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M3.1 - **SCINTILLATOR READOUT TEST-BENCH.**

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References and applicable documents

[1]

List of acronyms and abbreviations

CsI(Tl)	A transparent scintillator material, economical, doped with Tl with emission at 550 nm, which is better suited for LAPD and SiPM
APD	Avalanche Photo Diode
LAPD	Large Area Avalanche Photo Diode
SiPM	Silicon photo multipliers
lapping	After growing and cutting the crystal to its shape, it has significant stress in the surface of the material. This stress is removed by the process of lapping. This is a process in which the machined part is rubbed against another surface with an abrasive between them. For small items this process can be done by hand.
ALO	Absolute Light Output
LONU	Light Output Non-Uniformity

Executive Summary

In this JRA, we exploit novel scintillator materials and explore new techniques and concepts such as phoswich detectors and segmented or hybrid scintillators. We focus on developing the capability to simultaneously detect high-energy gamma rays, neutrons and charged particles. The emphasis is on a modular approach both in the scintillator crystals and photosensors as well as in the electronics where improved throughput and effective data processing will allow for compact scalable devices.

Introduction

The construction of scintillator detectors for nuclear physics applications needs a careful survey of the production process, including a quality assurance of the different elements. In order to guarantee that the final detector complies with the specifications, the acceptance tests corresponding to certain components are of highest importance. The scintillator readout test-bench for crystal quality, energy resolution and non-uniformity response for large CsI(Tl) crystals and performance properties of their avalanche photo diodes (APDs) is described in this document.

Section 1 Description of the selected CsI(Tl) crystals.

The average activator (Tl) concentration will be 0.08 mol %. This concentration was used in some of the supplied test detectors and minimises the effect of non-uniformity in the Tl-doping, allowing for an optimum light output [1,2].

The heterogeneity in activator distribution along the single crystal in the primary boule needs to be better than 2.4% and the azimuth heterogeneity less than 1%. This will ensure that light yield variations between different parts of the crystal are acceptable.

All surfaces will be polished to mirror reflectivity using ZrO_2 powder with 1µm grain size combined with ethylene glycol ($C_2H_6O_2$) as the solvent. As a first quality-criteria, the variation in absolute light output, defined relative to a reference crystal of size 25x25x25 mm^3, needs to differ less than 15% between crystals.

Samples showing a smooth exponential decrease in light output (LO) are most suitable in the direction of the photo sensor. The maximum non-uniformity, defined as $\Delta LO = (LO_{max} - LO_{min})/LO_{average}$ needs to be better than 7% (from the growth process).

These starting values will allow for a final light output non-uniformity less than 3% after lapping. A sorting of the samples based on the final quality of the different crystals provided will be requested of the manufacturer.

The lapping procedure is foreseen to be provided by the crystal suppliers. However, the quality of the polishing/lapping will be measured by ourselves before acceptance of crystals being delivered by the manufacturer. For all the received crystals, the light output along the crystal-length at 3 points (close to entrance, middle and close to APD) starting from the front face using standard gamma-ray sources of ^{22}Na, ^{137}Cs or ^{60}Co are measured. These tests will be completed following the wrapping and coupling to the APD, and will also perform as a quality test of the complete detection unit. An example of the crystals being tested is shown in the figure 1 below.

