisted of a 66 mm diameter 1 mm thick pure Ge crystal, covered with a 600 Å layer of SiO_2 to ensure good light absorption. A reflecting foil (3M VM2002) was placed around the TeO_2 crystal to enhance the light collection. The detector was operated deep underground in the Gran Sasso National Laboratories (Italy), in the CUORE R&D cryostat. The details of the experimental setup and of the data analysis technique can be found in [10, 11].

The detector was exposed to a ^{232}Th source placed outside the cryostat, to provide statistics to the β/γ sample, and to perform the energy calibration of the TeO_2 bolometer.

We used the calibration data to estimate the light emitted from γ interactions, and the background data to estimate the light from α interactions. The distributions of the light measured with the LD (E_L) for the two peaks close to the $0\nu\beta\beta$ energy, the γ -ray at 2615 keV and the α decay at 2310 keV are shown in fig. 1 left. The distribution of E_L

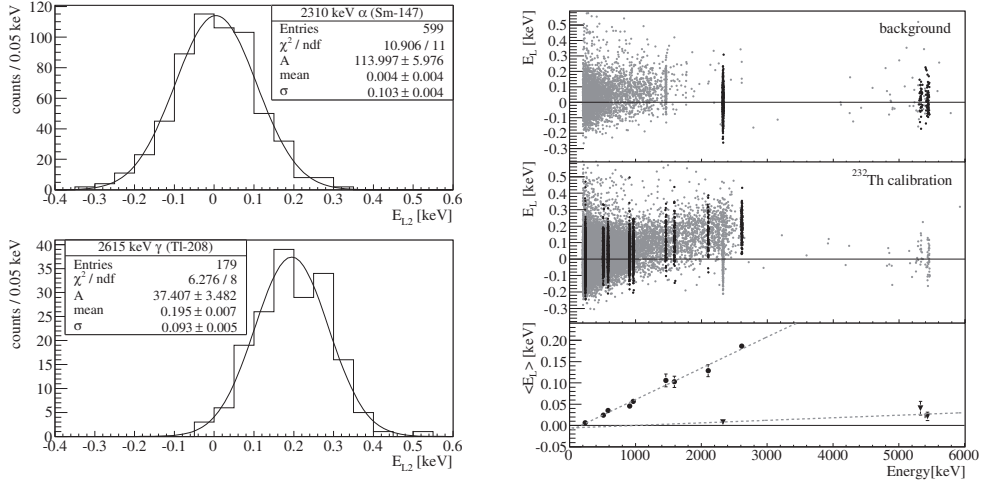


Fig. 1. – Left: Distribution of the light emitted from 2310 keV α decay (top) and 2615 keV γ -ray interactions (bottom), fitted with a Gaussian function. Right: Distribution of the emitted light E_L versus particle energy. In the top (background data) and middle (calibration data) figures all the peaks are marked in black. In the bottom figure the average light for each peak is shown, using background data for the α peaks (triangles) and calibration data for the γ peaks (circles); γ and α points are fitted with two different lines.

versus particle energy is shown in fig. 1 right. We estimated the average light of each peak, $\langle E_L \rangle$ and we performed separate linear fits for α 's and β/γ 's to the distribution of $\langle E_L \rangle$ versus energy (bottom of the figure).

The light measured for α particles is close to zero, which is expected if the light we detected from γ interactions is due to Čerenkov radiation; for β particles with energy close to the $0\nu\beta\beta$ Q -value we estimate an average light energy $\langle E_L^{0\nu} \rangle = 173$ eV.

3. – Conclusions

In this work we showed that a background suppression can be obtained detecting the Čerenkov light. By applying a threshold T on the detected light ($E_L > T$), we can decrease the α background and increase the sensitivity of the experiment. The sensitivity increase is proportional to the separation between signal and α particles, defined as the distance of $\langle E_L^{0\nu} \rangle$ from zero energy in units of the energy resolution σ . The separation obtained in this work is $\sim 2\sigma$, while one needs at least 5. A further improvement can be obtained by reducing the noise, which seems to be dominated by the read-out of the bolometer (thermistor, cables or electronics) or by increasing the efficiency of light collection which, in this work, was estimated to be only $\sim 20\%$.

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