The upgrade of the CMS $PbWO_4$ crystal electromagnetic calorimeter for the HL-LHC and prospects for precision timing resolution

GIORGIO GHILLARDI, *UNIVERSITÀ DEGLI STUDI DI TORINO* on behalf of the CMS Collaboration

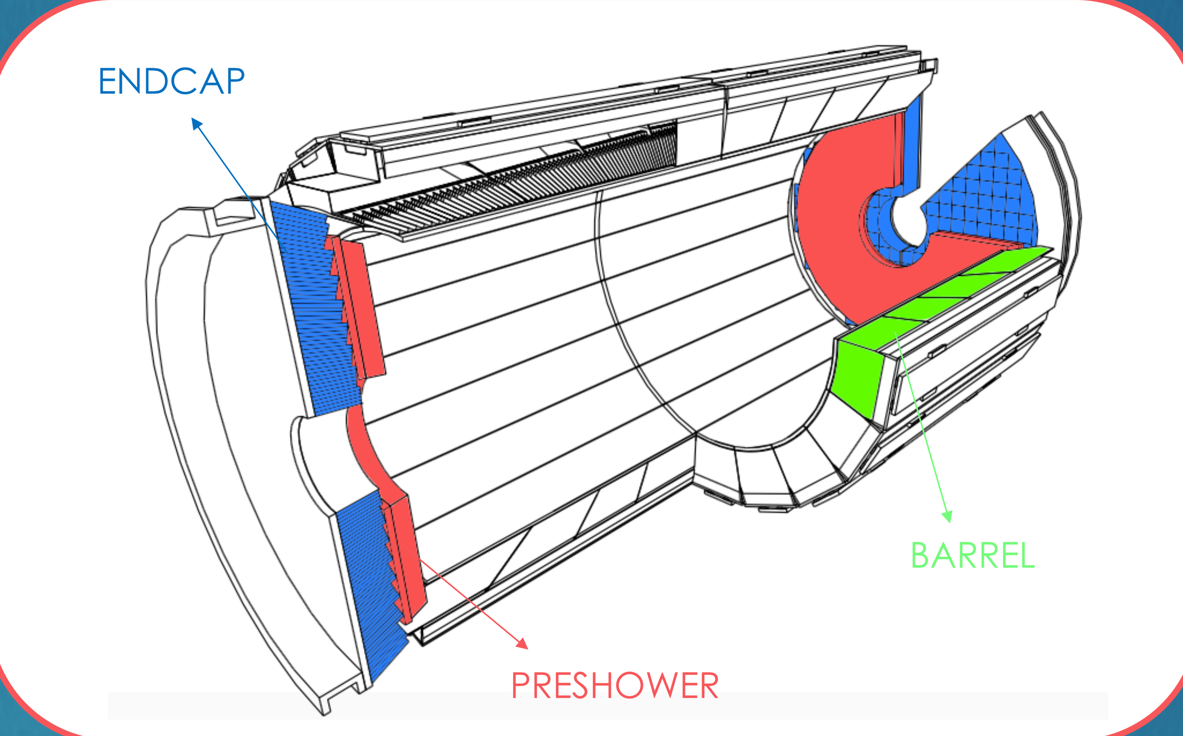
ELBA2018: 14TH PISA MEETING ON ADVANCED DETECTORS, 28TH MAY – 2ND JUNE

