




Quality control of LYSO:Ce crystals for the CMS barrel MIP timing detector

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ABSTRACT

In the next years, the Large Hadron Collider will enter its High-Luminosity (HL-LHC) phase. Many CMS subsystems will be upgraded to maintain the current physics performance, despite the higher levels of pileup and radiation. To further mitigate the pileup, a MIP Timing Detector (MTD) for charged particles will be constructed, with a target time resolution of 30 - 60 ps, to distinguish the primary vertices of tracks using timing information. The detector will be positioned between the tracker and the electromagnetic calorimeter. The MTD is divided into two regions, the Barrel and the Endcap Timing Layers (BTL/ETL). The active elements of BTL are arrays of lutetium-yttrium-orthosilicate (LYSO) scintillating bars doped with cerium (LYSO:Ce), each readout by two silicon photo-multipliers (SiPM) arrays. The quality of BTL LYSO crystals in the production phase is controlled in a dedicated laboratory in INFN-Rome1. This is done, both for a sample of arrays and single crystals, by monitoring dimensional properties, light output, time resolution, optical cross-talk and decay time, by means of a Na-22 radioactive source.

1. Barrel timing layer aim and layout

To cope with the increased level of collisions per bunch crossing, from about 60 to 140–200, in the High Luminosity phase of LHC (HL-LHC), the CMS experiment will install a new MIP Timing Detector (MTD) for charged particles, with a target time resolution of 30–60 ps, allowing to distinguish primary vertices by clustering tracks in the time dimension.

MTD will be placed between the tracker and the electromagnetic calorimeter and will be divided into two regions, the Barrel/Endcap Timing Layers (BTL/ETL). BTL technology is based on arrays of lutetium-yttrium-orthosilicate (LYSO) scintillating bars doped with cerium (LYSO:Ce), readout by silicon photo-multipliers (SiPM) arrays at both ends and wrapped with ESR.

For precision timing at HL-LHC, LYSO is an optimal candidate, because of its radiation hardness, high light yield (40k photons/MeV), high density, fast rise time (<100 ps) and decay time around 40 ns.

2. BTL LYSO quality control

The quality of BTL LYSO crystals in the production phase is controlled in a dedicated laboratory in INFN-Rome1. This is done, both for a sample of arrays and single crystals, by monitoring dimensional properties, light output ($>4 \gamma / \text{keV}$), time resolution (<140 ps), optical cross-talk (<25%) and decay time (<45 ns) in response to 511 keV photons [1–3].

About one third of the total production was delivered and checked so far, starting from February 2024. The total production is split in 9 batches of 1220 arrays each (1 batch delivered every 5 weeks).

2.1. Crystal optical properties

Each ingot used for LYSO array production is evaluated in terms of absolute light yield and decay time. Two bars are extracted from the top, middle and bottom part of each ingot, and are measured with a multianode PMT (Hamamatsu H8711-100), readout with a DRS4 based digitizer, allowing the simultaneous test of 4 bars, as shown in Fig. 1.



Fig. 1. Picture of the multianode PMT, kept in a 3D printed holder, with four LYSO crystals and the Na-22 source.

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The energy spectrum from γ rays coming from a Na-22 radioactive source is recorded in each bar. The light yield is extracted from the pulse charges at the 511 keV annihilation peak, upon calibrating the single photo-electron charge using low-light LED pulses. On the other hand, the decay time is measured from the digitized waveforms with an exponential fit.

For each test session, four crystals are measured as a reference, allowing to evaluate the setup reproducibility to be 5.5% in light yield and 0.22 ns in decay time. Moreover, for the crystals checked so far, a 1.2 ns uniformity in decay time was assessed, as shown in Fig. 2.

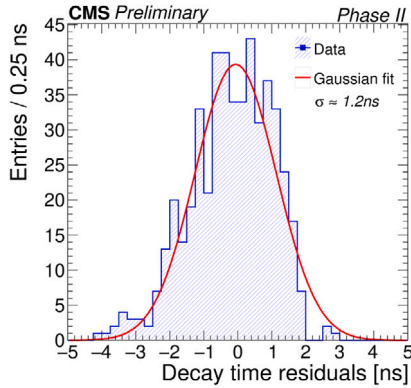


Fig. 2. Normalized decay time residuals for production crystals, respectively.

