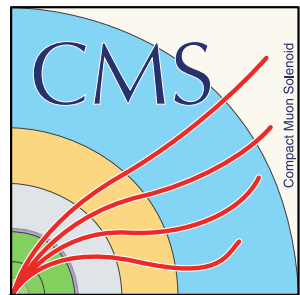


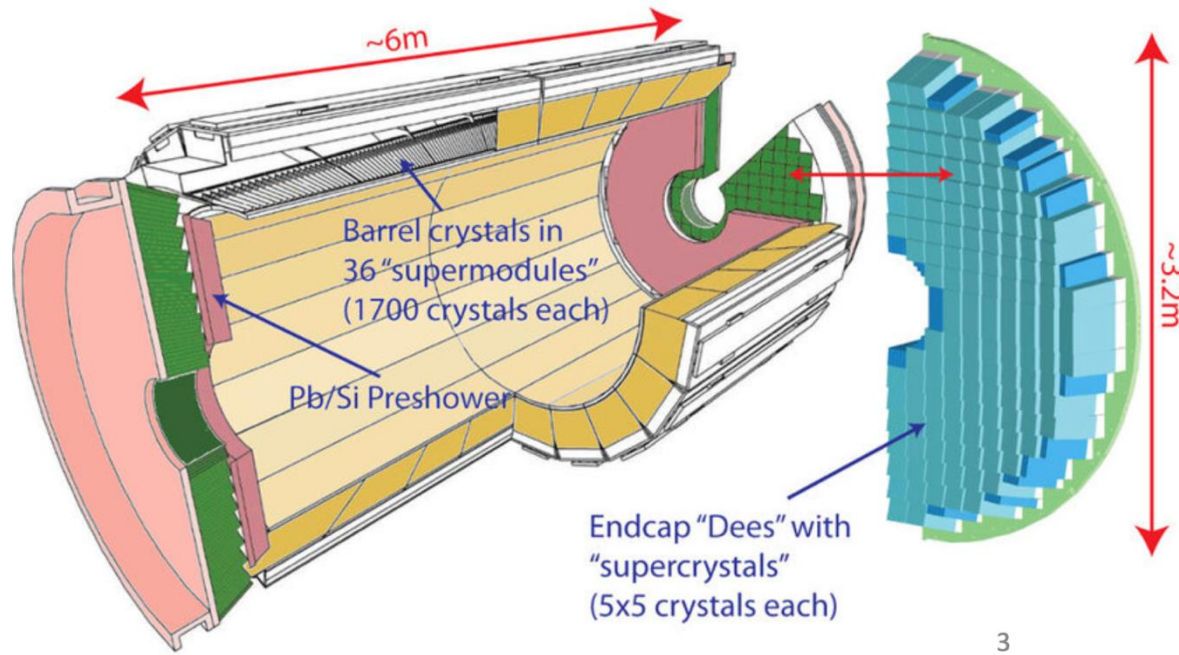
The upgrade of CMS ECAL for precise timing measurements at the High-Luminosity LHC

A. Ghezzi, on behalf of the CMS collaboration



The CMS ECAL

Designed for 10 y at $10^{34} \text{ cm}^{-2}\text{s}^{-1}$ and **500 fb⁻¹**

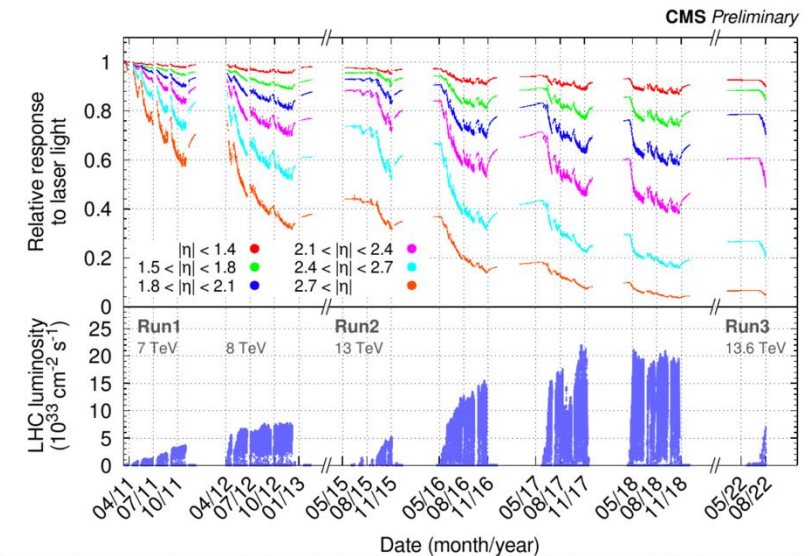


Laser monitoring system to measure radiation induced change in transparency and correct for it

Homogeneous PbWO_4 crystal calorimeter
high density and a fast scintillation
(~80% of the light in 25 ns)

Barrel: 61200 crystals read by APD

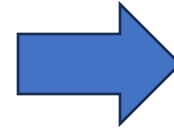
Endcaps: readout by VPT



HL-LHC challenges

Large increase in the luminosity
(and integrated luminosity of 3000 fb⁻¹)

Significant increase in the Pile Up (50 → 150-200)



