The upgrade of the CMS Electromagnetic Calorimeter for HL-LHC

A Faster Readout and a Cooler Home

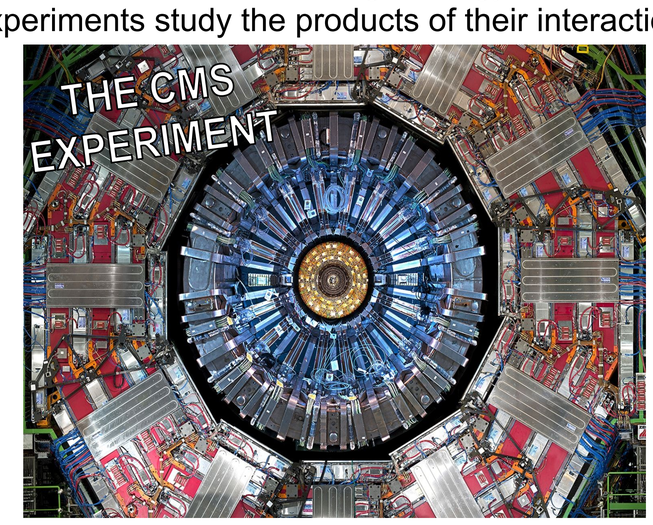
Davide Cristoforetti
University of Turin, INFN
On behalf of the CMS ECAL group

New to CMS? Start here!

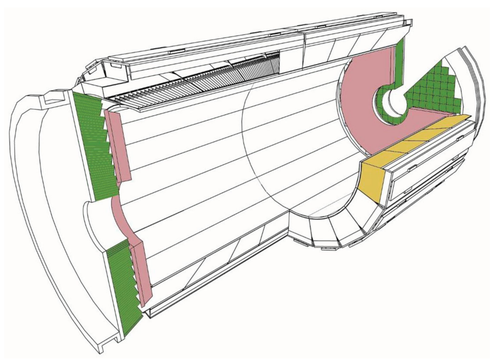
Otherwise, enjoy the rest of poster!

The CMS, Compact Muon Solenoid detector is one of the 4 main experiments at the Large Hadron Collider, LHC, the largest collider on Earth, located at CERN, close to Geneva.

LHC accelerates protons, *and more*, to almost the speed of light *(13.6 TeV center of mass energy)* and make them collide at high energy, then experiments study the products of their interaction.



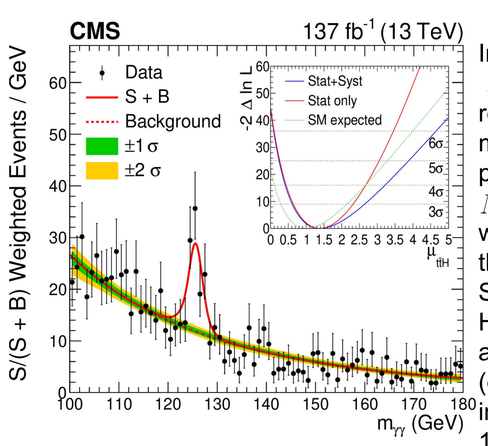
The CMS detector is frequently compared to a camera. When particle collisions occur, the detector *captures an image* of the numerous high-energy particles produced by the event.



CMS ECAL,
A schematic view:

- ENDCAP
- BARREL
- PRESHOWER

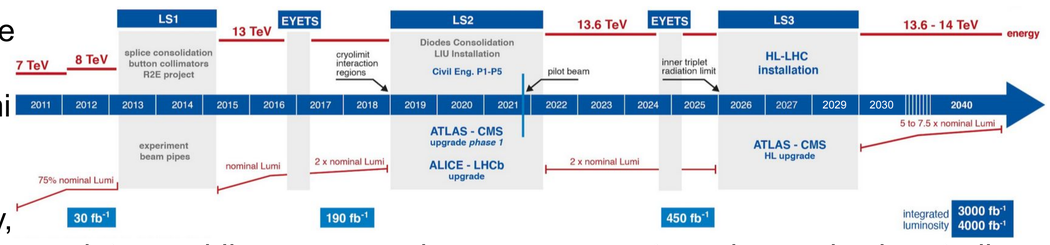
The electromagnetic calorimeter (ECAL), uses high density $PbWO_4$ crystals to perform measurements on photons and electrons via scintillation. Its contribution is crucial to study the rare Higgs boson (~1 in 10^9 pp collisions), as there is a 0.25% [1] chance that it decays into 2 photons, which are then detected by ECAL.



