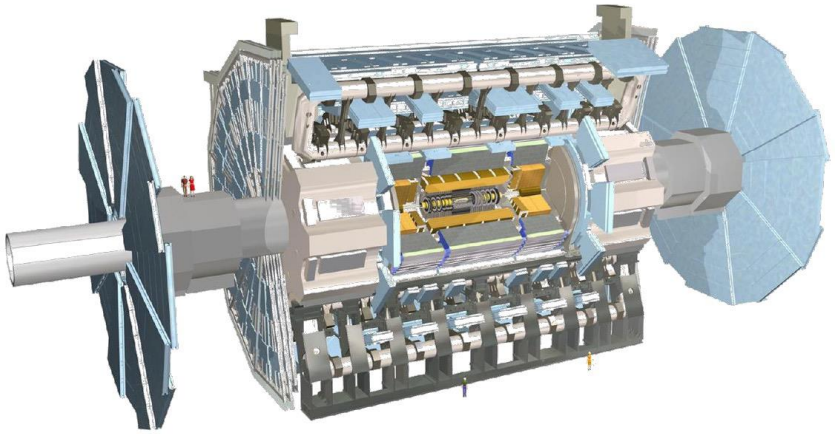
ATLAS Phase 2 upgrade

Khuram Tariq (IHEP, Beijing)

On behalf of the ATLAS collaboration



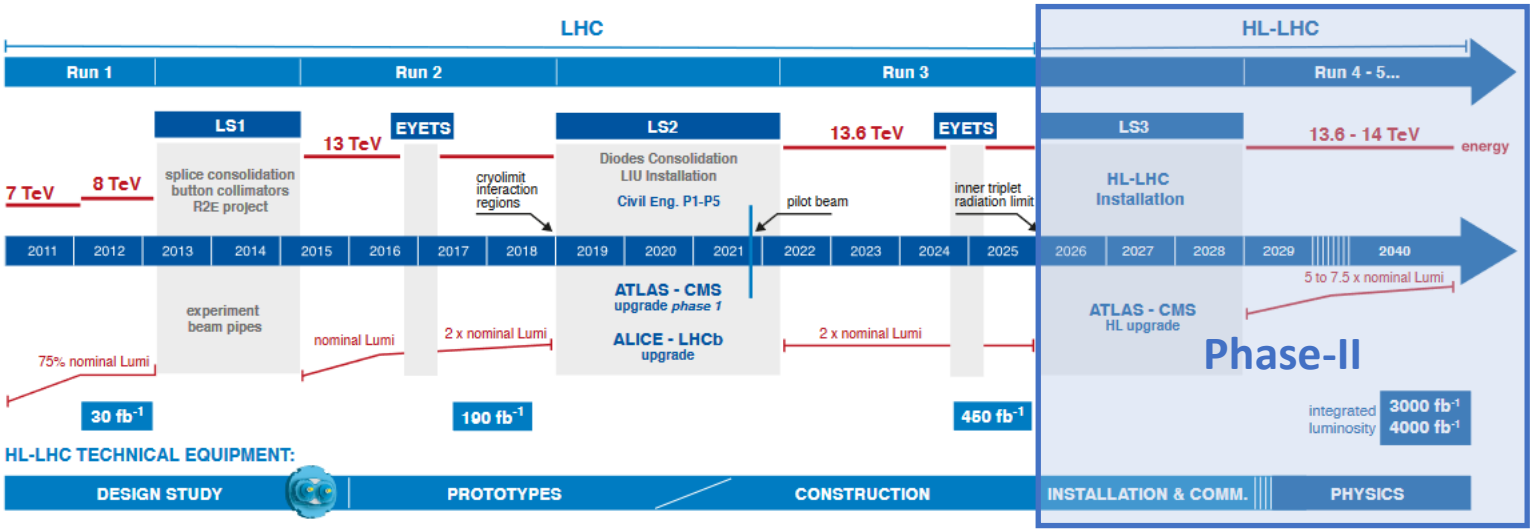
Higgs Hunting 2024

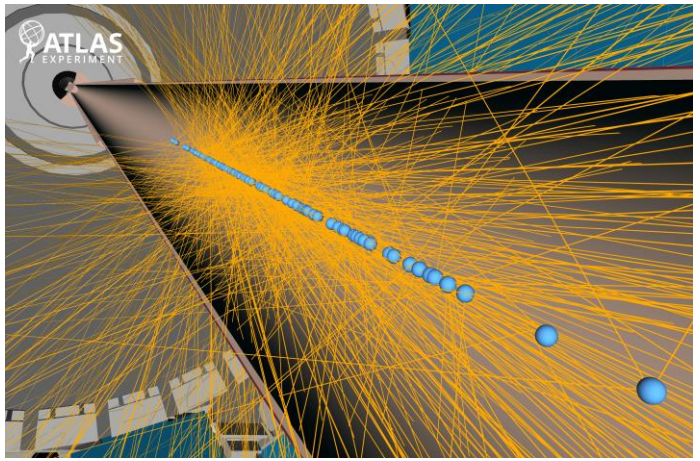
23-25 September 2024

Institute of High Energy Physics
Chinese Academy of Sciences

ATLAS EXPERIMENT

The High Luminosity LHC





The HL-LHC program aims at collecting at least 3000 fb^{-1} of 14 TeV pp collisions