**upgrades of the
detectors is required**

Significant increase in radiation levels

Upgrade of the trigger system that
will include track trigger

	Max Lev1 Rate	Max Latency
Current Ecal trigger	100 kHz	4 μs
Phase 2 trigger	750 kHz	12 μs

Use **timing information** to improve event
reconstruction and mitigate the effect of PU

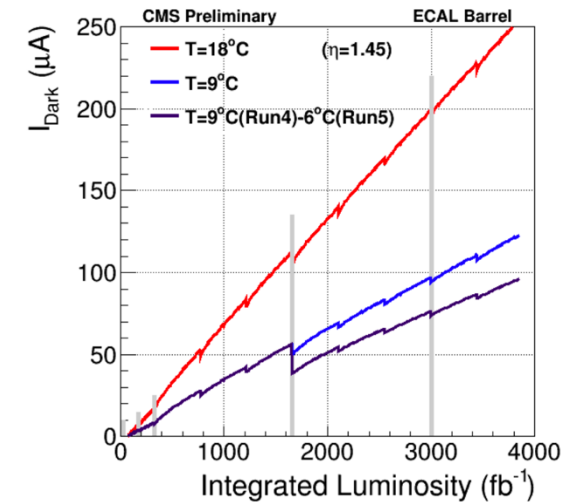
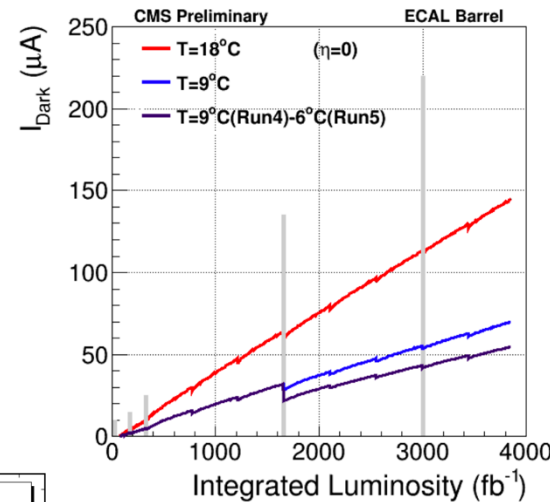
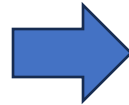
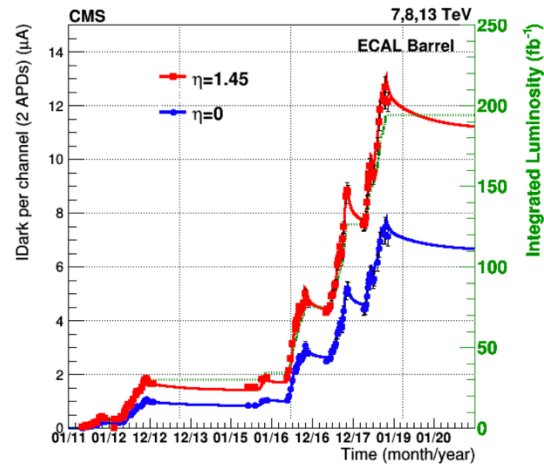


Enhance timing performance of the detectors
Add a novel detector for MIPs timing

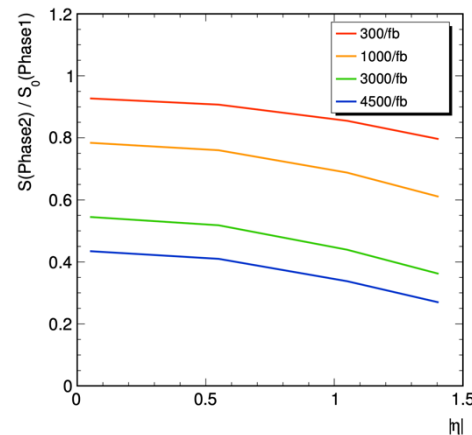
HL-LHC impact on APD and crystals

Increase in the APD dark current \propto fluence Φ , partial recover on months timescale, depends on temperature

Projection for HL-LHC from measurements at LHC



50% to 65% loss of the crystal LO due to irradiation expected after 3000 fb⁻¹



The endcap calorimeter will be replaced by high granularity sampling calorimeter HGCal