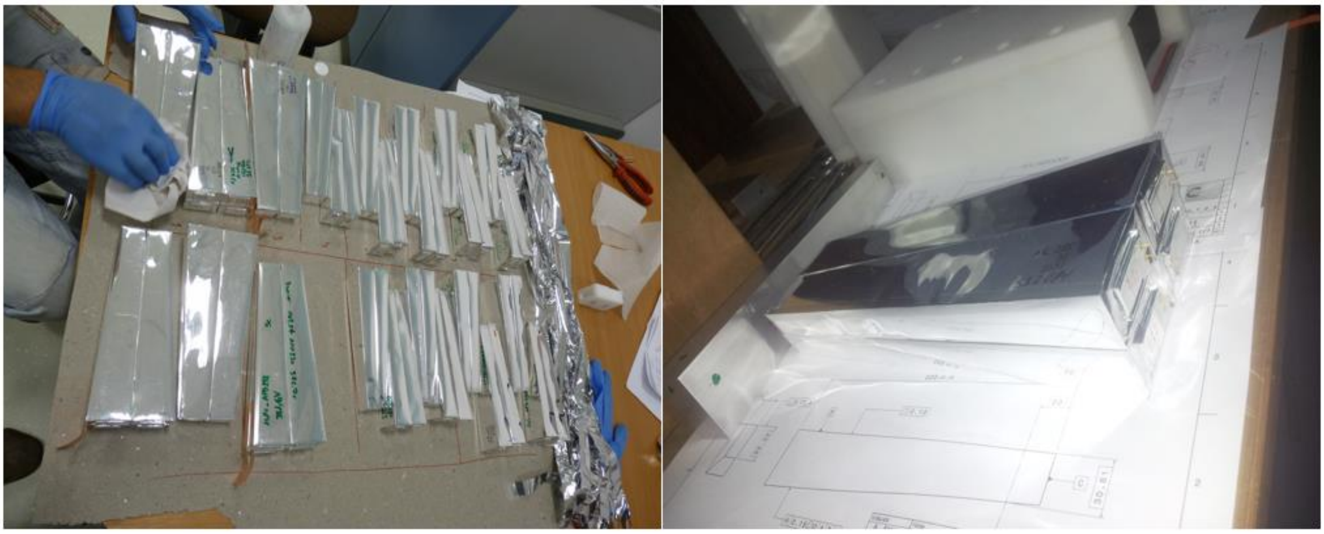

Figure 1: Samples of the CsI(Tl) crystals being tested in this work.

Double Hamamatsu S8664-1010 2ch APDs have been investigated and selected, matching nicely to the optical emission of the CsI(Tl) crystals. They were found to have a specified gain of M = 50 at T = 23° C. The dark currents (I_d) for the APDs given at their respective nominal voltage, V_{nom}, ranged from 10 to 50 nA, with an average dark current of 30 nA when no special requirement was asked of the producers. When a low I_d selection requirement was made, a dark current of approximately 18 nA with a very small spread was achieved. This low value of the dark current translates to a rather small dispersion. This selection is important as a spread in current corresponds directly to the spread in APD electronic noise and so affects the energy resolution. We have fixed $I_d < 20$ nA (±10 nA) as the limit accepted for the APDs. Additionally, differences lower than 5 V between the V_{nom} of a pair of APDs mounted on the same frame is requested. The Breakdown bias has been fixed to values lower than 390 V (to minimise the effect of noise in the low energy region).

Parameters such as the quantum efficiency (QE) and gain uniformity throughout the active surface will be checked by members of our collaboration, but only for a few control samples per delivery from the manufacturer. The integral response of each APD will be calibrated as described below.

The gain of APDs is highly dependent on the applied reverse bias and the temperature. The latter will be actively compensated for by the amplifier electronics, which measures the temperature and compensate properly in the gain. Prior to this, every APD must be characterised, hence the change of the gain as a function of temperature and bias has to be measured and the optimal correction parameter has to be deduced. Additionally, the bias for the nominal gain (M=50) at the nominal temperature (T=18º C), the noise level, and the slopes (that is ΔM/ ΔV and ΔM/ΔT) at different gain, bias, and temperature values will be stored in a database for later comparison.

SECTION 2 DESCRIPTION OF THE TEST BENCH TEST.

At the *Instituto de Estructura de la Materia* (IEM) in Madrid, a test bench was constructed to characterise the performance properties of APDs. Strict temperature controlled conditions were achieved by use of a set of Peltier units, with air flow control and complete light-tight conditions. An array of light emitting diodes (LEDs) were directed upon a grid of 4x4 APDs, where properties such as gain curves, linearity, energy resolution and dark current could be precisely determined under controlled conditions. A schematic of the test bench is shown in Figure 2.