This data will be essential to improve the knowledge of:

- Higgs couplings => uncertainty will be improved to~2-4%
- Extend the searches for physics beyond the Standard model
- More details in the talk [physics prospects for HL-LHC - ATLAS]

The HL-LHC programs challenges the detector and detector electronics

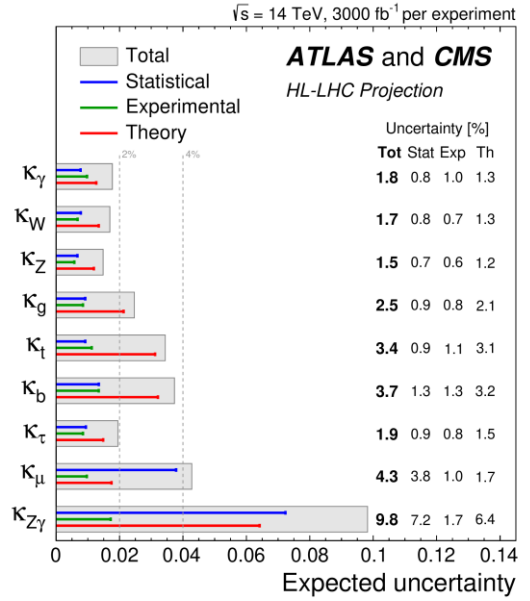
Higher luminosity => from 2x10^{34} cm^{-2}s^{-1} up to 7.5x10^{34} cm^{-2}s^{-1}

Higher L1 trigger rates => from 100 kHz to 1 MHz

Higher pile-up conditions => from <μ>=55 up to <μ>=200

Increased radiation doses => about 20x increase up to a few MGy TID for 4000 fb-1

Major upgrades of all experiments needed to cope with these requirements!



ATL-PHYS-PUB-2022-018

ATLAS Phase-2 Upgrade

New Inner Tracking Detector (ITk)

- All silicon with 9 layers up to $|\eta| = 4$
- Less material, finer segmentation
- Improve vertexing, tracking, b-tagging

New High Granularity Timing Detector (HGTD)

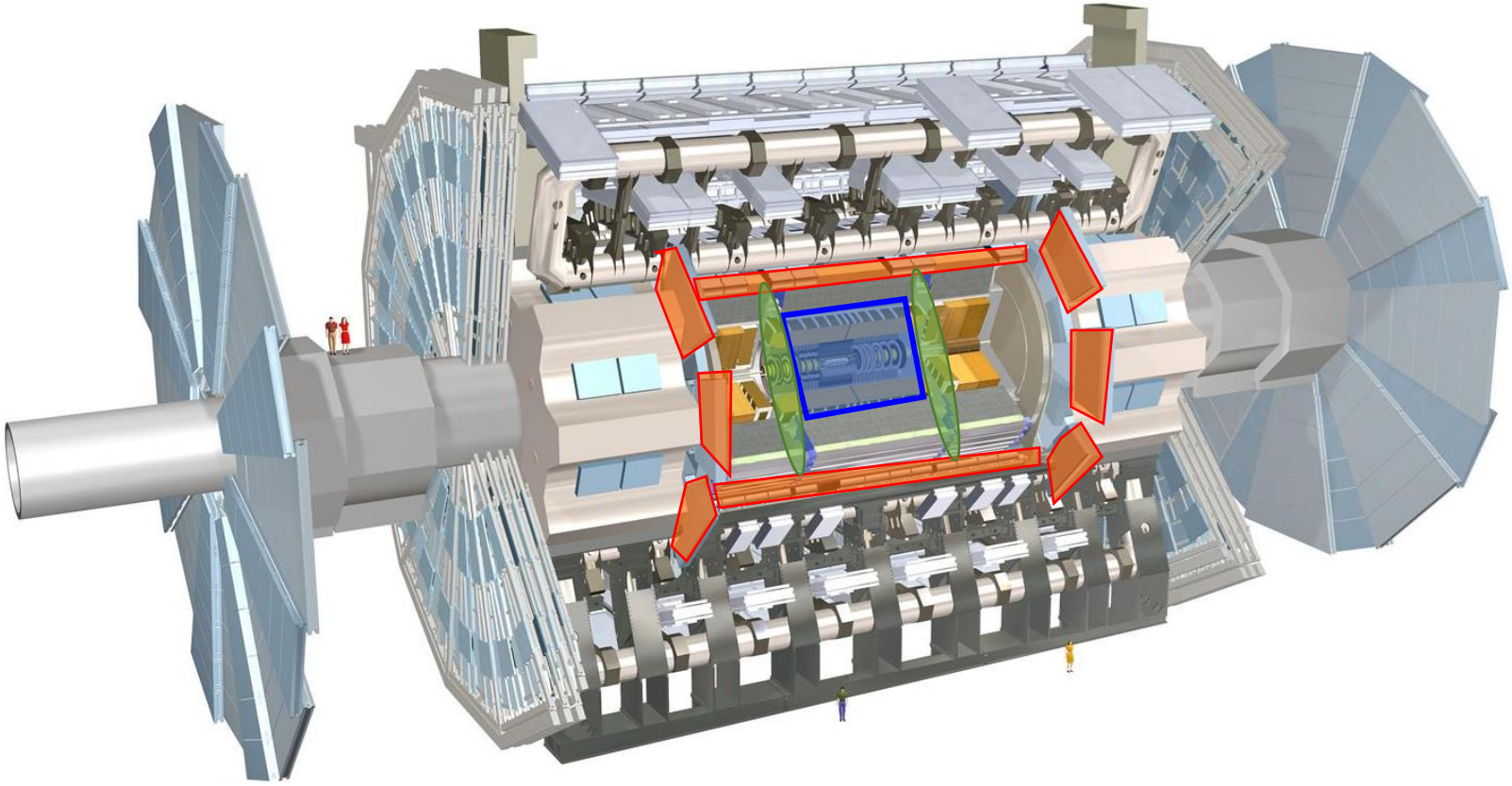
- Precision track timing (30 ps) with LGAD in the forward region
- Improved pile-up separation and bunch-by-bunch luminosity

