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Test beam performance of sensor modules for the CMS Barrel Timing Layer

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The minimum ionizing particles (MIPs) timing detector (MTD) will be installed during the Phase II Upgrade of the Compact Muon Solenoid (CMS) experiment at the CERN LHC. The MTD will provide time information for tracks with a time resolution of about 30-60 ps to handle the increased number of concurrent interactions and maintain the CMS detector's reconstruction performance. The barrel part of the detector (BTL) is instrumented with sensor modules made of 16 bars of cerium-doped lutetium-yttrium oxyorthosilicate (LYSO:Ce) scintillating crystals coupled at each end to silicon photomultipliers (SiPMs). The SiPMs will be exposed to an unprecedented radiation level by the end of the High-Luminosity LHC operations, up to a neutron fluence of 2×10^{14} 1 MeV n_{eq}/cm^2. The latest results of test beam campaigns conducted at CERN and FNAL during 2023 will be presented, demonstrating that the performances of non irradiated and irradiated final sensor modules are within the BTL design requirements.

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1. The barrel timing layer for the CMS Phase II Upgrade

The MIP timing detector (MTD) will be installed in the Compact Muon Solenoid (CMS) detector for High-Luminosity LHC at CERN [2]. The MTD will provide track time information with a time resolution of 30-40 ps at the beginning of operation (BoO), degrading to 60 ps at the end of operation (EoO) due to radiation damage. The time information provided by MTD is essential to maintain the actual CMS reconstruction performance even in an environment with a much higher (about 200) number of concurrent interactions per bunch crossing compared to the current about 60. The barrel part of the detector (BTL) is constituted by sensor modules made of 16 cerium-doped lutetium-yttrium oxyorthosilicate (LYSO:Ce) scintillating crystal bars ($3.75 \times 3.12 \times 54.7$ mm^3), each of them coupled at its ends to silicon photomultipliers (SiPMs) from Hamamatsu Photonics (HPK) and read out by the dedicated TOFHIR2 ASIC [3].

The time resolution is driven by three main contributions: the photo-statistics contribution, due to the spread in the time of arrival of photons to SiPMs, which scales with the number of photo-electrons (N_{pe}) approximately as $\sigma_{phot} \propto 1/\sqrt{N_{pe}}$; the electronics noise term, depending on the slope of the signal at the timing threshold (dI/dt) as $\sigma_{ele} \propto 1/(dI/dt) \propto 1/(gain \times N_{pe})$; the dark count rate (DCR) noise contribution, arising from radiation damage and going as $\sigma_{DCR} \propto \sqrt{DCR}/N_{pe}$.

This paper describes the optimization of the SiPM cell-size and crystal thickness to achieve the target time resolution. Results are obtained from a set of test beam campaigns carried out at CERN and Fermilab test beam facilities.

2. Results from test beam campaigns

Figure 1 reports the time resolution as a function of the over-voltage (V_{OV}) for 3.00 mm thick crystals (type 2) coupled to 15, 20, 25, and 30 μm cell-sized HPK SiPMs non irradiated (left) and irradiated to 2×10^{14} n_{eq}/cm^2 (right). SiPMs with larger cell-size have a better performance due to their higher photon detection efficiency (PDE) and gain, resulting in a suppression of the σ_{phot} and σ_{ele}; a reduction of $\sigma_{DCR} \propto \sqrt{DCR}/N_{pe}$ is observed thanks to the higher PDE, despite the DCR increase due to the SiPMs' larger effective area. In addition, the 20-30 μm SiPMs feature an improved PDE compared to 15 μm SiPMs thanks to a different wafer technology used by the manufacturer. After irradiation, the signal amplitude (gain×PDE) for 15 μm SiPMs (20-30 μm) is reduced by 30% (20%).