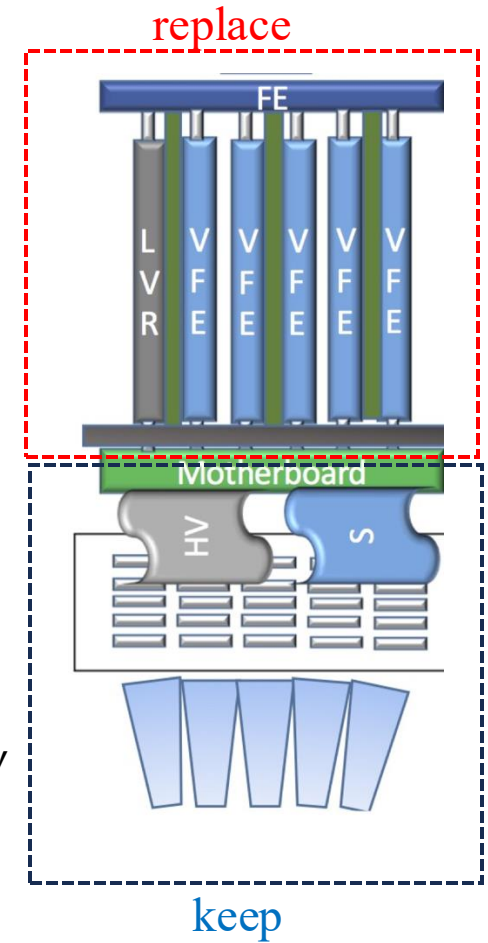
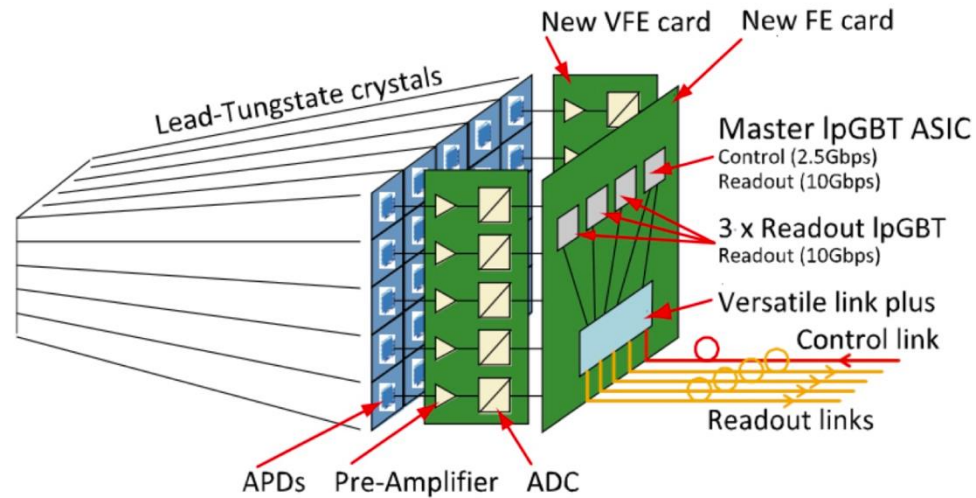
Ecal Barrel Upgrades

The ECAL Barrel will keep the APD and crystals, but **operating at a lower temperature (9 °C)** (reduce APD current, increase LY)

Fully replace the electronics

Shorter shaping time:

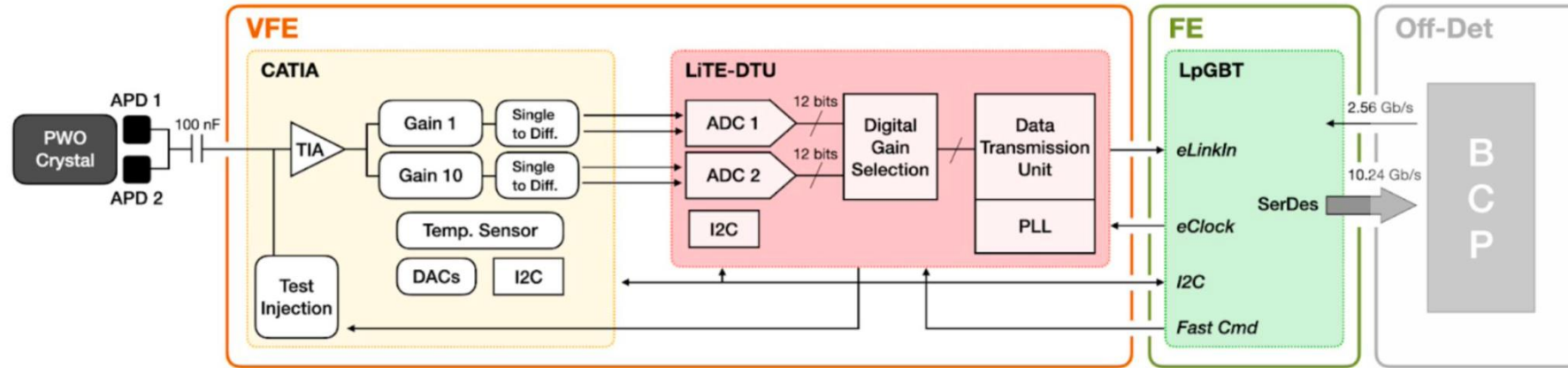
- reduce the noise from dark current
- reduce PU from other BX



With sampling at 160 MHz: **improve time measurement** reach ~ 30 ps for ~ 50 GeV e/γ

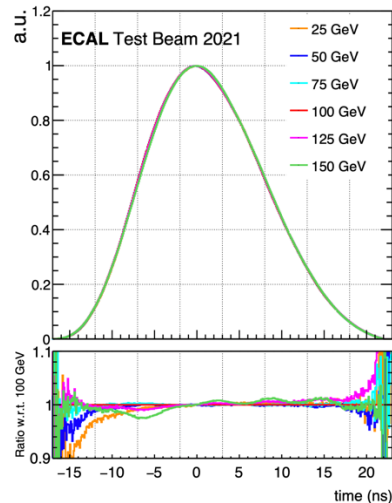
Move all the trigger reconstruction off-detector with full granularity