2.2. Arrays mechanical and optical properties

In order to ensure mechanical compatibility in the BTL assembly, arrays undergo dimensional measurements. The position of each crystal face is measured with a Coordinate Measuring Machine with a precision of 4 μ m, to measure non-planarity (deviations from flatness in the plane formed by the ends of the bars), which is well below the expected thickness of the glue layer coupling LYSO crystals and SiPMs (about 100 μ m) in order to fulfill BTL requirements, as shown in Fig. 3.

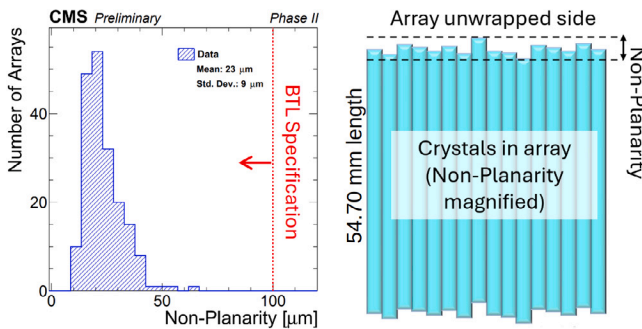


Fig. 3. Non-planarity distribution and measurement scheme, respectively.

On the other hand, LYSO arrays optical performances are monitored with a setup based on TOPPET2 ASIC, reading out both integrated charge and timestamps of LYSO pulses with a Na-22 radioactive source, in order to monitor light output, time resolution, and optical cross-talk. Each LYSO array is coupled to two 16 channels SiPM arrays without any optical couplant, as shown in Fig. 4.

The setup has multiple slots to allow the simultaneous measurement of up to 4 arrays, and is kept inside a cold box at a fixed temperature of 5 $^{\circ}$ C, which allowed to measure a 3.5% light output uniformity on crystals samples monitored so far.

Time resolution is measured using the time difference between signals at the two crystals readout ends. The events are selected requiring

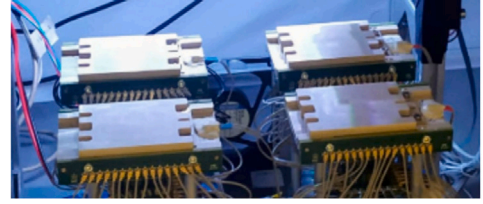


Fig. 4. Picture of the array test bench.

an energy deposition consistent with a 511 keV photon in the device under test and in a single reference bar oriented orthogonally to the array, to also constrain the hit position along the bars, as shown in Fig. 5.

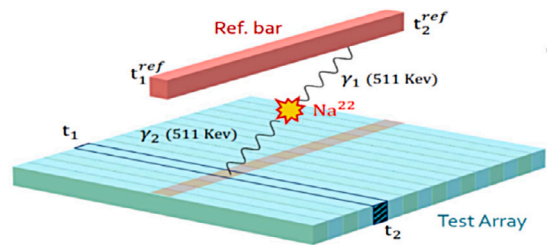


Fig. 5. Scheme explaining the measurement of time resolution.

Light output has been measured before (PreIrr) and after (PostIrr) arrays irradiation with 50 kGy from a Co-60 γ source, showing an 8% decrease with a 2% spread and satisfying BTL specifications (<20%), as shown in Fig. 6.

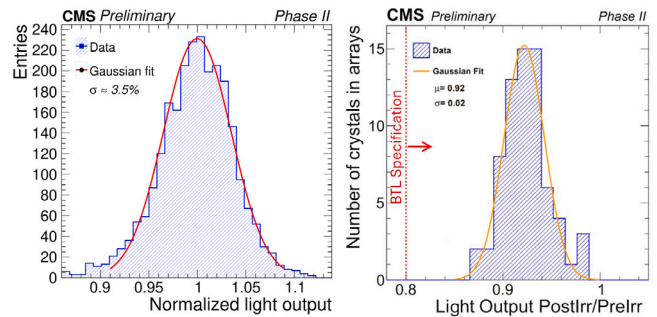


Fig. 6. Light output normalized residuals (left) and PostIrr/PreIrr ratio (right).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] F. Addesa, et al., Comparative characterization study of LYSO:Ce crystals for timing applications, J. Instrum. 17 (2022) P08028, <http://dx.doi.org/10.1088/1748-0221/17/08/P08028>.
- [2] M. Campana, Characterization of the lutetium-yttrium orthosilicate scintillating crystals for the CMS experiment, Nuovo Cim. C 43 (4-5) (2020) 110, <http://dx.doi.org/10.1393/ncc/i2020-20110-8>.
- [3] CMS collaboration, Barrel Timing Layer crystals quality control plots. CMS DP-2024/036.