Methods to identify and eliminate surface background events in bolometric detectors for very rare event searches

Claudia Nones

1 Dipartimento di Fisica G. Occhialini, P.zza della Scienza 3, 20126 Milano, Italy
2 Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, CSNSM-IN2P3/CNRS, Bat.108, 91405 Orsay, France
E-mail: claudia.nones@mib.infn.it

Abstract. The present limitation for experiments looking for rare events, such as neutrinoless double beta decay ($0\nu\beta\beta$) and direct WIMPs detection, is the radioactive background and in particular its discrimination. When the search is based on the bolometric technique, near-surface events constitute a serious problem, due to full volume sensitivity of the detector; in fact for a $0\nu\beta\beta$ experiment they may cause signals close to the $Q$-value while for a dark matter (DM) experiment, which exploits ionization signal for particle identification, they originates an incomplete charge collection simulating a nuclear recoil. We will described two recently developed techniques for the active suppression of the surface background.

1. Introduction
Background due to near-surface events is the main limitation for very sensitive searches on key topics in astroparticle physics based on the bolometric technique, such as EDELWEISS [1] (WIMP search) and CUORE [2] ($0\nu\beta\beta$ search). In a $0\nu\beta\beta$ experiment, these events cause counts in the energy spectrum close to the $Q$-value (2.5 MeV in the case of the candidate $^{130}\text{Te}$ discussed here), where the signal is expected, whereas in a Dark Matter experiment, which exploits also the ionization signal for particle identification, they originate an incomplete charge collection simulating nuclear recoils at low energies (< 100 keV) and mimicking therefore the Dark Matter signature. The main source of this surface background consists of radioactive contaminations in materials facing the detectors, such as $^{210}\text{Pb}$, $^{226}\text{Ra}$ or directly the natural radioactive chain progenitors $^{232}\text{Th}$ and $^{238}\text{U}$. It is therefore clear that detectors able to identify energy depositions close to the surface are powerful tools to eliminate or at least control this critical background component. These devices can be thought as a safe completion of extremely sophisticated procedures of surface cleaning.

2. How to fight against the surface background problem
There are at least three different approaches to fight against the surface background problem:

- increase the quality of the surface treatment both of crystals and of all the other materials facing them that can be translate into better cleaning procedures;

3 on behalf of the CUORE Single Module Detector group and on behalf of the EDELWEISS-CSNSM group.
• review the design geometry of the detector mounting structure, in order to minimize the copper surface and to gain efficiency from anticoincidence between closer detectors;

• realize bolometers able to discriminate the origin of the events providing information on the particle impact point exploiting different properties of solid state physics.

In this work we focus on the third approach illustrating two techniques studied and developed for the active suppression of the surface background.

The first approach [3], pursued in the framework of the EDELWEISS collaboration, concerns the identification of surface events in Ge bolometers (for Dark Matter search) or TeO$_2$ bolometers (for $0\nu\beta\beta$ search of $^{130}$Te) equipped with NbSi thin film thermometers acting as out-of-equilibrium phonons sensors. A particle interaction in the absorber produces athermal phonons diffusing away from the impact zone. In the case of a near-surface event, a significant amount of these out-of-equilibrium phonons are absorbed by the NbSi film and induce a signal with an athermal component much larger than for a bulk event of the same energy. Pulse shape analysis enables an effective rejection procedure. Ge bolometers were operated both aboveground and in the Modane underground laboratory, while the first TeO$_2$ prototype was tested aboveground at CSNSM-Orsay.

The second approach [4], for the moment applied only to TeO$_2$ bolometers in the framework of the CUORE collaboration, consists in the realization of surface-sensitive composite bolometers (SSB); auxiliary bolometers of different materials (Si, Ge and TeO$_2$ itself) were successfully coupled to TeO$_2$ absorbers, first in small scale prototype devices operated aboveground in the Insubria University and then in real CUORE size detectors operated in the Gran Sasso underground laboratory. The origin of the events can be clearly determined by comparing the amplitude of the pulses from the different detector elements. If an $\alpha$ particle comes from outside the bolometer, it interacts with an active layer releasing there all its energy ("surface" event). As a consequence, the temperature will rise and there will be a signal on both the layer thermistor and the TeO$_2$ one. Because of the small heat capacity of the layer, its thermistor signal will be much higher and faster than that of the TeO$_2$ thermistor. On the other hand, an event inside the TeO$_2$ crystal ("bulk" event) will lead to pulses with similar amplitudes and shapes on both thermistors.

3. Experimental results

We report here the main results obtained with two different detectors:

(i) NbSi/TeO$_2$-1 [5]: the sample is a 12 g TeO$_2$ crystal (20x20x5 mm$^3$) characterized by an under layer of amorphous Ge (500 Å) deposited on the two opposite faces of the crystal to improve its roughness. Then two interdigitized combs of electrodes (400 Å of Nb protected by 40 Å of Ir) are deposited, being 1 mm the distance between two adjacent teeth. Finally a square of 14x14 mm$^2$, 650 Å thick, 8.65 Nb atomic percentage of NbSi is deposited by coevaporation technique. The NbSi films are stabilized by a 60°C annealing and protected with 250 Å SiO coating. This detector has been tested aboveground at the C.S.N.S.M. Laboratory in Orsay, France.

(ii) SSB$_1$: it is made of a TeO$_2$ absorber with rectangular shape (2×2×0.5 cm$^3$) thermally coupled by means of four epoxy spots to a Ge single crystal with a 1.5×1.5 cm surface and 500 µm thickness. Neutron transmutation doped (NTD) Ge thermistors were glued at the main absorbers and at the auxiliary Ge bolometers with six epoxy spots. This detector has been tested aboveground at the Cryogenic Laboratory of the Insubria University in Como, Italy.

Fig.1 (a) shows the plot of all the events read in coincidence by the two thermometers of detector NbSi/TeO$_2$-1; in particular we plot the amplitude of athermal component for pulses
Figure 1. Main results on surface event discrimination obtained with detectors NbSi/TeO$_2$-1 and SSB-1. More details in the text.

...read by film_A vs. the amplitude of the athermal component for pulses read by film_B. We clearly recognize two different populations of events: a population for which the amplitude of the athermal components of the two thermometers are the same and a population for which the amplitude of the athermal component of film_A is higher than that of film_B. The events “out of the diagonal” are surface events; we clearly identify the $\alpha$ events of the source (used again to test the technique) at high energy but also the 60 keV (zoom), considering that 60 keV $\gamma$ are absorbed in $\sim 300 \mu$m in a TeO$_2$ crystal and hence are absorbed at the surface of the film_A.

Fig.1 (b) shows the scatter plot of the pulse amplitudes acquired in coincidence from the main absorber (X-axis) and from the active layer (Y-axis) for detector SSB-1. The two classes of events are well separated: the surface events populate a band with a steeper slope with respect to the bulk event band. In particular the four main $\alpha$ lines of the source used to test the technique are clearly appreciable, as also pointed out in the inset where the energy spectrum obtained by selecting surface events is shown.

In both cases, a high rejection efficiency (close to 100% for $\alpha$ particles) has been achieved and demonstrated. It is possible that both techniques can be shared and effectively used as rejection or at least diagnostic methods by the EDELWEISS and CUORE collaborations.

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