The High Granularity Calorimeter Upgrade to the Compact Muon Solenoid Detector

Snowmass 2021 Letter of Interest

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The Phase 2 upgrades of the Compact Muon Solenoid (CMS) detector will enable the detector to function in the environment of the High Luminosity Large Hadron Collider (HL-LHC). Slated to begin operations in 2027, the HL-LHC will have an instantaneous luminosity of $5 - 7.5 \times 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, a projected total integrated luminosity of $3 - 4.5\,\mathrm{ab}^{-1}$, and $140 - 200$ pileup interactions per bunch crossing. These benchmarks significantly exceed those of the LHC, for which the current CMS detector was designed. The Phase 2 upgrade program largely encompasses improvements to the data acquisition (DAQ) system to increase the Level-1 trigger accept rate from 100 to 750 kHz and replacements of aging front end materials with new ones expected to withstand the HL-LHC total ionizing dose and 1-MeV-equivalent neutron fluence in the CMS interaction region [1].

Central to the Phase 2 upgrades is the replacement of the current endcap ($1.5 \leq |\eta| \leq 3.0$) calorimeter, consisting of a total absorption scintillating crystal electromagnetic section followed by a brass and plastic scintillator sampling hadronic section, with the High Granularity Calorimeter (HGCAL) [2], a 6M channel particle flow (PF) sampling calorimeter. The HGCAL is a 50-layer sampling calorimeter with 28 layers constituting a front electromagnetic section (CE-E) of 25 electromagnetic radiation lengths (X_0) and 1.5 hadronic interaction lengths (λ_I) thickness and 22 layers composing a rear hadronic section (CE-H) of 7.8 λ_I thickness. Copper, tungsten, and lead are used as absorber materials in the CE-E, while stainless steel is used in the CE-H. Detector planes equipped with either silicon sensors or scintillator tiles with silicon photomultiplier (SiPM) readout are used. The silicon sensors will account for ~55% of the total active area, which is 1100 m^2. The silicon is divided into ~6 million channels with an area of either ~0.5 or ~1 cm^2. The CE-H design foresees ~400,000 scintillator+SiPM channels. The longitudinal cross section of one half of one endcap of the HGCAL design is shown in Figure 1.

The final phases of sensor prototyping will conclude by the end of 2021, with major construction to begin in late 2021 and early 2022. Drawing on years of research and development (R&D) pioneered by the linear e^+e^- collider community, the HGCAL will be the largest PF calorimeter ever built, and the first to operate at a hadron collider. Throughout the next decade, the lessons of the HGCAL project–how to construct high quality, highly segmented calorimeters on a budget; and the utility of PF design at high luminosity hadron colliders especially in pileup rejection and radiation tolerance–will be instrumental in efforts to adapt the PF technology to ambitious new experiments. The HGCAL Collaboration supports continued investment in PF calorimetry, both in direct support of HL-LHC construction and operations and at the R&D level, and continued communications between the e^+e^- and hadron collider calorimetry communities.

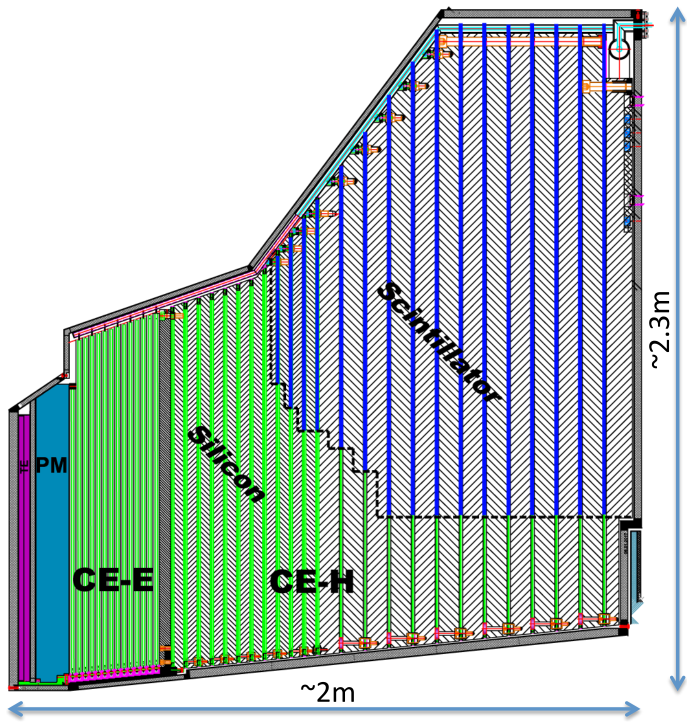

Figure 1: Longitudinal cross section of one half of one endcap of the proposed HGCAL design. Reprinted from Ref. [2].

References

[1] D. Contardo, M. Klute, J. Mans, L. Silvestris, and J. Butler, Report No. CERN-LHCC-2015-010, LHCC-P-008, CMS-TDR-15-02, CERN, Geneva (2015), URL `http://cds.cern.ch/record/2020886`.

[2] CMS Collaboration (CMS), Report No. CERN-LHCC-2017-023, CMS-TDR-019, CERN, Geneva (2017), URL `http://cds.cern.ch/record/2293646`.