Calorimeter Electronics

- On-detector/off-detector electronics upgrades of LAr and Tile Calorimeter
- Provide 40 MHz readout for triggering

New Muon Chambers and electronics

- Inner barrel region with new RPCs, sMDTs, and TGCs
- Improved trigger efficiency/momentum resolution, reduced fake rate



Upgraded Trigger and Data Acquisition System

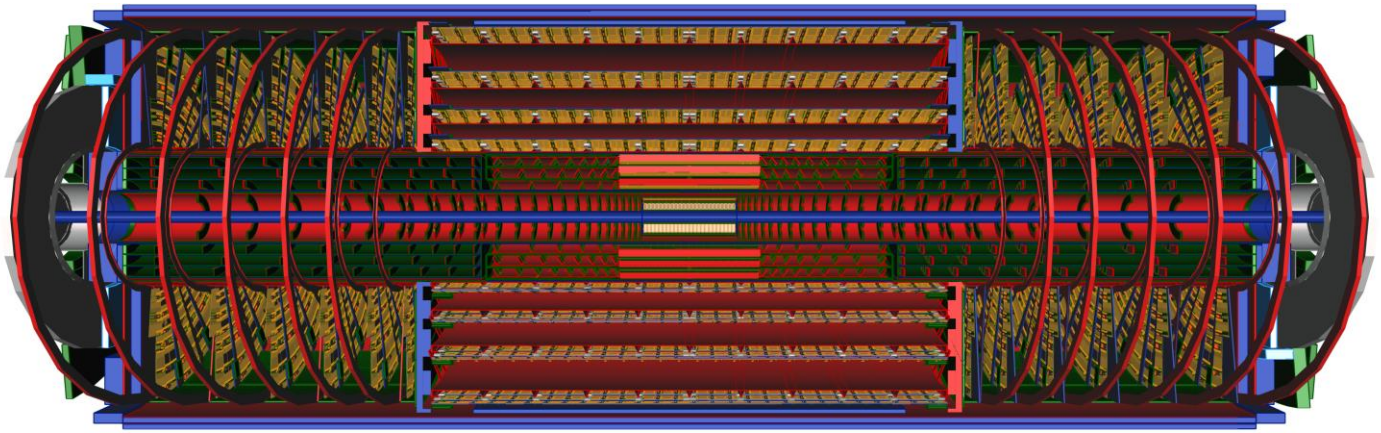
- Single Level Trigger with 1 MHz output (x 10 current)
- Improved DAQ system with faster FPGAs

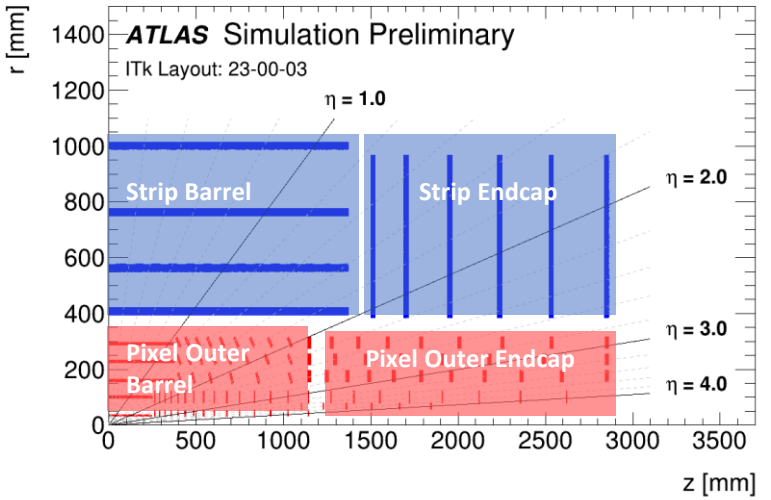
Additional small upgrades

- Luminosity detectors (1% precision)
- HL-ZDC (Heavy Ion physics)

Not covered in this talk!

