Precision Timing with the upgraded CMS ECAL for HL-LHC

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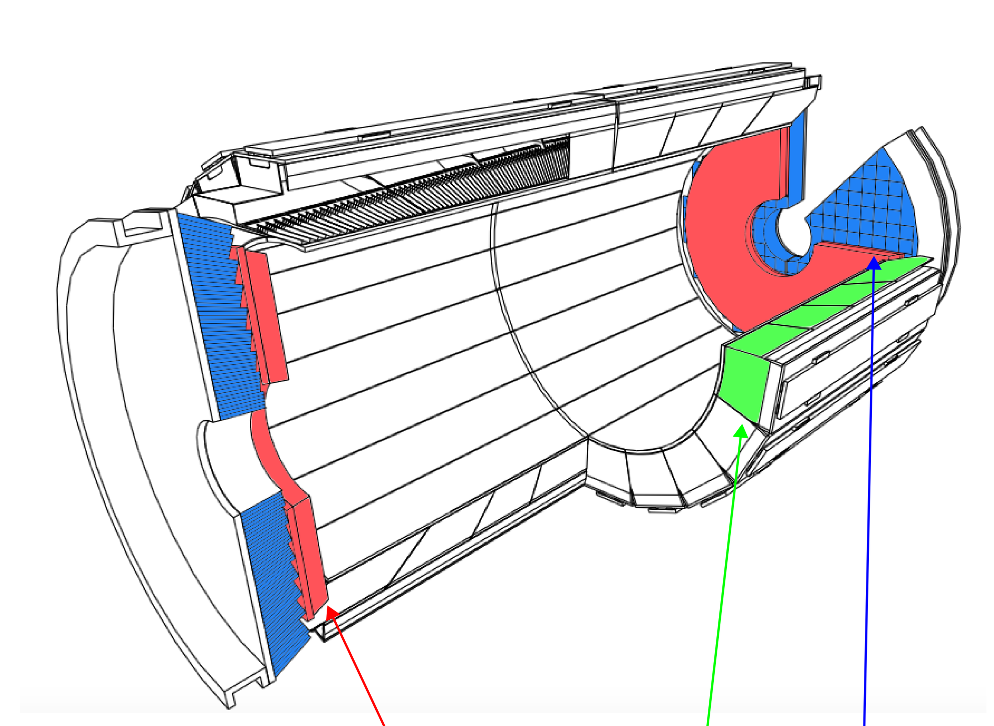
The CMS ECAL is:
- a homogeneous calorimeter made of 75,848 $PbWO_4$ scintillating crystals
- compact, hermetic, fine-grained and with excellent energy resolution

ECAL Barrel (EB):
- divided into 36 super-modules of 1700 crystals
- scintillation light read out by avalanche photodiodes (APDs)

Current EB On-Detector Electronics:
- Trigger Tower
- Very-Front-End (VFE)
- Front-End (FE)
- Readout

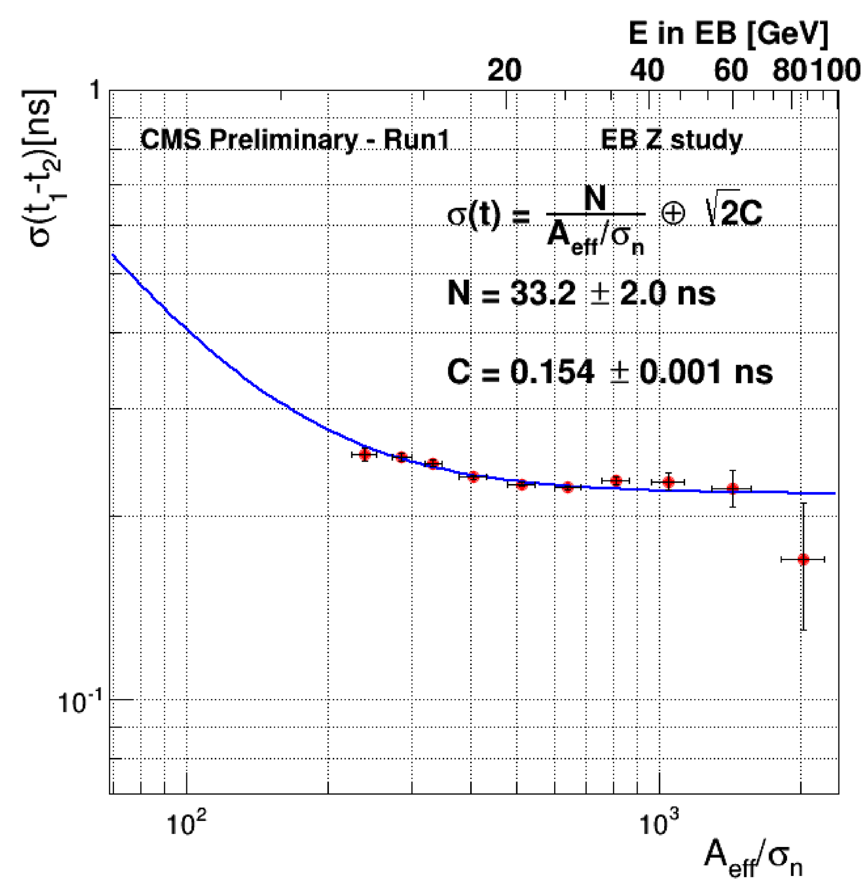
ECAL Endcaps (EE):
- 7,324 crystals for each of the 2 endcaps

