The CMS ECAL Upgrade for Precision Crystal Calorimetry and Timing at the HL-LHC

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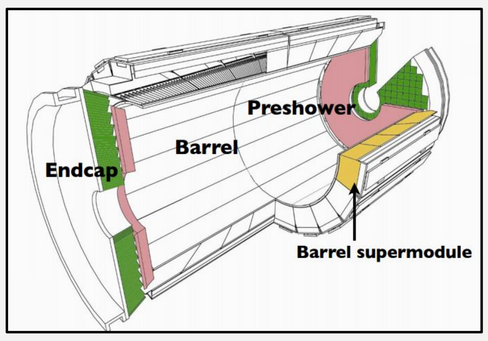
Abstract

The electromagnetic calorimeter (ECAL) of the Compact Muon Solenoid Experiment (CMS) has been operating at the Large Hadron Collider (LHC) with proton-proton collisions at 13 TeV center-of-mass energy and a bunch spacing of 25 ns since 2015. Challenging running conditions for CMS are expected after the High-Luminosity upgrade of the LHC (HL-LHC). We will present the design and R&D studies for the CMS ECAL barrel crystal calorimeter upgrade. Particular challenges at the HL-LHC are the harsh radiation environment, the increasing data rates, and the extreme level of pile-up events, with up to 200 simultaneous proton-proton collisions. We will present test beam studies of the new readout and trigger electronics, which must be upgraded due to the increased trigger and latency requirements at the HL-LHC. In addition, the CMS ECAL barrel upgrade will achieve a timing resolution of around 30 ps for high energy photons and electrons. The benefits of precision timing for the ECAL event reconstruction at HL-LHC will be presented. Simulation and test beam studies carried out for the timing upgrade of the CMS ECAL barrel will be shown, and the prospects for a full implementation of this option will be described.

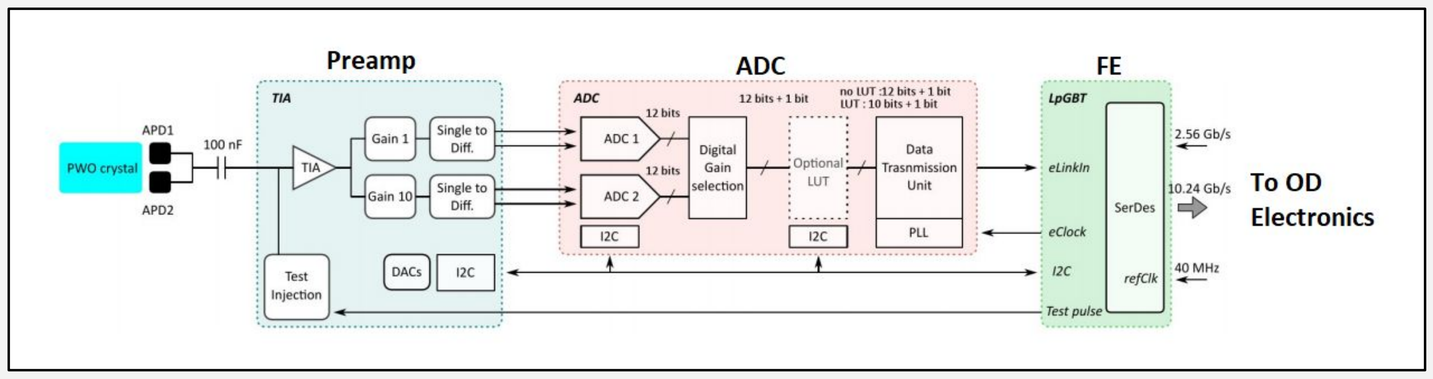
CMS ECAL

- Precisely measures the energies of photons and electrons
- Composed of 75,848 $PbWO_4$ (Lead Tungstate) crystals. Barrel (EB): 61,200. Endcaps (EE): 14648
- Essential for $H \rightarrow \gamma\gamma$ and many other physics studies
- For upgrade:
  - Replace EE, upgrade EB on and off-detector electronics