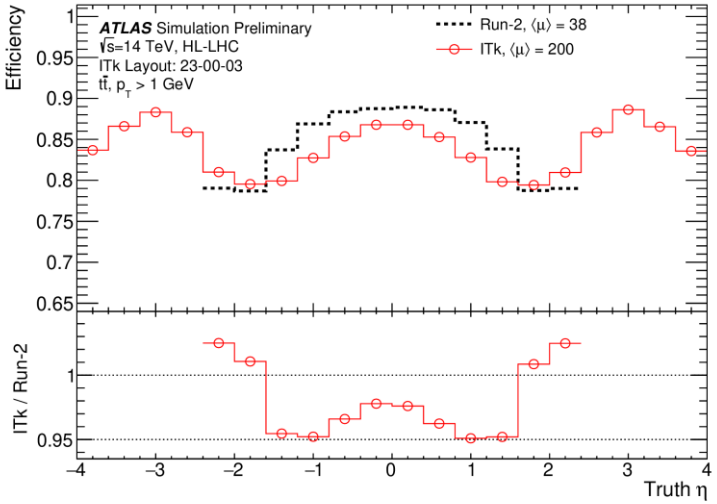
A new tracker system, Inner Tracker(Itk)





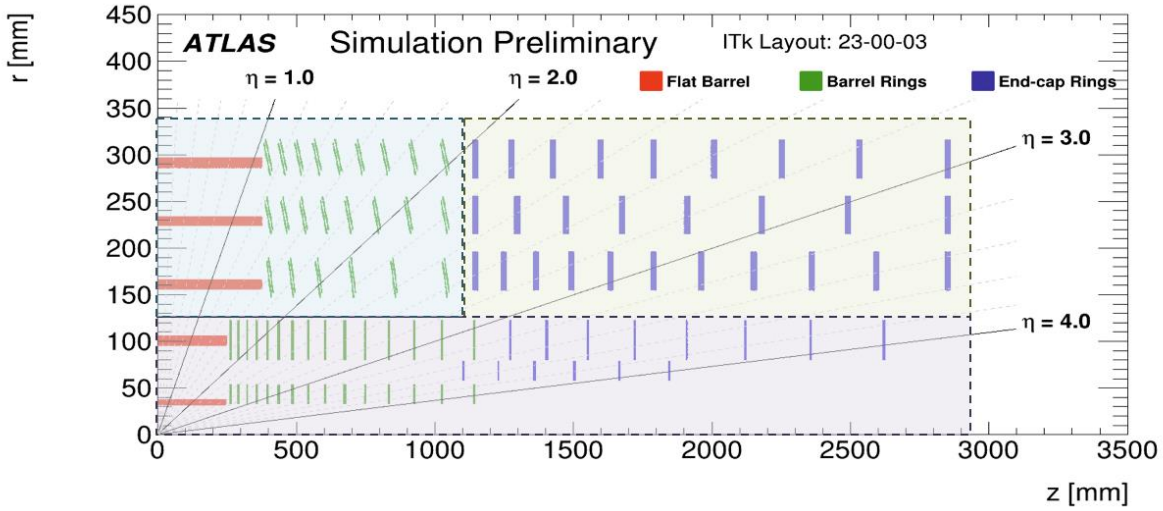
Full replacement of ATLAS tracking detectors with new all-silicon Inner Tracker (ITk)

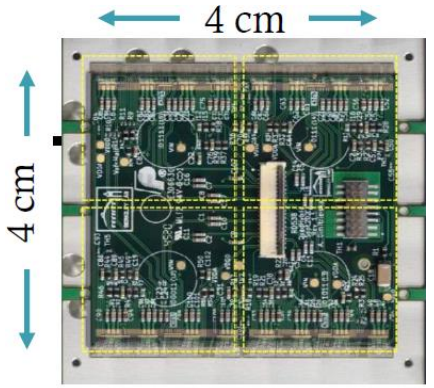
- Extended tracking acceptance up to $|\eta|=4$:
  - increased lepton reconstruction + jet flavour-tagging acceptance
  - improved pile-up suppression
- Inner part made from 5 barrel layers and end-cap rings of pixel detectors, outer part made from 4 barrel layers and 6 end-cap disks of strip detectors
  - Pixel: 13m^2 active area, 9400 modules, 1.4 giga-channels
  - Strips: 165m^2 active area, 17888 modules, 60 mega-channels
- Reduced material budget with respect to current ID
- Reduced fake rate even considering increased pileup
- Tracking performance comparable or better than before at much higher pile-up conditions
  - ≥ 13 hits/track in the barrel and ≥ 9 hits / track in the forward region



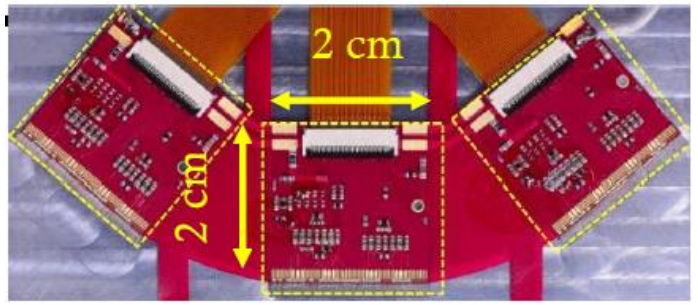
ATL-PHYS-PUB-2021-024

The ITk Pixel Detector





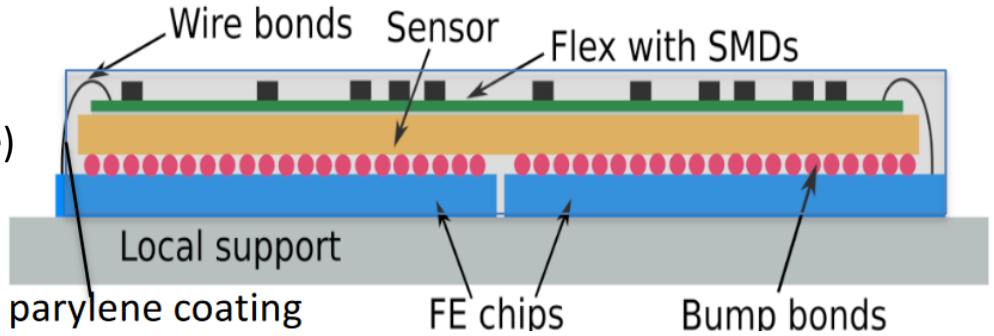
quad module



triplet module

Organized as three sub-systems (inner, outer barrel, outer endcaps)