Electronics Upgrade



Analog ASIC CALorimeter Trans-Impedance Amplifier

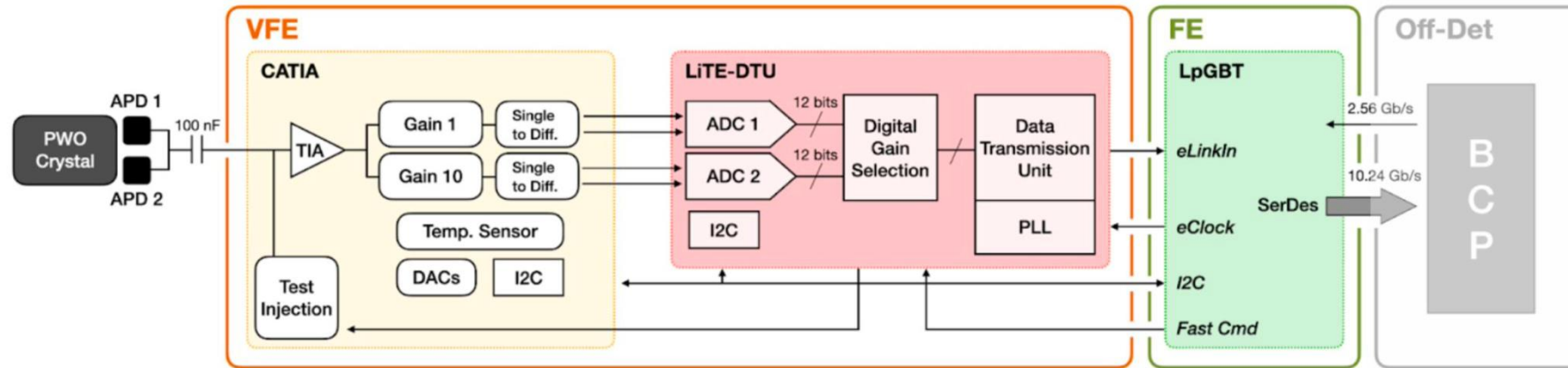
35 MHz bandwidth
2 Gains (x1, x10)
Dynamic range from
50 MeV to 2 TeV



Digital ASIC Lisbon Torino ECAL Data Transmission Unit

12 bits ADC, sampling at 160 MHz
DTU with gain selection (G10 saturates at ~200 GeV),
data compression and transmission
(6 bits if < 2.5 GeV, 13 bits if >2.5 GeV)

Electronics Upgrade



Barrel
Calorimeter
Processor

FPGA based, placed outside the detector,
connected to up to 12 Readout Towers and to neighbour BPCs.

BCP controls and receive data from the FE.

Decompress data, forms L1 triggers and transmit data to the central DAQ.

Reconstruction of time and energy of each channel, can implement algorithm for
suppression of anomalous signals and for clustering

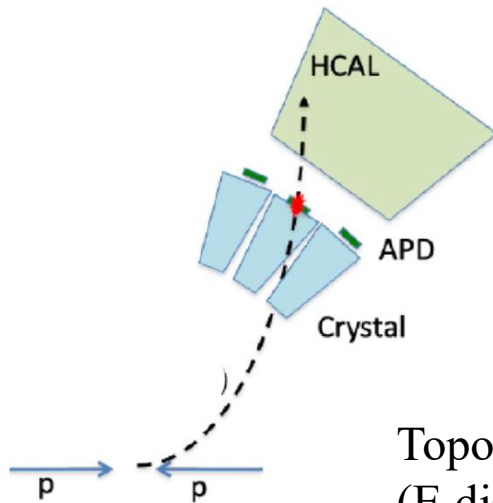
Spikes rejection

«Spikes»:

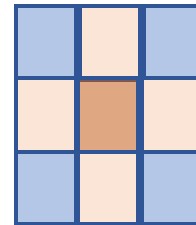
direct ionization of the APD

large and isolated signal, with a different time profile

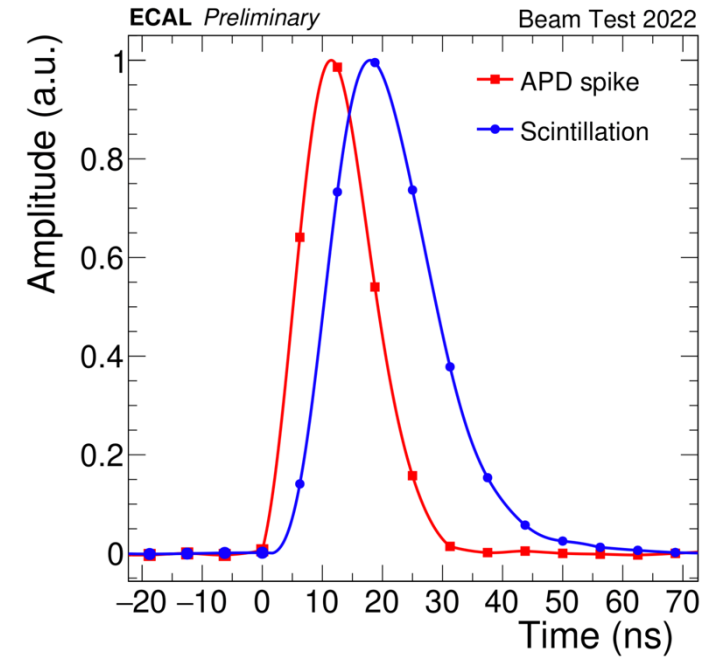
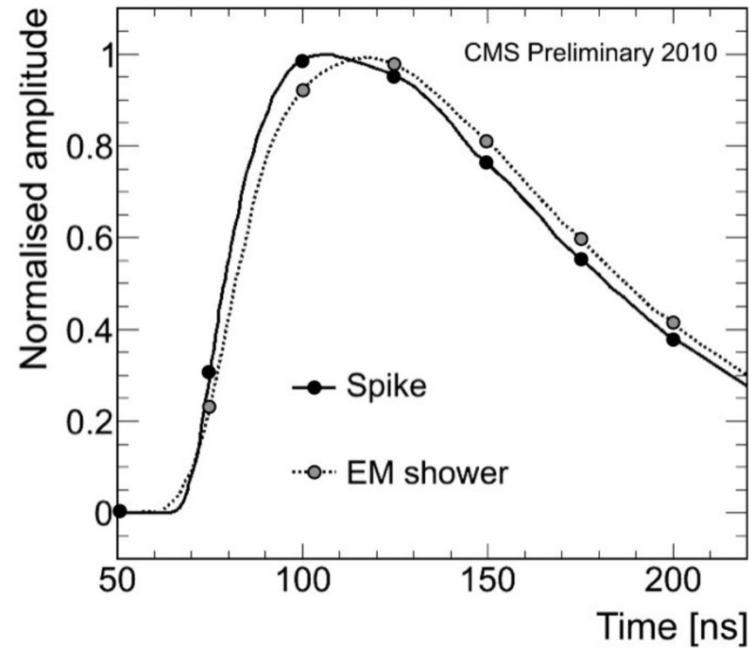
would saturate L1 rate if not suppressed



Topological selections
(E distribution in a 3x3 matrix)



Phase 1

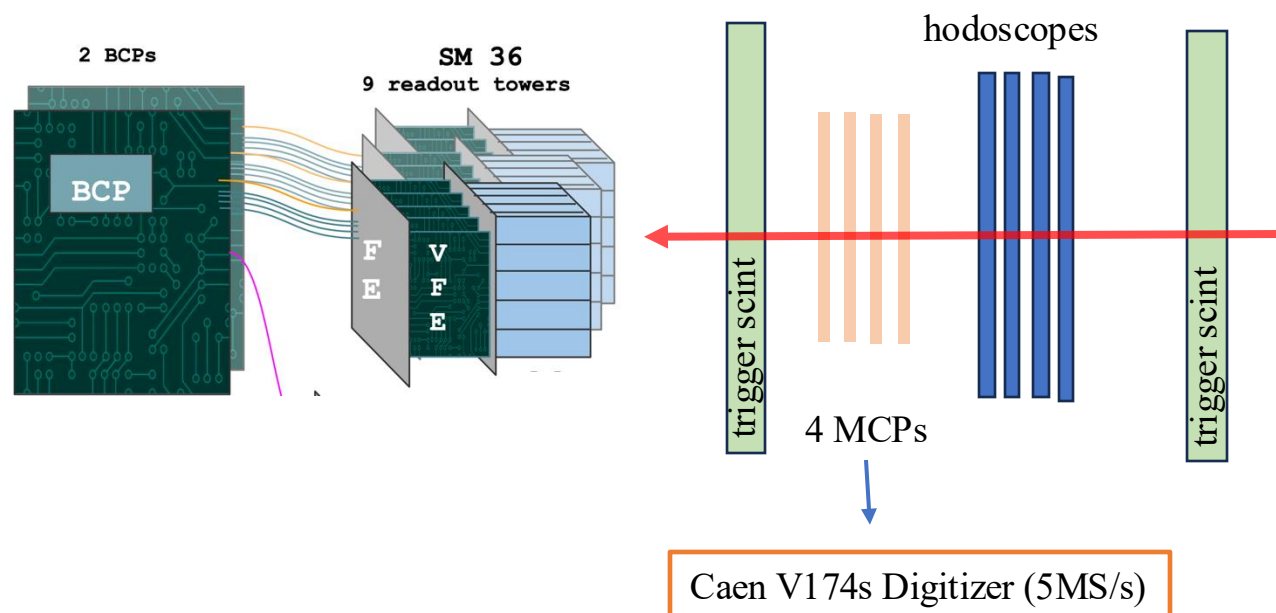


Full information available in the BCP for spike rejection algorithm at trigger

Test beam measurements

Several test beam campaigns to validate the design of the different components:

- starting from 5x5 crystals with first version of CATIA, (2018),
- 5x5 crystals with with CATIA and LiTE-DTU prototypes, (2021)
- and with the full chain, on ~200 channels



