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The LUCIFER/CUPID-0 demonstrator: searching for the neutrinoless double-beta decay with $Zn^{82}Se$ scintillating bolometers

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Abstract. Future experiments on neutrinoless double beta-decay with the aim of exploring the inverted hierarchy region have to employ detectors with excellent energy resolution and zero background in the energy region of interest. Cryogenic scintillating bolometers turn out to be a suitable candidate since they offer particle discrimination: the dual channel detection of the heat and the scintillation light signal allows for particle identification. In particular such detectors permit for a suppression of α-induced backgrounds, a key-issue for next-generation tonne-scale bolometric experiments.
We report on the progress and current status of the LUCIFER/CUPID-0 demonstrator, the first array of scintillating bolometers based on enriched $Zn^{82}Se$ crystals which is expected to start data taking in 2016 and the potential of this detection technique for a future tonne-scale bolometric experiment after CUORE.

1. Introduction

The Neutrinoless Double Beta Decay (0νDBD) [1] is an extremely rare and hypothetical process where the parent nucleus decays by the simultaneous emission of two beta-particles only. A positive detection requires according to common theories the neutrino to be of Majorana nature [2] and thus the presence of physics beyond the Standard Model of particle physics. For future bolometric experiments on 0νDBD, with the goal to entirely explore the inverted hierarchy region of the neutrino mass [3], three requirements are of pivotal importance: first a reduction of present background in the energy region of interest (ROI) in direction of a zero-background framework, second an increase in active isotope mass by applying enriched crystals only and third excellent energy resolution in the ROI. These challenges are planned to be met within CUPID (CUORE Upgrade with Particle Identification) [4, 5], a project which at the moment is following different lines of research and development in order to identify the most promising approach for a tonne-scale future bolometric experiment, planned to be hosted in the CUORE [6] infrastructure.

2. CUPID-0

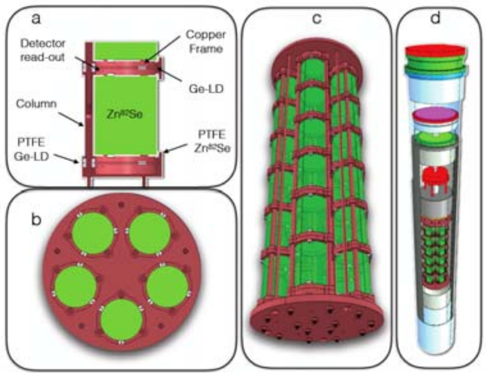

Figure 1. The CUPID-0 experimental layout. (a) Lateral view of a $Zn^{82}Se$ crystal enclosed by two light detectors. Both crystal and light detector are fixed in a copper structure using PTFE elements. Top (b) and 3D (c) image of the CUPID-0 detector arrray housing in total 5 towers. (d) 3D image of the CUPID-0 array as mounted in the dilution refrigerator.

Figure 2. Photograph of a single $Zn^{82}Se$ crystal surrounded by reflective foil and its Ge light detector (top) as assembled for the first test run. See text for details.

LUCIFER/CUPID-0, the first demonstrator within the frame of CUPID, will run an array of 24 enriched $Zn^{82}Se$ and two natural ZnSe crystals (equivalent of 5.3 kg of ^{82}Se, Q-value is 2997.0±0.3 keV [7]) arranged in five towers and hosted in the Hall A cryostat (former CUORICINO [8] and CUORE-0 [9]) at the underground site Laboratori Nazionali del Gran Sasso in central Italy. The 96.3% enriched and radiopure ^{82}Se powder [10] was produced at URENCO Stable Isotop Group. The $Zn^{82}Se$ synthesis and crystal growth was performed at the Institute for Scintillation Materials in Kharkov, Ukraine. Each crystal (∼44 mm in diameter and between (21-55) mm in height) is faced to a cryogenic light detector (Ge-LD) [11] consisting of a thin germanium wafer (44 mm in diameter, 170 μm in thickness) which is coated with a layer of SiO_2 (70 nm) for better light absorption. In order to read the thermal signals both the crystal and the Ge-LD are equipped with Neutron Transmutation Doped (NTD) Ge thermistors using a semi-automatic gluing system. In order to correct offline for thermal drifts a Si Joule heater is in addition attached to each crystal. A detailed overview of the detectors as mounted in their setup using NOSV tough pitch copper structures is shown in Figure 1.