- Inner system replaceable (radiation damage)
- Almost 10 times larger than current one in terms of area and number of modules
- Pixel sizes: 25x100 μm^2 (innermost barrel layer only), 50x50 μm^2 (everywhere else)
- 3D sensors in the innermost layer and planar sensors in the other layers
- Pre-production modules tested in test beams meet requirements after irradiation
- Sensor production is in progress
- ASIC production has been started
- Most of other components in pre-production phase

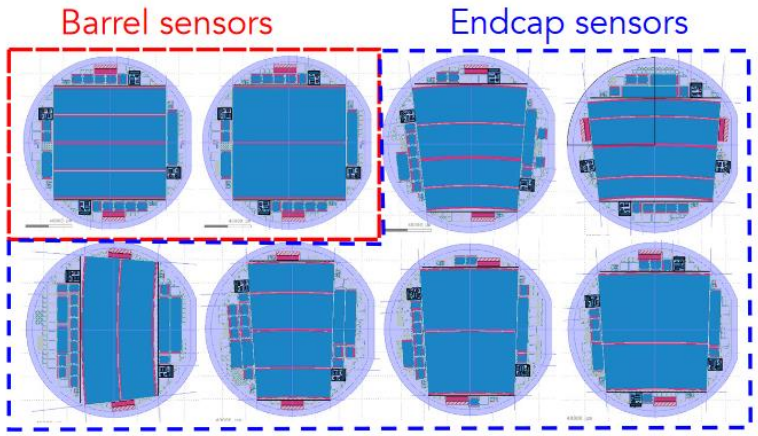


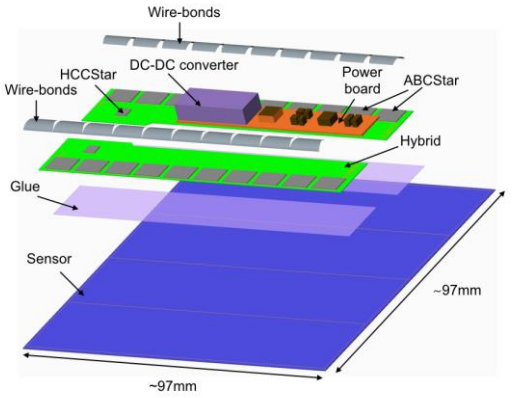
FE chip connected to the sensor by bump-bonds

The ITk Strip Detector

Organized as two systems (Barrel and Endcaps):

- Strip subsystem covering up to $|\eta|<2.7$ with 4 barrel layers, 6 end-cap disks
- Almost 3 times larger than current one in terms of area and 5 times as number of modules to be built
- Smaller strip lengths for better occupancy
- Radiation-tolerant up to fluences of 1.6×10^{15} n_{eq}/cm^2 (expected max 5.4×10^{14} n_{eq}/cm^2

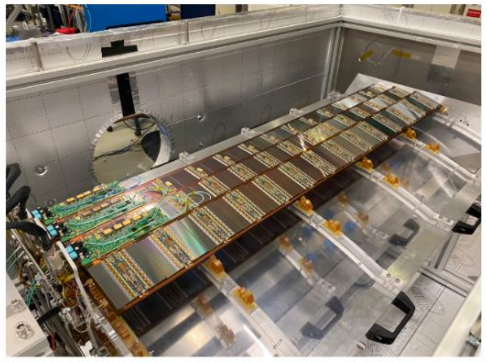


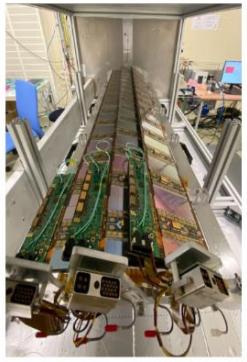


Short Strip Barrel module

Status:

- ITk Strips is entering production for all components
- ASICs and sensors mostly delivered
- Mechanical sub-structures in pre-production
- Many system tests are ongoing