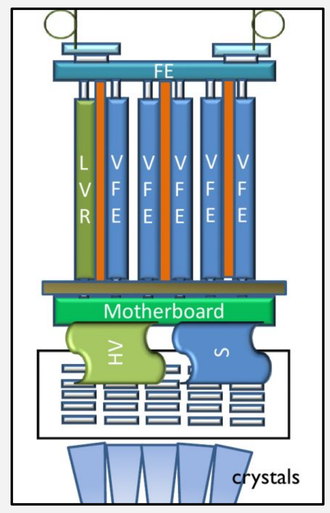
CMS ECAL Schematic

Barrel Upgrade



VFE and FE Electronics

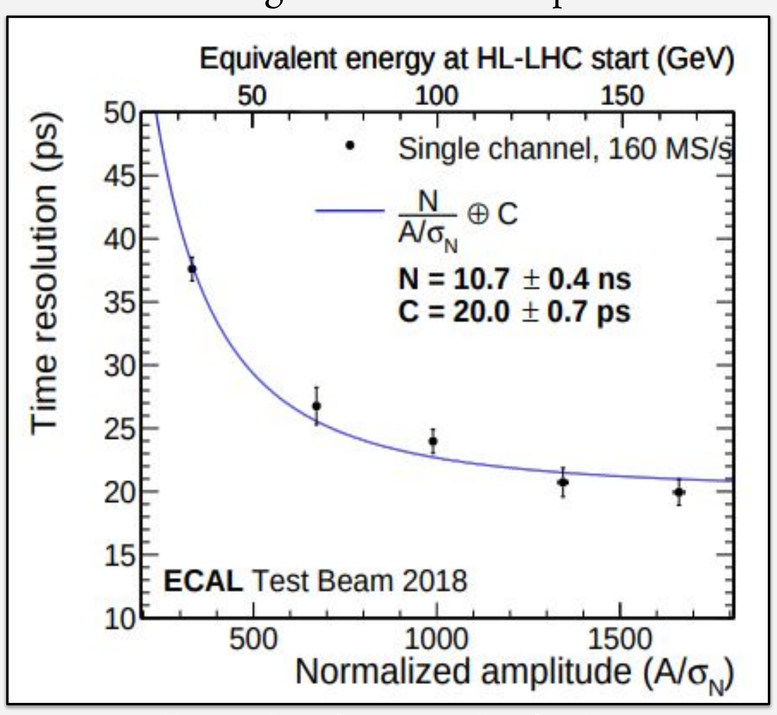
- Three main on-detector electronics components:
  - Pre-Amplifier
  - Analog to Digital Converter (ADC)
  - Front End (FE)
- They will be upgraded to:
  - Decrease shaping time
  - Increase sampling rate from 40 MHz → 160 MHz
  - Stream increased rate of information off-detector at 40 MHz
- Improve:
  - Timing resolution
  - Electronics noise reduction
  - Spike (fake signal) suppression
- Operating temperature:
  - 18℃ → 9℃
- Off-Detector will implement trigger logic with single crystal information