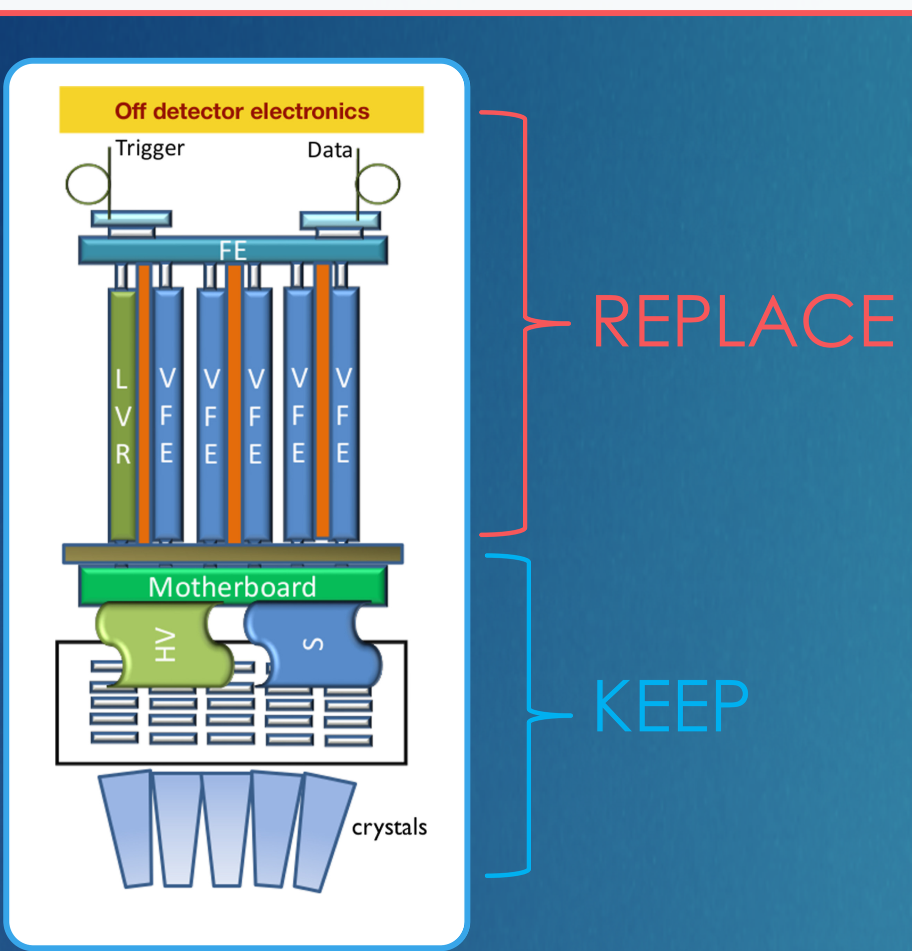
ECAL

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)

ECAL Endcaps (EE):
- 7,324 crystals for each of the 2 endcaps
- scintillation light read out by vacuum phototriodes (VPTs)