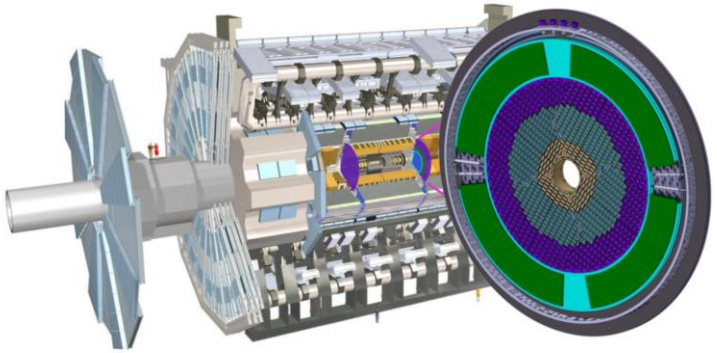


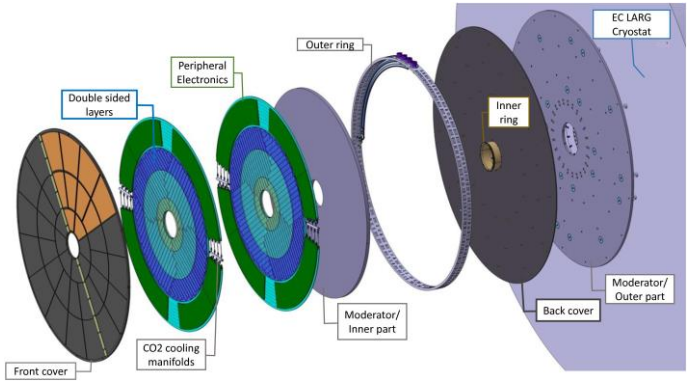


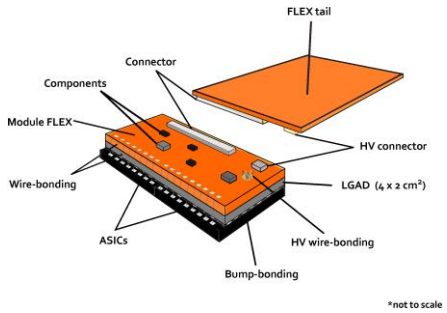
Barrel system test @ CERN

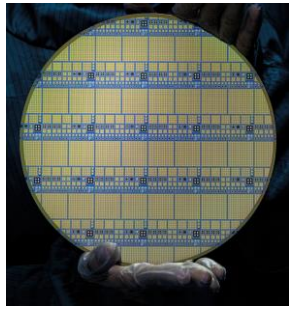
Endcap system test @ DESY

High-Granularity Timing Detector

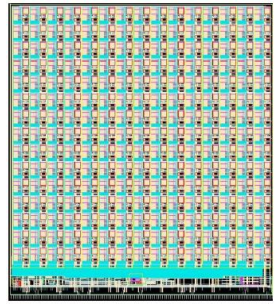








LGAD sensor



ALTIROC-A

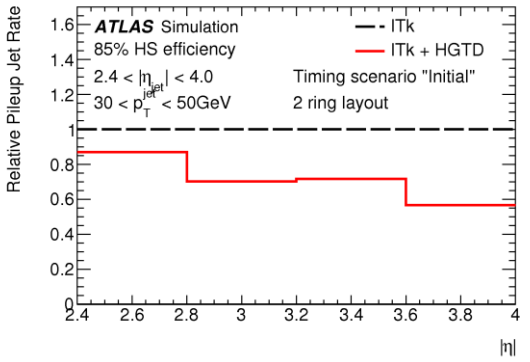
Completely new detector between ITk and endcap calorimeter

High Granularity Timing Detector (HGTD)

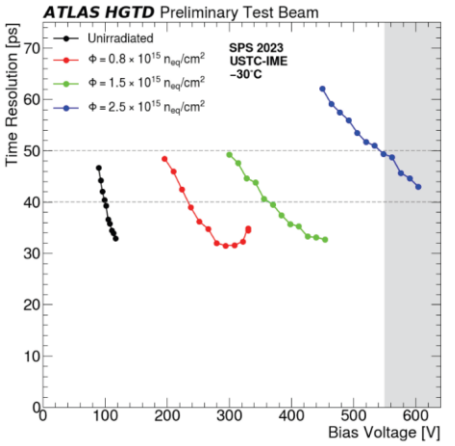
- Add time information to be combined with ITk position to improve pile-up rejection $(2.4 < |\eta| < 4)$
- Time resolution per hit of 35 ps and 70 ps after 2.5×10^{15} n_{eq}/cm^2 irradiation

Low gain avalanche detector (LGAD) technology sensors, bump-bonded to read-out ASIC.

- Pre-production complete, performance matches design requirements
- Read-out ASIC (ALTIROC3) shows good performance
- First ALTIROCA and irradiated hybrids are being characterized at test beam



CERN-LHCC-2020-007



ATL-HGTD-SLIDE-2024-384

R&D coming to an end, moving towards mass production and construction of HGTD

Muons Spectrometer upgrade

Upgrades of several types of muon chambers along with readout electronics and power systems upgrade

Improved trigger efficiency and momentum resolution, reduced fake rate

sMDT

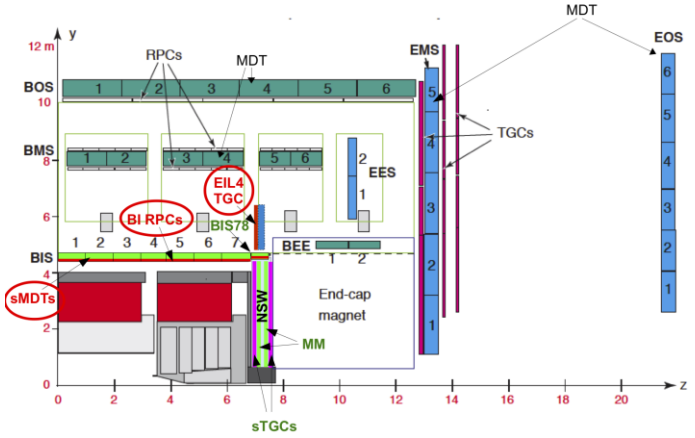
- Chamber production complete, High precision and performance
- ASICs are fully produced, Pre-production boards are being validated

