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XXXII Cycle

Design of the new front-end readout electronics for the ECAL upgrade of CMS

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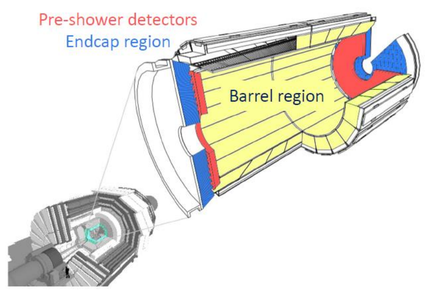
Research context and motivation

During the foreseen High-Luminosity (HL-LHC) upgrade of the Large Hadron Collider (LHC), the electromagnetic calorimeter (ECAL) of the Compact Muon Solenoid (CMS) will have to cope with a challenging increase in the number of interactions per bunch crossing and radiation levels.

The **CMS** detector is one of the general-purpose particle physics detectors at the LHC.

ECAL is compact, hermetic and fine-grained detector, it contains homogeneous lead-tungstate scintillating crystals and its purpose is to measure the energy of electrons and photons that are crucial for Higgs boson precision studies.



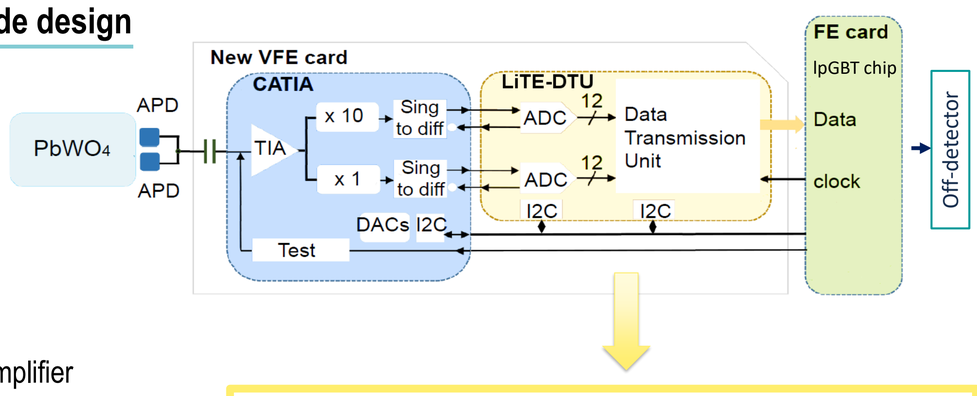
The **HL-LHC** conditions are a significant challenge to both detector performance and longevity because the HL-LHC will provide:

- Higher instantaneous and integrated luminosity;
- Increase of the number of proton-proton interactions per bunch crossing;
- 6x increase in the accumulated radiation dose with respect to LHC.

Addressed research questions/problems

To provide the desired energy resolution over the full range of the signal events, the readout system must be fast to minimize the event-pile-up, the impact of signals generated by direct hits of particles in the photodetectors and to optimize the time resolution. Moreover the readout system must have a low power consumption and radiation hard components.

Front-end upgrade design



CATIA ASIC:

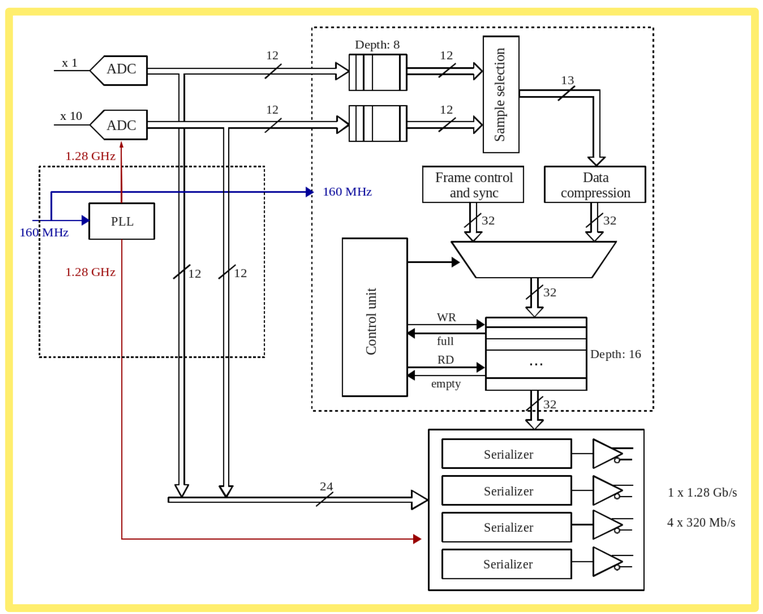
Trans-impedance Amplifier architecture
2 outputs, gain values: **x1** and **x10**

LiTE-DTU ASIC:

ADC resolution: **12-bit**
ADC sampling frequency: **160 MS/s**
Selection and compression unit

New Front-End card:

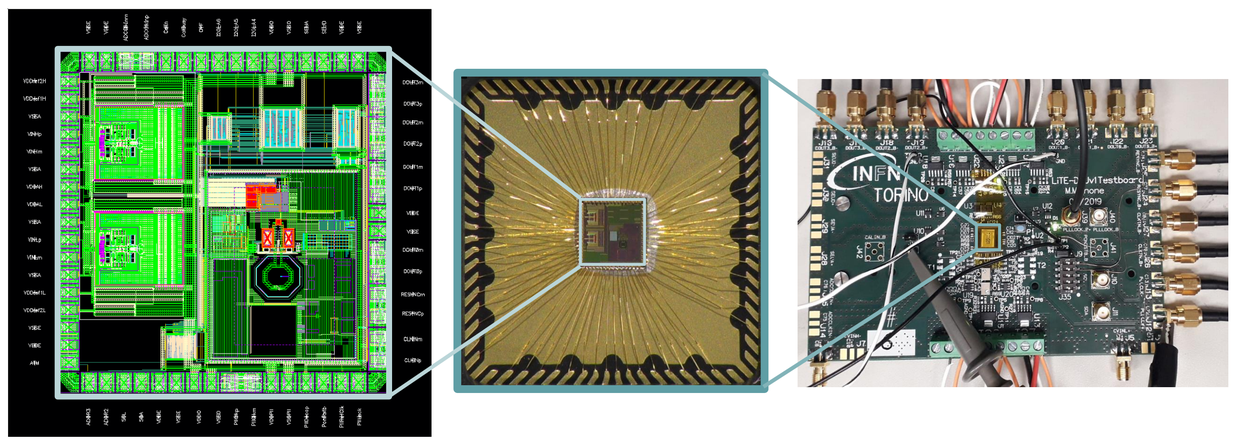
Fast rad-hard optical links to stream crystal data off-detector through CERN lpGBT/VL
Trigger data granularity: crystal level



Adopted methodologies

- **Design implementation:**
  - **Online data selection:** Look-ahead algorithm for gain data selection
  - **Lossless data compression:** simplified Huffman code in order to reduce the output bandwidth: data output format is optimized on code probability
  - **Data frame and trailer generation:** Cyclic Redundancy Check information transmitted in the frame trailer (data width: 32 bit polynomial: $x^{12}+ x^{11}+ x^3+ x^2+ x+ 1$)
  - **Data flow synchronization:** handshake process for idle pattern insertion
  - **Radiation damage mitigation techniques:**
    - Triple Modular Redundancy applied to registers and Finite State Machine
    - Hamming code for the FIFO: 32bit - 38bit
    - Spatial separation (at least 20 µm) between triplicated entities in order to avoid radiation-induced errors on more than one entity copy
- **Software:**
  - Verilog for RTL code, Genus and Innovus (Cadence) for synthesis and Place&Route purposes and Python scripts for debugging
  - VHDL for FPGA firmware

Novel contributions



- Technology: CMOS 65 nm
- Die size: 2 x 2 mm^2
- 63 pads
- Radiation tolerance validation
- TID tolerance up to 100 kGy
- SEU-protected control logic

- 2 ADC IP blocks (designed by an external company)
- Data selection, compression and transmission unit: **DTU**
- I^2C interface
- Phase Locked Loop (inherited from lpGBT project)
- Synchronization unit

Future work

LiTe-DTU tests:

- PLL clock qualification and ADC characterization
- Selection and compression methods validation
- Single Event Upset characterization, radiation hardness qualification and field test

Submitted and published works

- Mazza G., Cometti S., "*The front-end data conversion and readout electronics for the CMS ECAL upgrade*", Journal of Instrumentation JINST, vol. 13, no.03, 2018
- Cometti S., Mazza G., "*Design of the New Front-End Electronics for the Readout of the Upgraded CMS Electromagnetic Calorimeter for the HL-LHC*", Topical Workshop on Electronics for Particle Physics, Santa Cruz, 2017
- CMS collaboration, "*Observation of t t H Production*", Physical Review Letters, 2018
- Cometti S., Mazza G., "*The upgraded front-end electronics of the CMS electromagnetic calorimeter for the HL-LHC*", Incontri di Fisica delle Alte Energie, IFAE XVII edizione, 2018
- Cometti S., Mazza G., "*LiTE-DTU: Online Data Selection, Compression, and Transmission ASIC for the Upgraded Front-End of the CMS Electromagnetic Calorimeter*", 8th International Conference on Modern Circuits and Systems Technologies, MOCAST 2019
- Cometti S., Mazza G., "*New ASICs for the Very Front-End Card Upgrade of the CMS ECAL Barrel at the HL-LHC*", 15th Conference on PhD Research in Microelectronics and Electronics, PRIME 2019
- Cometti S., Mazza G., "*The upgraded readout electronics of the CMS ECAL: system overview*", Topical Workshop on Electronics for Particle Physics, Santiago de Compostela, 2019

List of attended classes

- 03QRHRV - Microelectronics for radiation detection II (03/06/2019, pt.: 35)
- 01SWPRV - Time management (08/01/2019, pt.: 2.67)
- Third Barcelona Techno Week Course on semiconductor detectors (02/07/2018, pt.: 35)
- 01RPQIW - Turbolenza atmosferica (14/06/2018, pt.: 25)
- 02RHORV - The new Internet Society: entering the black-box of digital innovation (14/05/2018, pt.: 8)
- Comprehensive Digital IC Implementation & Sign-Off (22/01/2018, pt.: 30)
- SQUAD 2017: Advanced School on Quantum Detectors (16/10/2018, pt.: 12)
- 01QTGIU - Advanced techniques for highly reliable electronic system design (25/07/2017, pt.: 33.33)
- VII International Course "Detectors and Electronics for High Energy Physics, Astrophysics, Space Applications and Medical Physics" (31/05/2017, pt.: 27)
- 01QTEIU - Data mining concepts and algorithms (27/02/2017, pt.: 26.67)
- 01QCOKG - Introduzione all'ottica e all'informazione quantistiche (24/02/2017, pt.: 33.33)
- 01SEZRV - Managing Ph.D. Thesis as a Project (20/09/2017, pt.: 10.67)
- 01PJMRV - Etica informatica (05/05/2017, pt.: 26.67)
- 01RISRV - Public speaking (16/02/2017, pt.: 6.67)
- 02LWHRV - Communication (16/02/2017, pt.: 6.67)

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PhD program in
Electrical, Electronics and Communications Engineering