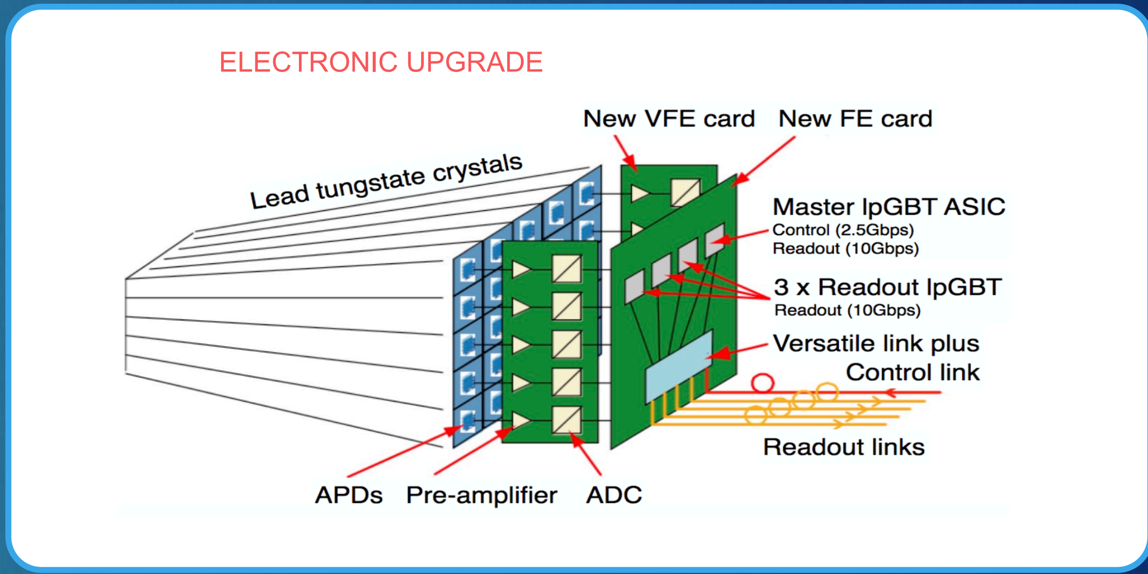
ECAL at HL-LHC

High-Luminosity:
- Increase istantaneous luminosity of a factor 2 to 5
- Accumulate 3 ab^{-1} of data until the end of Run 4, in 2030
- 200 PU concurrent interactions per LHC bunch crossing

GOAL: maintain the same performance as in phase1.

EB will be upgraded to:
- increase trigger flexibility
- mitigate the effect from spurious signals ("spikes")
- 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 (useful for $H \to \gamma\gamma$ channel)

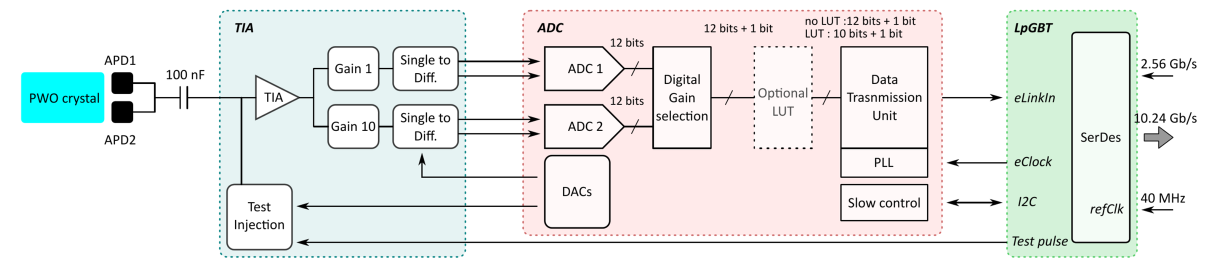
EE replaced by high-granularity silicon-based detectors



ELECTRONIC UPGRADE

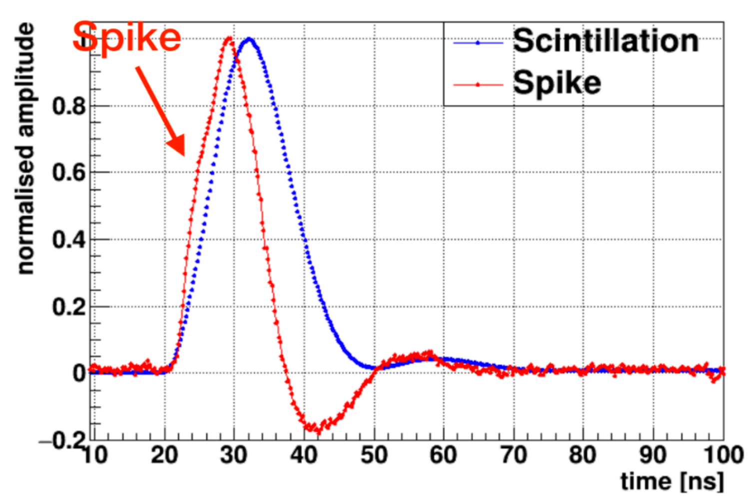
The barrel upgrade is a good opportunity to mitigate several radiation and pileup induced effects
- mitigate radiation-induced increase in APD noise
- improve direct hadronic interaction rejection ("spikes")
- improve timing resolution

How?
- New VFE boards with fast trans-impedance amplifier (TIA) 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 (~ 9° C)
- Off-detector transmission of all samples and off-detector trigger formation



SPIKE REJECTION

Direct hadronic interaction in the APD (spikes) must be discriminated from scintillation signals. TIA architecture applies minimal shaping to the APD pulse. Characteristics difference between the pulses can be seen.