CMS Electromagnetic Calorimeter



Insight of current CMS ECAL structure, with its BARREL, ENDCAP and PRESHOWER

Current Timing Performance



Resolution of time difference between the two electrons from $Z \to ee$ decays, as a function of the effective amplitude, normalized to the noise in the ECAL Barrel for 2011+2012 data

Towards High-Luminosity LHC...

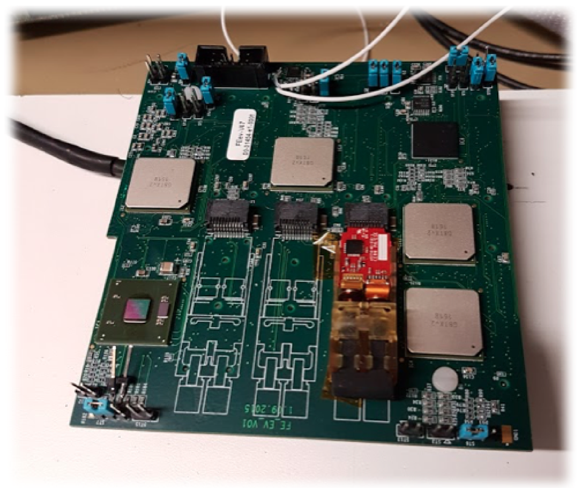
HL-LHC main feature & drawbacks:
- higher instantaneous and integrated luminosity
- much higher level of overlapping events: the **Pile-Up (PU)** will increase from $\sim 40-60$ to ~ 140
- radiation levels will be 6 times higher than for LHC

EB will be upgraded to:
- allow higher trigger rates
- mitigate PU from previous and following bunch crossing
- mitigate signal contamination from concurrent interactions in the same bunch crossing (through timing)
- mitigate the noise effect from APD leakage current, increased by long exposure to radiation
- identify the vertex of origin of the photons

EE will be replaced by a different detector

EB electronics upgrade perspectives

- New VFE boards with fast trans-impedance amplifier and 160 MHz ADC sampling, characterized by 2 gains per channel (i.e. two ADCs)



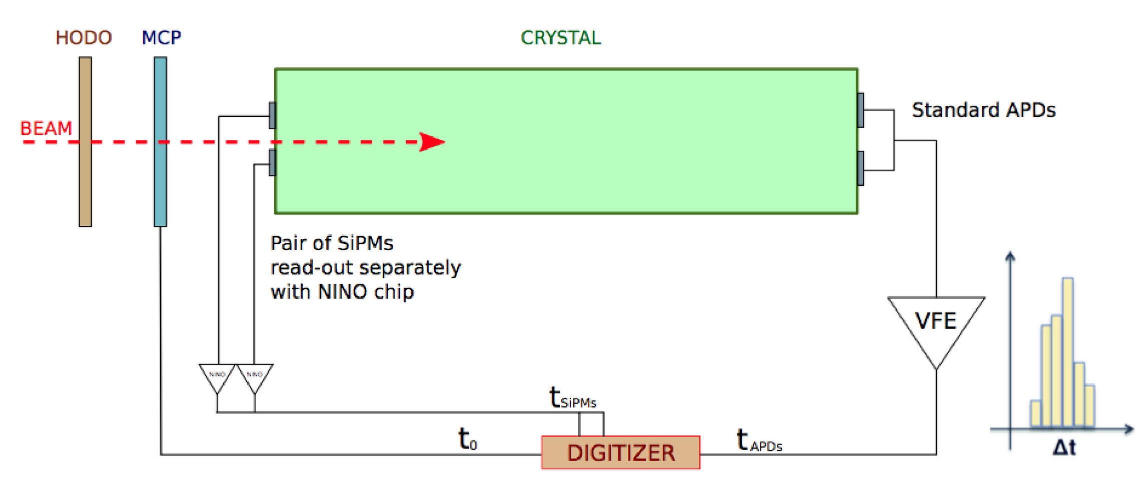
- New streaming Front End (FE) card
- New low voltage regulator
- Lower operating temperature ($\sim 8^o\ C$)
- **Off-detector** transmission for all samples and off-detector **trigger** formation