Invariant mass spectrum $H \to \gamma\gamma$ [2], each entry represents the invariant mass of a pair of photons: $M^2 = 2E_1E_2(1-\cos\theta)$ with θ the angle between the two photons. Since the mass of the Higgs is 125 GeV we see an excess of entries (events) for which the invariant mass is close to 125 GeV.

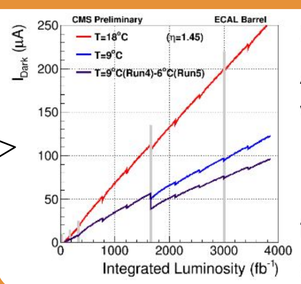
What is High-Luminosity LHC?

Luminosity is a measure of the collision rate per unit of area. The HiLumi upgrade will increase it 5–7.5× beyond the nominal LHC luminosity, granting access to far more data, enabling more precise measurements and new physics studies

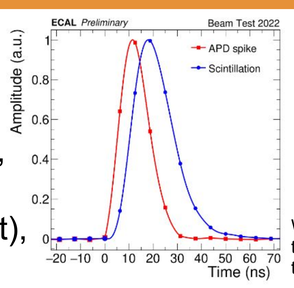


More data, More challenges

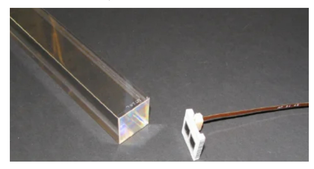
More radiation, more challenges for the APDs



Scintillation light is read by Avalanche Photodiodes (APDs), which face two challenges: radiation-induced leakage current, mitigated by reducing operating temperature from 18°C to 9°C (left), and *spikes* from direct hits (right).



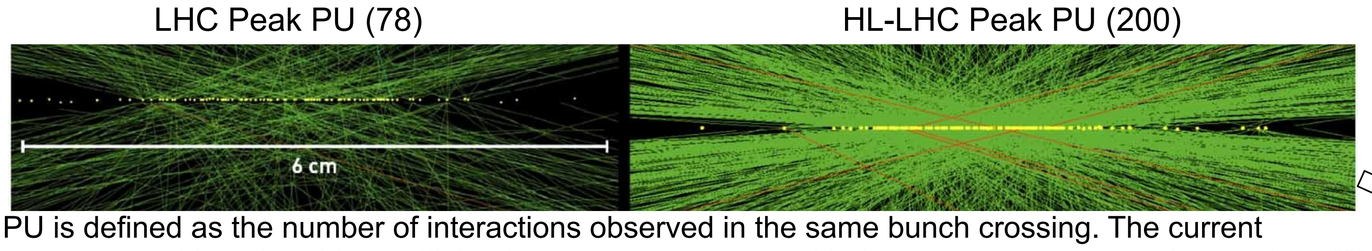
ECAL crystal with its APDs



When a particle interacts directly with the APD it produces a spike signal rather than a scintillation signal.

Higher luminosity, Higher Pileup (PU)

LHC Peak PU (78) — HL-LHC Peak PU (200)



PU is defined as the number of interactions observed in the same bunch crossing. The current systems would not be able to efficiently reconstruct events with these many concurrent interactions [3].

