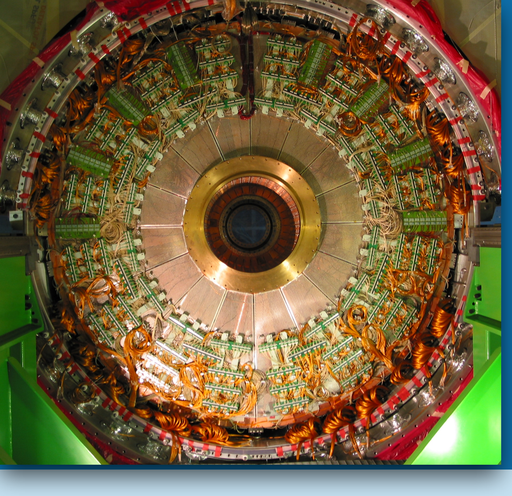

ATLAS Liquid Argon Calorimeter Frontend electronics Phase 2 upgrade

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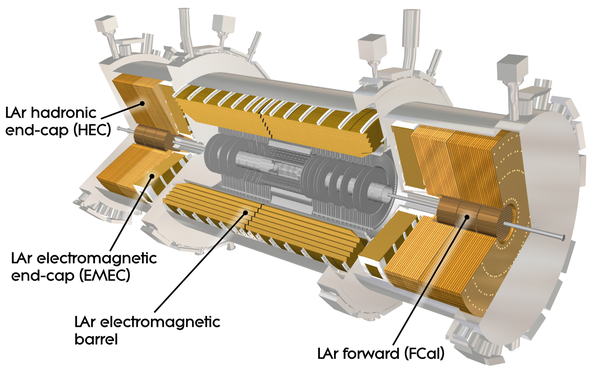
1. Introduction

ATLAS Liquid Argon (LAr) Calorimeter

- Sampling calorimeter based on **liquid argon** as **active medium**.
- Measures energy, position and timing of **electromagnetic showers** (electrons and photons) + jets [1].



EM calorimeter (barrel + endcap)
- Lead + LAr
- 173,312 read-out channels
- Coverage: $|\eta| < 3.2$

Hadronic Endcap (HEC)
- Copper + LAr
- 5632 read-out channels
- Coverage: $1.5 < |\eta| < 3.2$

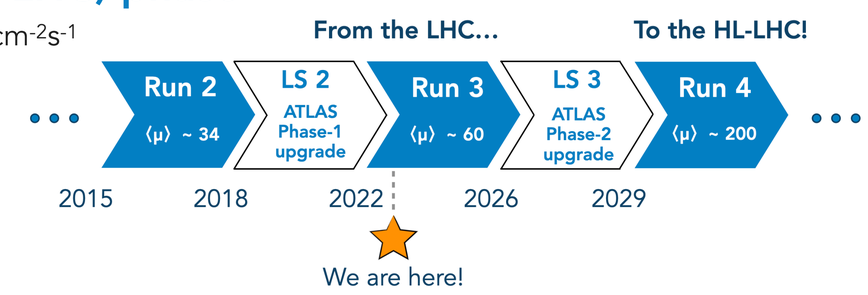
Forward Calorimeter (FCal)
- Copper/Tungsten + LAr
- 3524 read-out channels
- Coverage: $3.1 < |\eta| < 4.9$

= **182,468 cells**!

➡ **Read-out electronics** samples at **40 MHz** and sends off the detector for analysis and triggering!