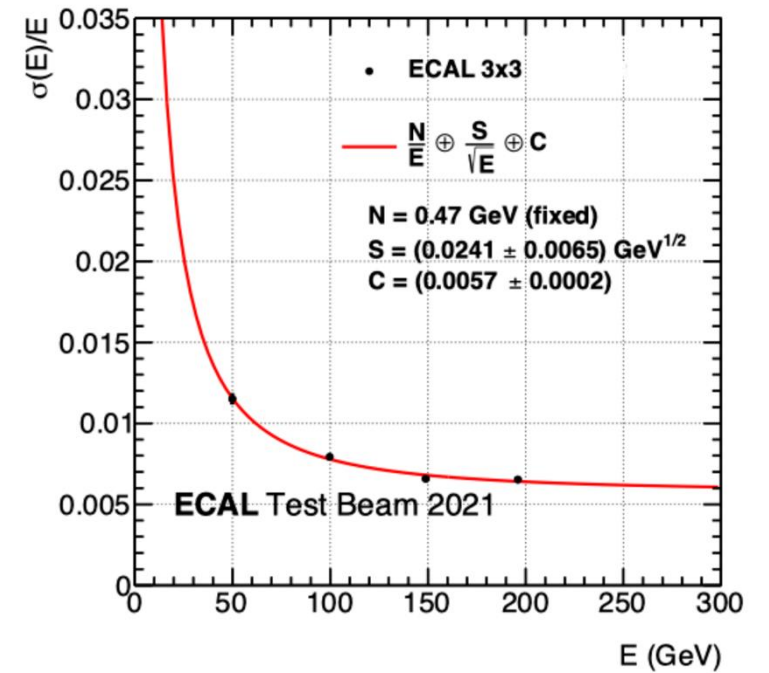
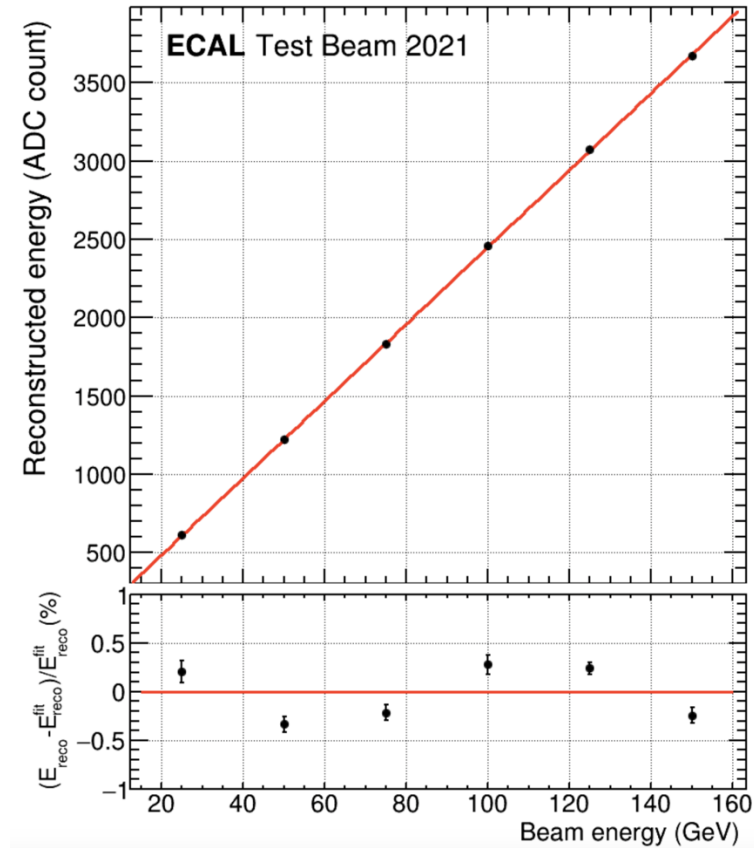
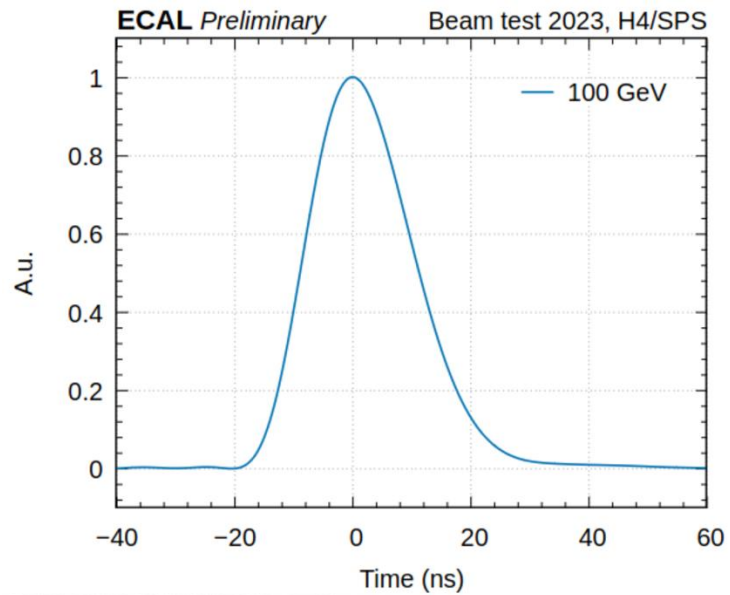
(~ 200 crystals, in a ECAL SM)