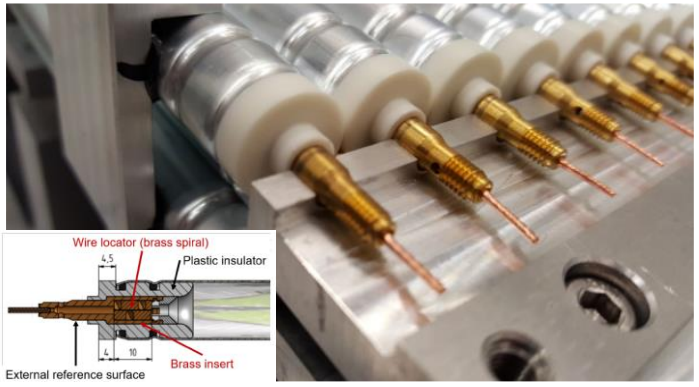
RPC (to improve trigger coverage)

- Mechanics design validated , Production is about to start
- ASICs submitted for production, Full validation of readout chain

TGC (to improve trigger rejection)

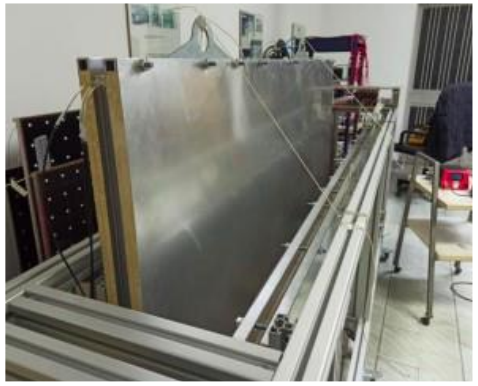
- Chamber production started, Several chambers already done
- ASIC production completed, Moving towards board production



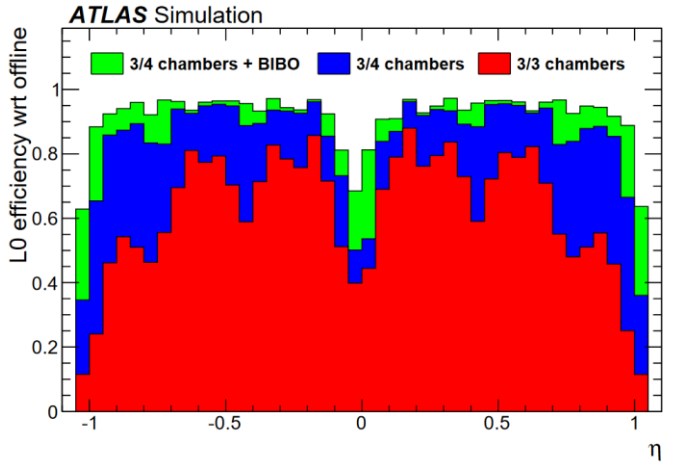


New sMDT chamber tubes

TGC EIL 4 prototype



RPC prototype



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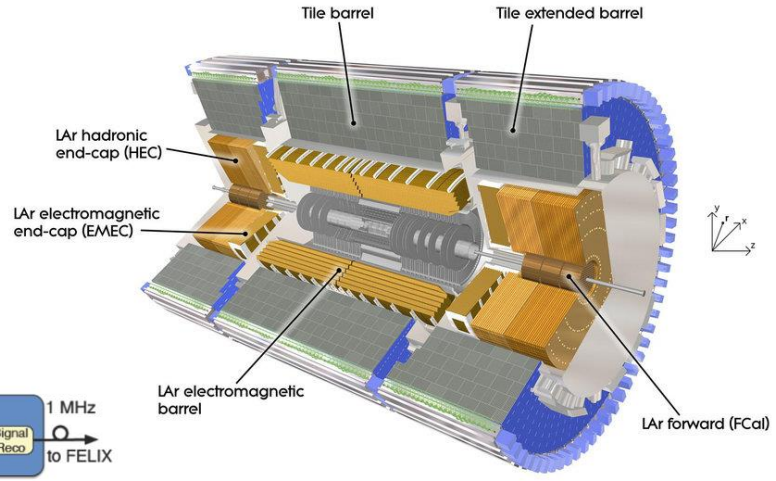
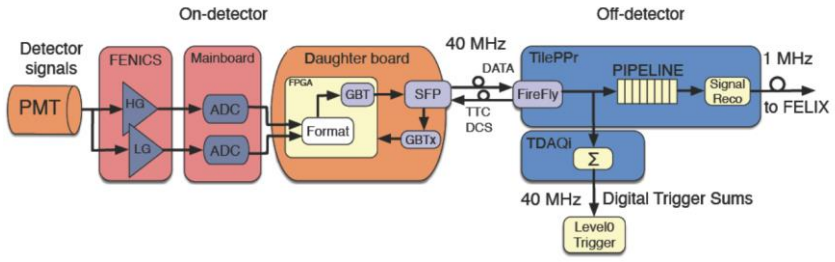
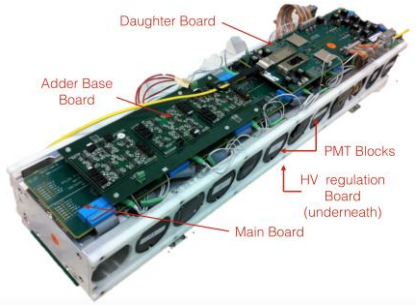
Calorimeters upgrade