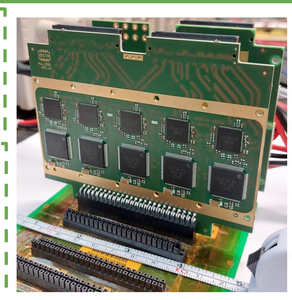
Difficult task, Ecal has a solution

A faster readout: CATIA and LiTE-DTU ASICs

How we read out CMS data

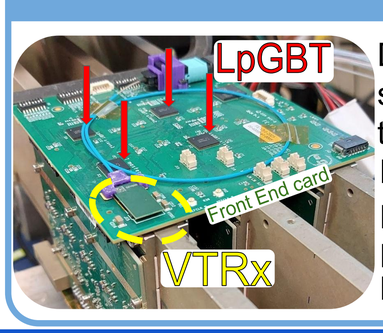
CATIA, the amplification stage:
Provides amplification (x1 and x10 gain) to the signal from the APDs, covering an energy range from 50 MeV to 2 TeV [4].

LiTE-DTU, digitizer and data compression:
Digitizes the CATIA signal with a 12-bit ADC at 160 MHz (four samples per bunch crossing), using lossless compression to manage the data rate. The whole system is designed for ~30 ps time resolution at 50 GeV, to handle high pileup [5]



Top row LiTE-DTUs, bottom row CATIAs, installed on a Very Front End (VFE) card.

To the counting room: lpGBT → VTRx → BCP

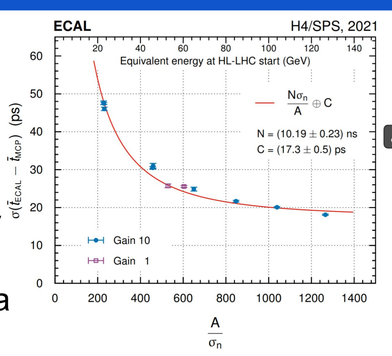


Data from the VFE is sent to four serializers (LpGBTs) via 1.28 Gb/s serial links. The VTRx converts it to optical signal and sends it to the the Barrel Calorimeter Processor (BCP) via four 10.24Gb/s optical links. Powerful FPGAs are used to process data and generate trigger primitives, a task previously handled by the front-end electronics [6]

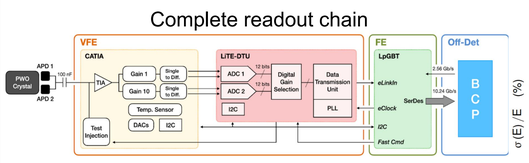
Putting it all together

Summary, results, and final remarks

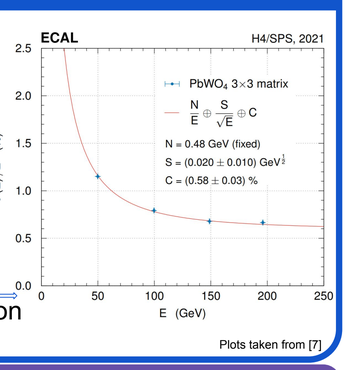
Despite the harsh HL-LHC environment, the upgraded readout will preserve ECAL physics performance. With CATIA and LiTE-DTU mass-produced and currently being installed on the VFEs, and CMS will start taking data again in 2030.



Time Resolution



Energy Resolution



Plots taken from [7]

References

[1] R. L. Workman et al. (Particle Data Group), *Review of Particle Physics*, Prog. Theor. Exp. Phys. 2022, 083C01 (2022).
[2] CMS Collaboration, Measurements of ttH production and the CP structure of the Yukawa interaction between the Higgs boson and top quark in the diphoton decay channel
[3] Summers et al (2026). Roadmap on fast machine learning for science. Machine Learning: Science and Technology. 7. 10.1088/2632-2153/ae484b.
[4] P. Baron et al., Performance of CATIA ASIC, the APD readout chip foreseen for CMS Barrel ECAL electronics upgrade at HL-LHC, PoS TWEPP2017 (2018) 036.
[5] S. Argirò et al 2026 JINST 21 C04063DOI 10.1088/1748-0221/21/04/C04063
[6] A. Singovski et al., CMS ECAL Upgrade Front End card: design and prototype test results, PoS TWEPP2018 (2019).
[7] The CMS ECAL Group, Performance and test of the new CMS ECAL barrel front-end electronics for HL-LHC".In: Nuclear Instruments and Methods in Physics Research

Thank you for make it this far!

More questions?
Contact me at:
davide.cristoforetti@cern.ch