Figure 2 reports the comparison of time resolution for 3.75 mm (type 1) and 2.40 mm (type 3) thick crystals coupled to 25 μm HPK SiPMs. The modules with thicker crystals show an improved time resolution before and after irradiation. Thicker crystals are coupled with SiPMs with dimensions matching the crystal end face. Despite the larger DCR due to the larger active area, they benefit from larger energy deposits as well as a larger light collection efficiency [5], which increase the N_{pe}, thus leading to better performance.

We reported the results of recent test beam campaigns to characterize the BTL sensors. The sensors with 3.00 mm thick crystals coupled to 25 μm HPK SiPMs reach a time resolution of 25 ps at BoO and 60 ps at EoO, after about 3000 fb^{-1} of integrated luminosity. Thicker LYSO crystals are beneficial for non irradiated and irradiated sensors, providing an additional performance margin. Thus, 3.75 mm thick crystals and 25 μm HPK SiPMs have been chosen as the final BTL design.

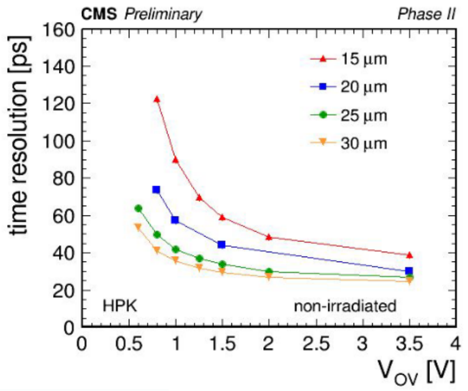

Figure 1: Time resolution as a function of the over-voltage for non irradiated (left) and irradiated module (right) with 3 mm thick crystals (type 2) coupled to HPK SiPMs of different cell-sizes [1].

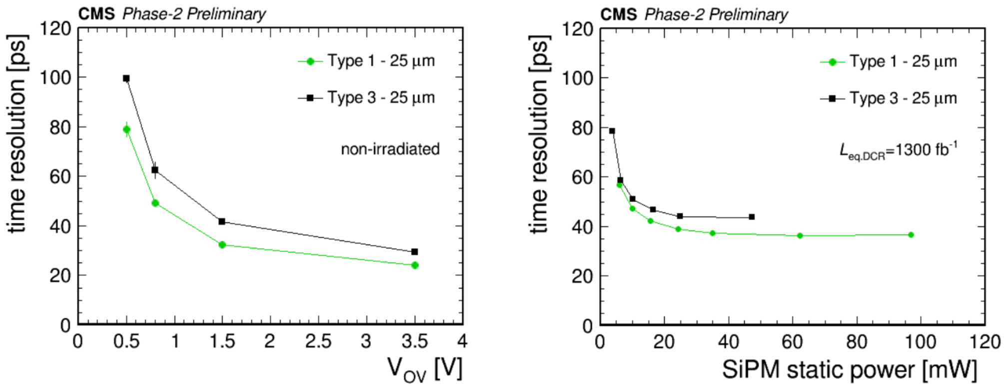

Figure 2: Time resolution for non irradiated (left) and irradiated 25 μm HPK SiPMs coupled to 3.75 mm (type 1) and 2.40 mm (type 3) thick crystals [4].

References

[1] CMS Collaboration, *Barrel Timing Layer Performance Plots*, CERN-CMS-DP-2024-049, CERN, Geneva (2024).

[2] CMS Collaboration, *A MIP Timing Detector for the CMS Phase-2 Upgrade*, CERN-LHCC-2019-003, CERN, Geneva (2019).

[3] E. Albuquerque et al., *TOFHIR2: the readout ASIC of the CMS barrel MIP Timing Detector*, *JINST* **19** P05048

[4] CMS Collaboration, *Barrel Timing Layer Performance Plots*, CERN-CMS-DP-2023-093, CERN, Geneva (2023).

[5] S. Palluotto for the CMS Collaboration, *Characterization of sensor modules for the CMS Barrel Timing Layer at HL-LHC*, Il Nuovo Cimento 46 (C) (Jul 2023).