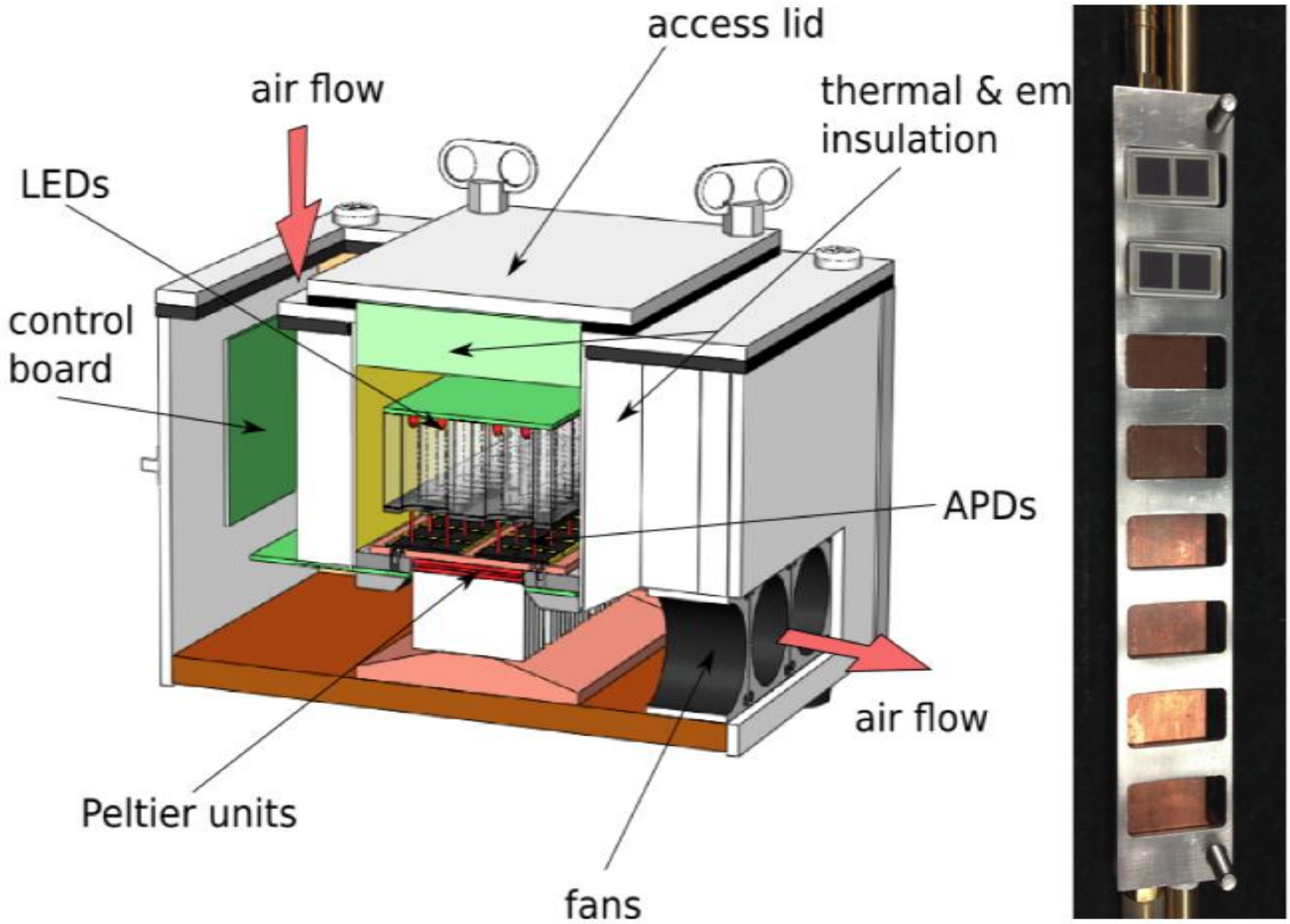

Figure 2. Left: The IEM APD test bench, highlighting the different components required to characterise the resident APDs. Right: A row of APDs on the copper heat controlled backing.

At the *Grupo Experimental de Núcleos y Partículas* at the University of Santiago (GENP - USC) the crystal properties were measured in a light-tight box using an MPRB-32 preamplifier with the temperature-gain correction. This test bench can be seen in Figure 3.