Test beam results

Amplitude and time from a template fit:

$$f(t) = A \cdot S(t - t_0)$$

Energy linearity < 0.5 %



Energy resolution matching the current energy resolution

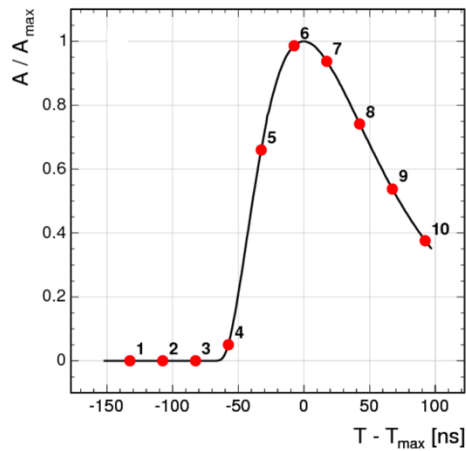
Timing measurements with the current ECAL

time measured with the «ratio method»:
 the ratio of two consecutive samples
 depends on timing

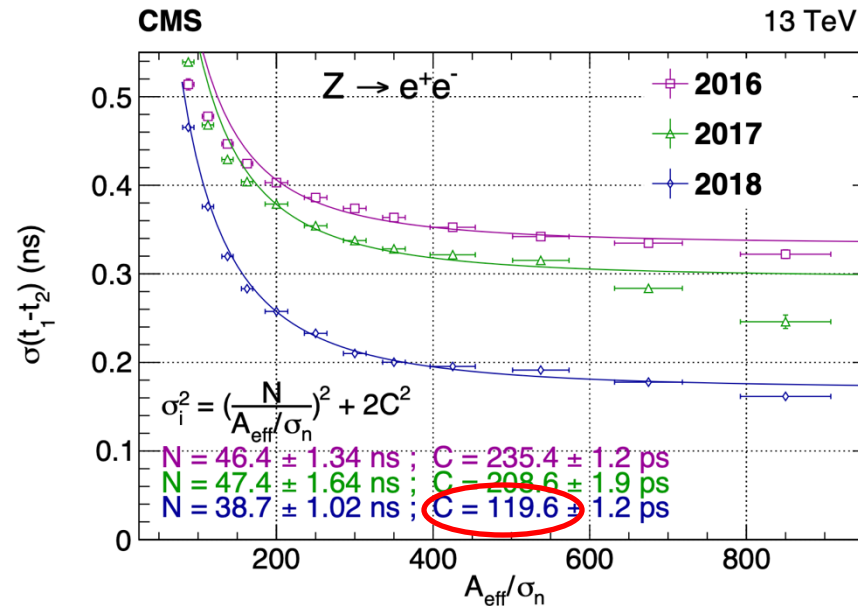
$$\sigma_T^2 = \left(\frac{N \cdot \sigma_n}{A} \right)^2 + \left(\frac{S}{\sqrt{A}} \right)^2 + C^2$$

Stochastic term is negligible

Constant term is affected by variation in
 the e.m. shower within the crystal,
 systematics of the method, time calibration
 between channels, stability of the clock



Results from pp collision LHC Run 2,
 on $Z \rightarrow e^+e^-$ events

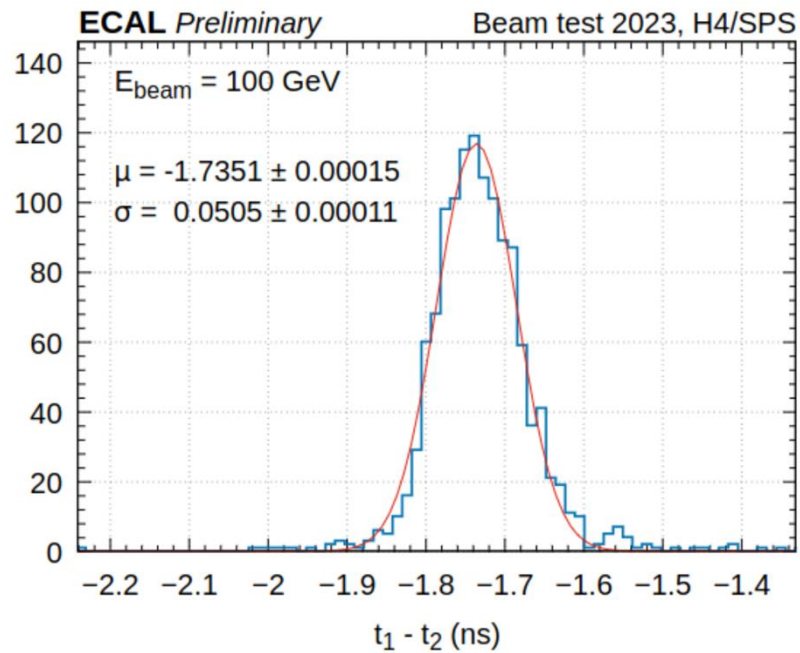


$e^+ e^-$ in different detector regions

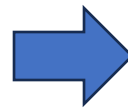
Clock distribution for
phase2 designed to
 contribute less than **10 ps**
 to the time resolution