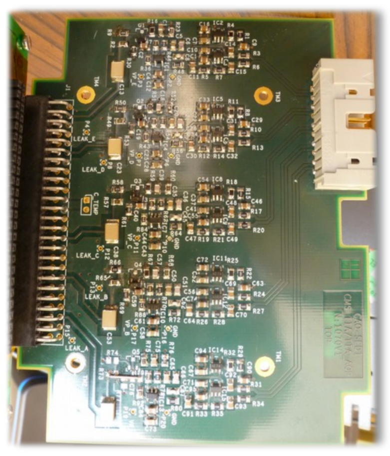
TEST BEAM

Electron beam from CERN SPS 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.

Timing resolution: 25 ps

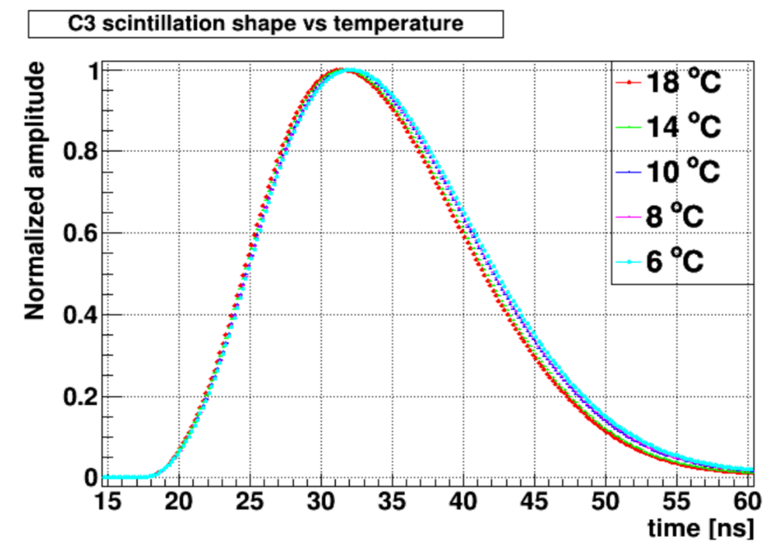
EB prototype setup: 6x5 matrix of PbWO4 crystals + APD