Figure 3.
Left: A photo showing the inside of the GENP-USC test bench with a CsI(Tl) crystal mounted to be tested. The crystal light output non-uniformity is measured by the use of a collimated ^{207}Bi source that is moved over the length of the crystal by the help of a step motor.
Right: A photo of the electronics to perform fully automated measurements using the Arduino micro-controller and a Gecko micro-step drive.

The energy resolution and absolute light output (ALO) were measured to determine if the crystals achieved the quality control limits agreed with the manufacturer, but also most importantly the light output non-uniformity (hereafter LONU) was measured by use of a step motor and a collimated ^{207}Bi source. A set procedure was carried out for all 128 crystals plus spares that comprise the two CALIFA-Demonstrator petals [3], with an excellent LONU & LO found for in the majority of cases, within the agreed requirements. Shown in Figure 4 are two 220 mm crystal measurements, one excellent, the other with a sub-average LONU. The sub-average case is still acceptable, the 570 & 1064 keV peaks providing a self-confirmation of the LONU measurement at each point. The measurement was taken in 2 cm steps, with a live-time of five minutes at each point. While not in motion, the step motor voltage was cut using a SSR controlled by the Arduino card, as even when stationary the motor was found to induce significant noise on the APD signal.

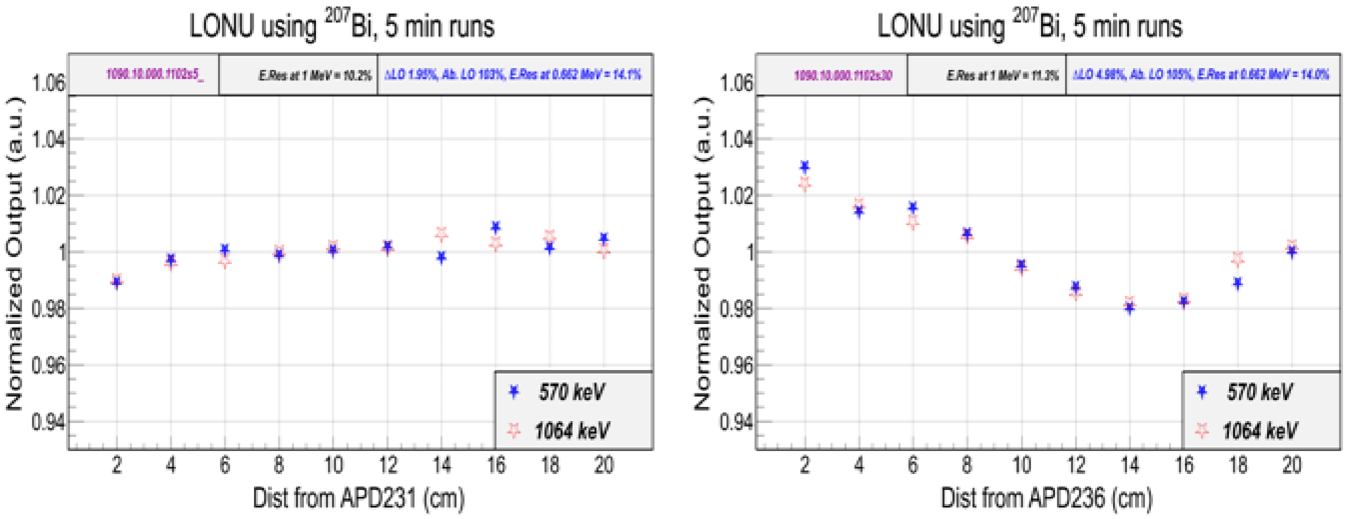

Figure 4. Left: The LONU of an excellent crystal measured with the GENP-USC test bench.
Right: A crystal yielding a sub-average LONU, the two peaks of ^{207}Bi providing a self-confirmation of each measurement.

CONCLUSION

Two test benches for characterizing big scintillator crystals have been developed at IEM-CSIC and GENP-USC respectively. Acceptance measurements have been performed. These test benches will be further used in the continuation of the PASPAG project.

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