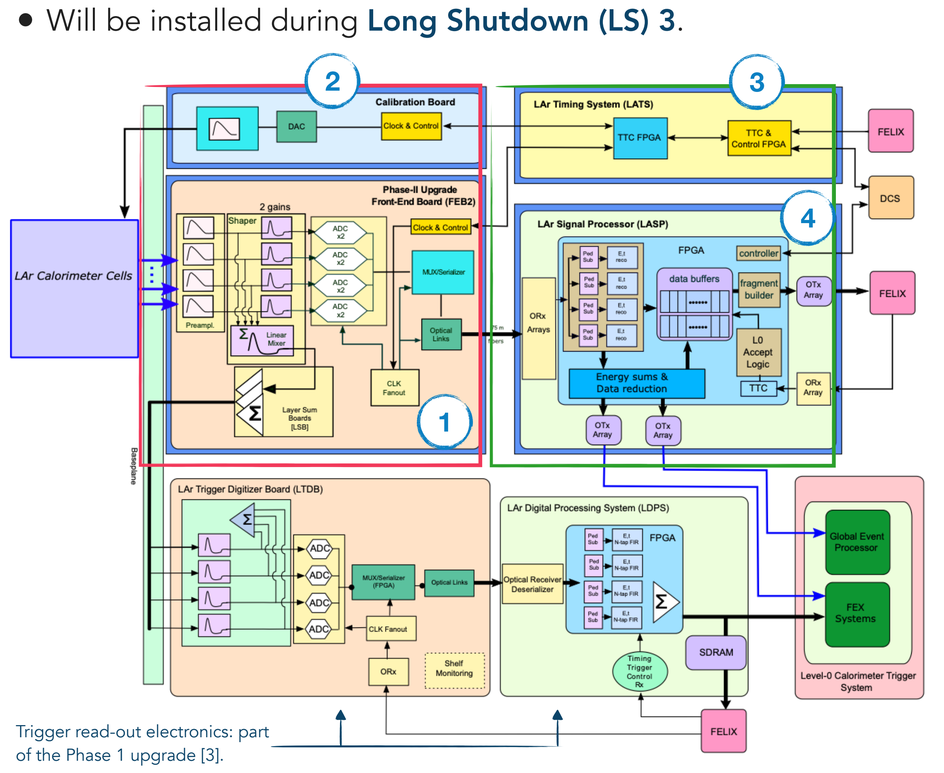
The High Luminosity LHC (HL-LHC) phase

- Instantaneous luminosity up to 7×10^{34} cm^{-2}s^{-1} = **7 × design luminosity**.
- **Challenging operation** environment!
  - ATLAS **TDAQ** system needs to handle **simultaneous *pp* interactions** (⟨μ⟩) up to ~**200**.
  - Stronger **radiation tolerance** for on-detector electronics.



2. LAr Phase 2 upgrade

- To accomodate the data volume of HL-LHC, the **on-detector** and **off-detector electronics** need to be **redesigned** and replaced [2].
- Will be installed during **Long Shutdown (LS) 3**.

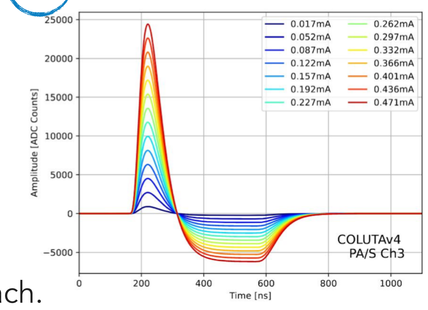


Trigger read-out electronics: part of the Phase 1 upgrade [3].

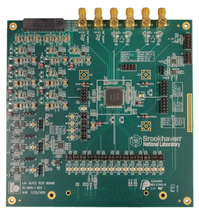
3. On detector electronics

Front-end board (FEB2) 1

- Receives signal from calorimeter cells and performs **analog processing**.
- Signals are **digitized**, **serialized** and **transmitted** off-detector via lpGBT protocol.
- **1524 FEB2s** with **128 channels** each.



ALFE2 custom ASIC: Pre-Amplifier/Shaper (PA/S)

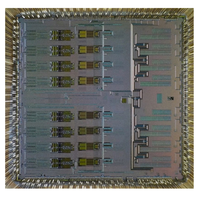


Provides **amplification** and **CR-(RC)² shaping** over **two overlapping gain scales** (High and Low), based on 130 nm CMOS technology, and will have 4-channel summing for hardware trigger.

- Non-linearity < 0.1% and noise < 350 nA for 10 mA channels.
- Radiation tolerance: performant after 12 kGy doses.

= **Exceeding specifications**!

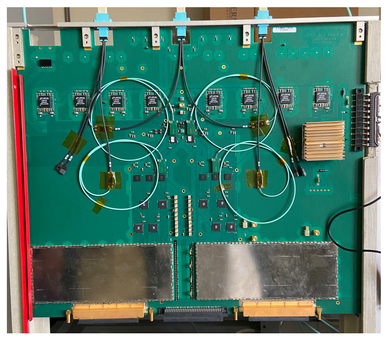
COLUTAv4 custom ASIC: Analog to Digital Converter (ADC)



Digitizes PA/S outputs at **40 MHz** with **16-bit dynamic range** and > 11-bit precision, covering **8 channels** (4 LAr channels × 2 gains), based on 65 nm CMOS technology.

- Excellent uniformity performance with injection of 2MHz sine wave.
- Low pedestal noise: RMS of 12 ADC counts.

FEB2 testing (Slice Test Board)

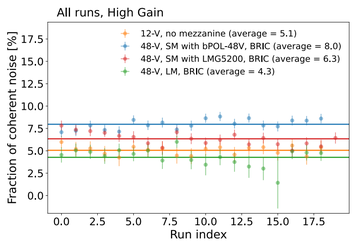


- Slice board with **32 channels** (1 / 4 of FEB2) with same **density** as **final** FEB2.
- Used for **characterizing energy** and **timing**, **linearity**, and **multi-channel performance**.