3. First $Zn^{82}Se$ measurement

A first test of *three* of the 24 enriched $Zn^{82}Se$ crystals, mounted as a single tower in the Hall C underground R&D facility of the Laboratori Nazionali del Gran Sasso was carried out in order to assess the detector performance parameters [12].

In Figure 2 a single module consisting of a Ge-LD equipped with NTD and heater is shown on top of

a $Zn^{82}Se$ crystal which is surrounded by reflective foil. In order to study particle discrimination and energy resolution, the detectors were exposed to the following radioactive sources: an external ^{232}Th-source, temporarily irradiating the $Zn^{82}Se$ crystals to allow for energy calibration; a smeared Sm α-source (0.2-2.3 MeV), permanently placed in vicinity of each crystal, in order to evaluate the particle discrimination power between β/γ-events and α-events in the ROI; a ^{55}Fe source (5.9 keV and 6.4 keV X-rays) irradiating the Ge-LD for their direct energy calibration.
Particle discrimination in scintillating $Zn^{82}Se$ crystals can be achieved via two different parameters: first, the ratio of light to heat signal (referred to as light yield) and second, via the pulse shape of the light signal which exhibits a strong dependence on the particle type [13]. The inset of Figure 3 demonstrates the time development of light pulses produced by a β/γ (red) and an α (blue) interaction at an energy of 2.6 MeV. In Figure 3 we show the shape parameter of a Ge-LD plotted versus the energy deposited in the $Zn^{82}Se$-1 [12]. The two distributions resulting from β/γ-interactions (red band) and α- interactions (blue band) in the crystal are well separated. The green dashed line indicates the Q-value of ^{82}Se. The high potential of α-background rejection in the ROI for 0νDBD of this detection approach is clearly visible.

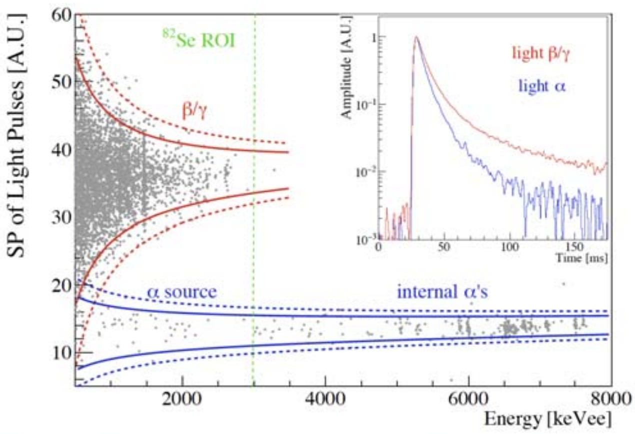

Figure 3. Shape parameter of the light pulses vs. energy deposited in the $Zn^{82}Se$-1. The boundaries indicate the 2σ (continuos) and 3σ (dotted) regions where β/γ (red) and α-events (blue) are expected. The αs from the smeared Sm-source (< 2.5 MeV) and from internal bulk contaminations ($>$ 5 MeV) can be well discriminated from β/γ-events. Inset: time development of a light pulse produced by a β/γ-and α-event.

4. CONCLUSION

The successful operation of the first three enriched $Zn^{82}Se$ crystals did prove that detector performance is excellent in energy resolution (30 keV FWHM at the Q-value of ^{82}Se) and particle identification. With a total of 24 enriched $Zn^{82}Se$ crystals (equivalent of 5.3 kg of ^{82}Se) and an expected background level of $<1.5\text{x}10^{-3}$counts/(keV kg y) in the region of interest CUPID-0 will reach a sensitivity which is comparable to existing experiments. The detector mounting and commissioning of the CUPID-0 demonstrator is planned to be completed this autumn and first data are expected still within 2016.

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