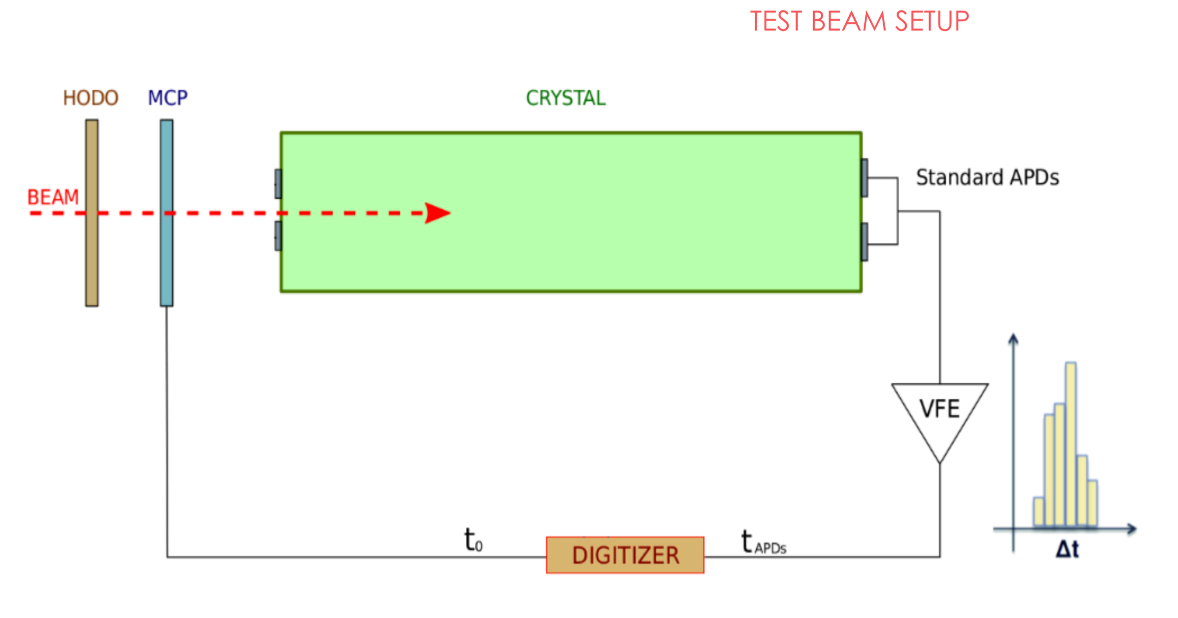


Prototype VFE with TIA

TEMPERATURE TEST

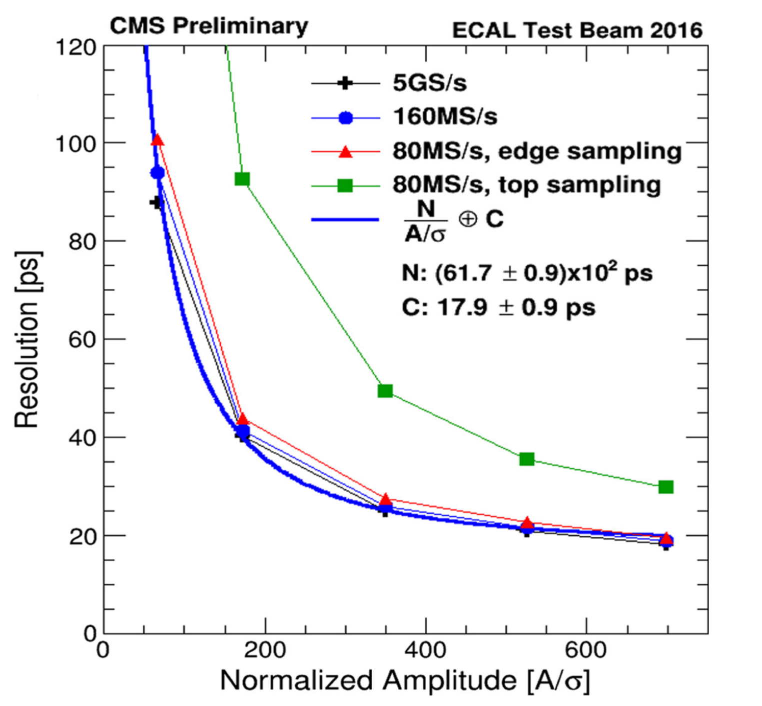
Upgrade of the cooling system is needed in order to mitigate the increase of APDs dark current. The VFE are tested in a range of 18 to 6 °C varying also the beam energy. A minimal change in pulse shape is observed at lower temperature (slightly longer $PbWO_4$ decay time).





TIMING PERFORMANCE

The time of arrival of the electrons is measured using a template fit. The timing resolution is obtained by comparing the time of the APD pulse at the rear face of the crystal with the time of arrival of the electron at the front face, given by a MCP. The timing resolution is compared as a function of pulse amplitude divided by the elctronic noise $\frac{A}{\sigma}$ for different sampling frequencies: 80 MS/s (for two different phases), 160 MS/s and 5 GS/s. N and C are free premeters of the fit.
The figure shows a dependence of 80 MS/s from the phase; 160 MS/s is required. 160 MS/s timing resolution gives the same performance as 5GS/s. Resolution of 30 ps is achievable at $\frac{A}{\sigma} \sim 250$, which corresponds to a 25 GeV photon at the start of the HL-LHC.



made by Ghillardi Giorgio and Riccardo Salvatico