Power distribution

Key results

- Tested various solutions for **on-board stepping down 48-V** power supply to the **voltages** needed by the **ASICs** with the help of **mezzanines**.
- **Noise** level **under control** using **radiation-soft** solutions.



Outlook

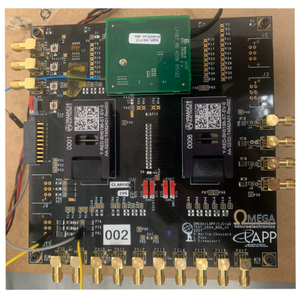
- Tests with **CERN-developed radiation-hard** solutions using bPOL48V + bPOL12V.
- Perform deeper testing with **full-sized FEB2 prototype** (now in production, expected in Summer 2023).

Calibration board 2

- Injects **known** calorimeter **signals** to **calibrate** read-out electronics.

  ➡ Must cover **full dynamic range** (320 mA, up to 7.5 V output): requires HV-CMOS technology.

- **122 boards** with **128 channels** needed to calibrate 182,468 cells!



CLAROCv4 custom ASIC

Creates pulse by opening high frequency (HF) switch (based on 180 nm XFAB technology).

LADOCv2 custom ASIC

16-bit **Digital to Analog Converter**, commands HF switch (based on 130 nm TSMC technology).

Key results

- Both ASICs meet **linearity requirements** (non-linearity < 0.1% up to 300 GeV).
- Radiation testing of ASICs ongoing.

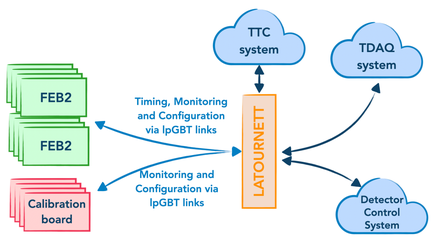
Outlook

- **Refine layout** in LADOCv2b and CLAROCv4b.
- **Install** the chips **on prototype calibration boards** for testing.

4. Off detector electronics

LAr Timing System (LATS) 3

Handles Trigger, Timing and Control (**TTC) distribution, configuration, and monitoring** of the **FEB2** and **Calibration** boards, relying on **lpGBT protocol**.



LATOURNETT ATCA board

Equipped with **1 central + 12 array** AREA Cyclone 10 **FPGAs**, each communicating with **12 on detector boards** via optical links.

Key results

- Completed **test board design** and prepared **test bench**.
- Proposed architecture for **integration** with **ATLAS TTC and TDAQ systems**.

Outlook

- Test prototype and system integration.

LAr Signal Processor (LASP) 4

Applies **digital filtering** to waveform from the FEB2, calculates **energy** and **time**, and **transmits to TDAQ** systems. ➡ Considering **ML architectures** to implement in FPGA for **energy reconstruction**.

LASP ATCA board (main blade) + sRTM

- Receives data from 8 FEB2s (=**1024 channels**).
- Computes energy and time at up to **1.8 Tb/s**.
- **Sends output** to DAQ **at 25 Gb/s** upon receiving a trigger accept signal.
- Implemented using two **Stratix 10 FPGAs** (migration to **Intel Agilex** ongoing)

Key results

- **Continuously running** test board thanks to **regular monitoring** of **temperature**, **voltage** and **current**.
- Validated power, I²C sensors, and FPGA configuration.

Outlook

- **Optimize** FPGA **resource usage** and **power** consumption.
- Test **integration** with **FEB2**.

5. Summary

- **On-detector** and **off-detector electronics for the LAr calorimeter** are being re-designed, to cope with the **challenges** of **data taking** conditions at **HL-LHC**.
- All electronics will be **replaced** by **2029**, and are designed to **run** throughout the **full HL-LHC operation** (~ **2041**).
- Major **progress** on **LAr Phase 2 upgrade**:

  ➡
  - Custom **ASICs meet / exceed specifications** for analog performance!
  - **Promising test results** on FEB2 pre-prototype (**Slice Test Board**), and full-size FEB2 prototype in preparation.
  - **LASP** test boards **running** and firmware design on track.

On schedule for installation into ATLAS cavern after the end of Run 3!

References

[1] ATLAS Collaboration. *ATLAS liquid-argon calorimeter: Technical Design Report*, CERN-LHCC-96-041.

[2] ATLAS Collaboration. *ATLAS LAr Calorimeter Phase-I Upgrade: Technical Design Report.* CERN-LHCC-2013-017.

[3] ATLAS Collaboration. *ATLAS LAr Calorimeter Phase-II Upgrade: Technical Design Report.* CERN-LHCC-2017-018.

LHCP 2023 - Large Hadron Collider Physics Conference. Belgrade, 22-26 May 2023