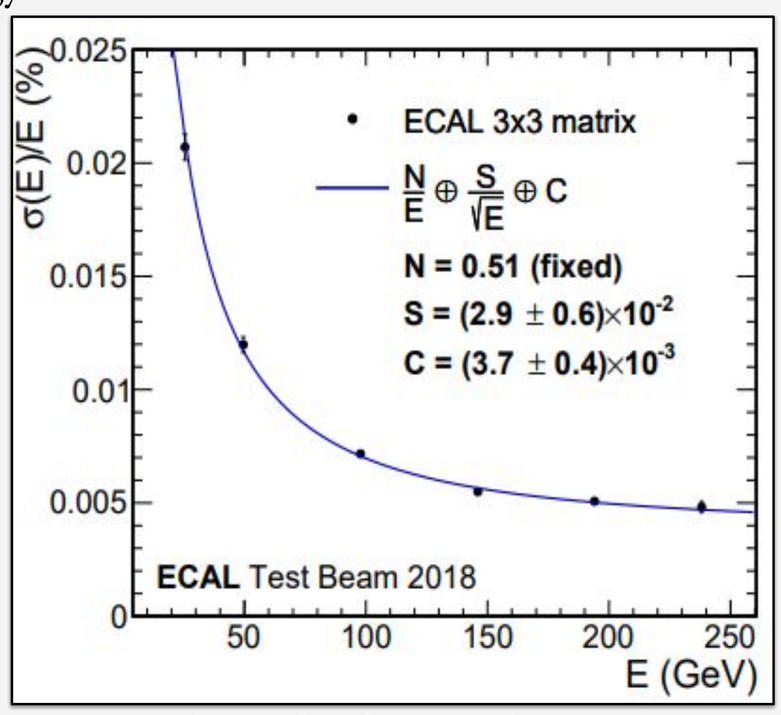
ECAL Electronics Schematic

2018 Test Beam

- June and October 2018: Test Beam for pre-amplifier prototype (CATIA V0)
- Used electron beams at 25, 50, 100, 150, 200, and 250 GeV
- Desired timing resolution: 30 ps
- Measured timing resolution: ~20 ps. Measured energy resolution: < 1%



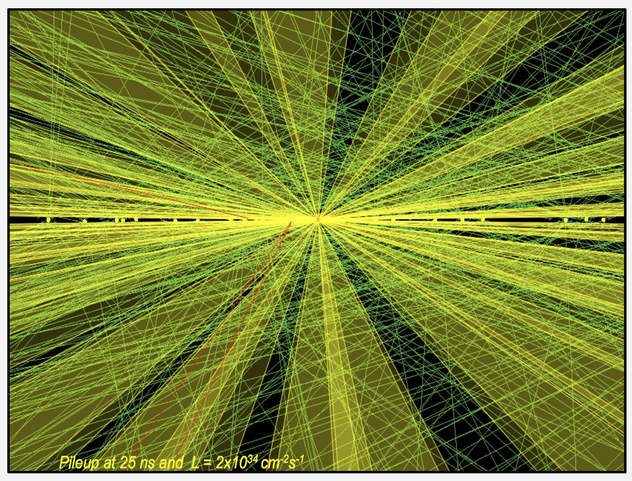
Timing Resolution vs. Amplitude



Energy Resolution vs. Energy

HL-LHC

- When 2026 arrives:
- LHC → HL-LHC
- L1 Trigger latency: 3.8 μs → 12.5 μs
- L1 Trigger rate: 100 kHz → 750 kHz
- ∫ Ldt: ~500 fb^{-1} → ~4000 fb^{-1}

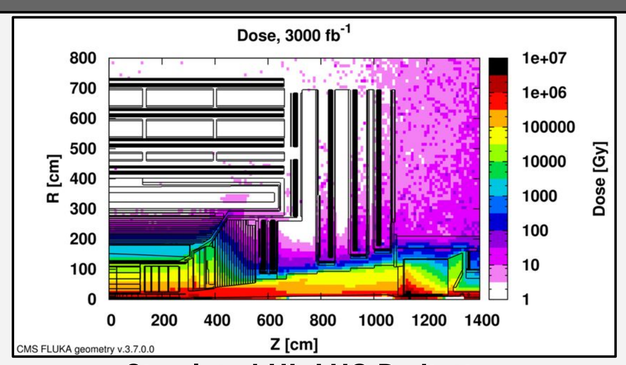


HL-LHC like Pileup

Conclusions and Outlook

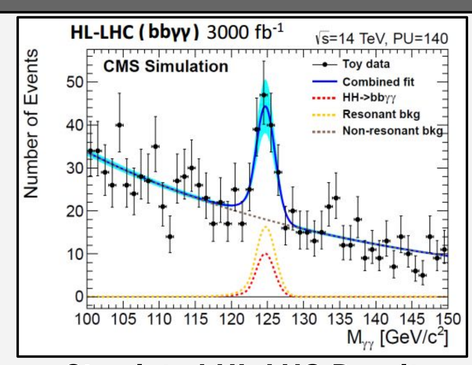
- Initial TB results of CATIA V0 prototype meet and exceed expectations
- Further R&D to be done during LS2 and Run 3

If we can overcome this:



Simulated HL-LHC Radiation

We can obtain this:



Simulated HL-LHC Result