Electron beam from CERN H4 test line:
- 20, 50, 100, 150, 200 GeV

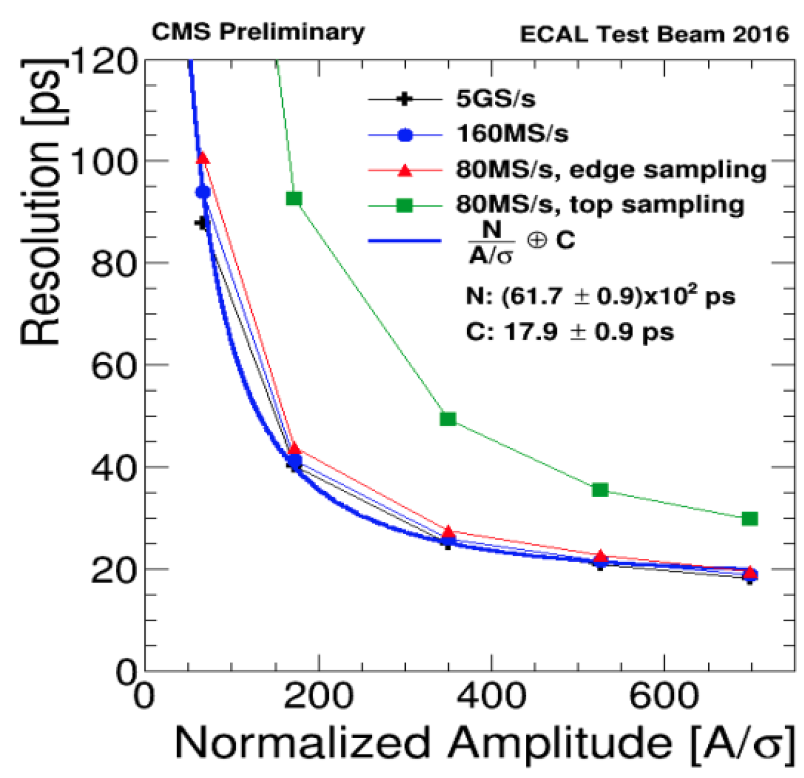
Reference time defined by a Multi-Channel-Plate Detector (MCP), used to measure the electron time of arrival. Time resolution: 25 ps

EB prototype setup: 6x5 matrix of $PbWO_4$ crystals + APD

Test Beam Setup (Summer 2016)



New electronics (VFE boards) tested and **temperature** kept in a $(6-18)^o\ C$ range, in order to:
- mitigate the noise effect from APD leakage current
- measure **amplitude and timing resolution**
- measure **pulse shapes** of scintillation signals and **spikes** with high bandwidth digitizer
- test **timing** resolution and spike rejection performance vs digitization frequency



The time of arrival of the electrons is measured at the test beam using a **template fit**. The known signal shape is used as a template that is superimposed to the acquired signal and shifted in time until the best fit is obtained. Timing resolution is obtained by studying the distribution of the estimated arrival times using the time measured by the MCP as a reference. At each available energy $\sim 10^4$ events are collected. Various possibilities for the **sampling frequency** are explored : 5 GHz, the maximum frequency of the digitizer used in the test setup, 160 MHz and 80 MHz. At 80 MHz, two choices of phase are investigated: top and edge sampling. At 80 MHz, a good timing resolution is reached only for edge sampling: lowering the sampling frequency requires a precise knowledge of the signal phase. Experimental data are fitted with the function:

$$\frac{N}{A/\sigma} + C$$

where N and C represent the free parameters. It is evident that, for high signal amplitudes, the **timing resolution** is well **below** 30 ps.