Timing results for the new electronics in test beam

Timing from the template fit

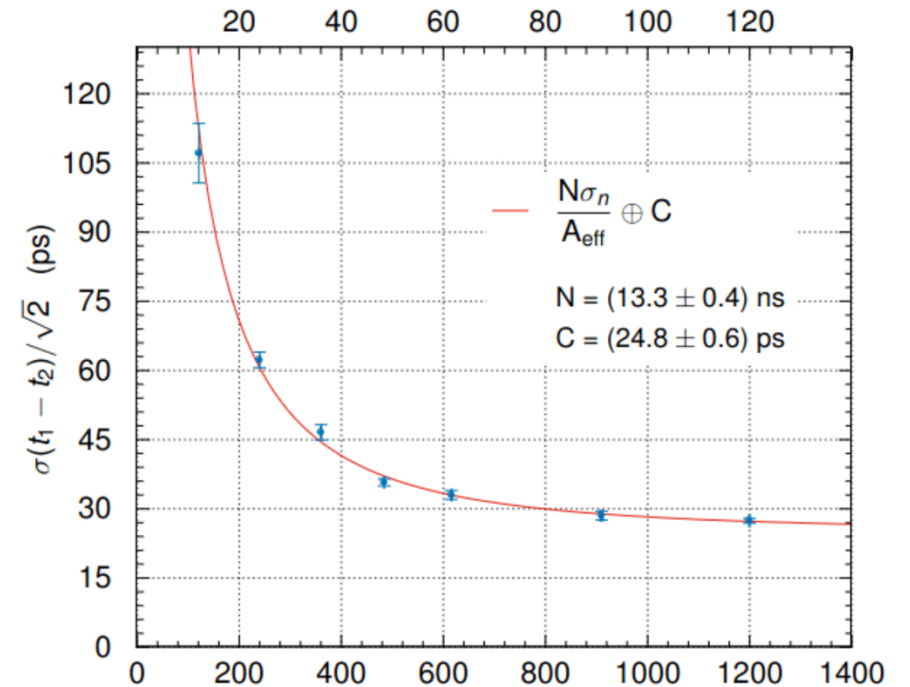


Time difference between two channels



CMS ECAL Preliminary Beam Test 2023, H4/SPS

Equivalent energy at HL-LHC start (GeV) $\sigma_n = 100 \text{ MeV}$



$$\frac{A_{\text{eff}}}{\sigma_n} = \sqrt{\frac{2}{\left(\frac{\sigma_1}{A_1}\right)^2 + \left(\frac{\sigma_2}{A_2}\right)^2}}$$

Summary

The upgrade of the Ecal calorimeter to withstand the harsher condition of HL-LHC will:

- **Maintain the PBWO_4 crystals and APD for the barrel**, completely change the endcap (HGCAL)
- **Fully replace the barrel readout electronics** (on and off detector) to:
 - Reduce the noise from APD dark currents
 - Improve time measurements
 - Comply with the CMS DAQ and trigger requirements for HL-LHC

New FE electronics have been designed with **large bandwidth** TIA (CATIA) followed by LiTE-DTU with a **sampling at 160 MHz** to improve timing measurement.

Full information from LiTE-DTU is transferred **to off-detector BCP** → trigger objects with full granularity

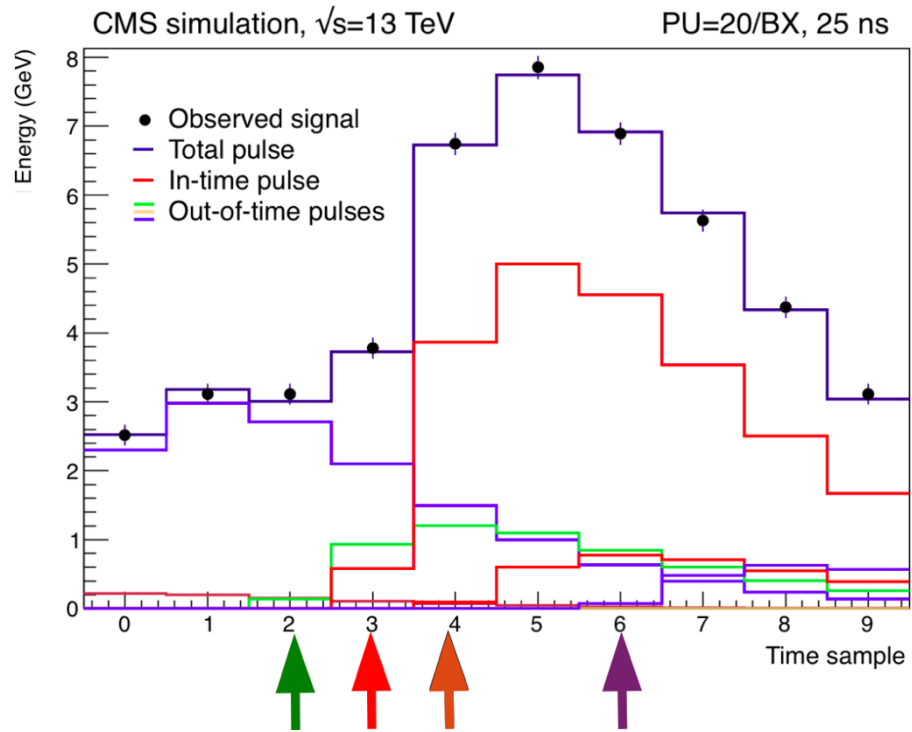
Test beam campaigns with the prototype upgraded electronics have validated the new design showing promising results:

- Energy resolution matching the current performance
- Timing resolution in the **30 ps** target for typical $\text{H} \rightarrow \gamma\gamma$ photons

BACK UP

Pile UP

Phase 1



Phase 2