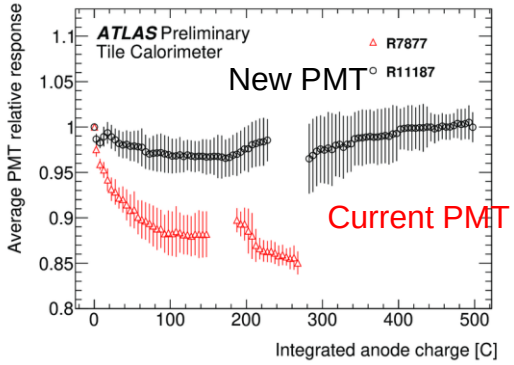
Tile Calorimeter Upgrade

- Replacement of on detector and off detector readout electronics
- Replacement of LV and HV systems
- Upgrade of calibration systems
- New super-drawer mechanics









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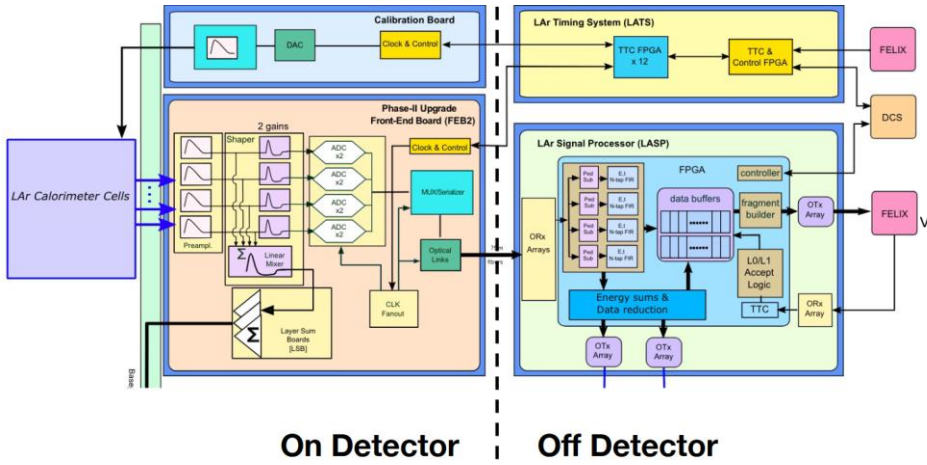
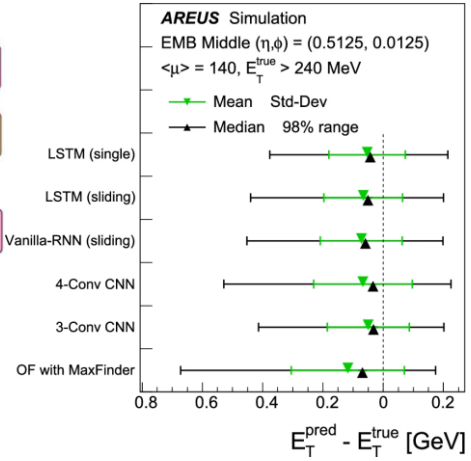
Electromagnetic calorimeter (LAr)

- new radiation hard readout electronics, providing precision readout of all calorimeter cells at 40 MHz
- Final designs for the off-detector
- boards and firmware are underway
- Irradiation tests ongoing
- On schedule for installation into
- ATLAS cavern beginning in 2027





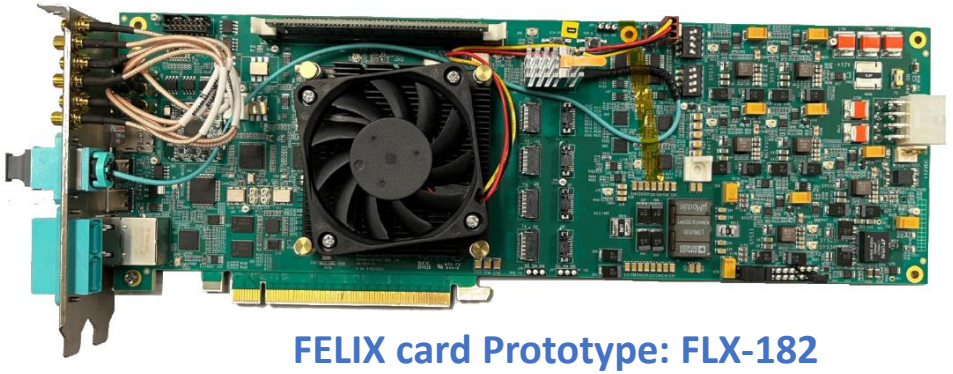
ATL-LARG-PROC-2021-001

Trigger and DAQ (TDAQ) upgrade

Huge increase in data rates and thus data throughput, bringing extra complexity!

DAQ:

- Completely new architecture based on custom **FPGA cards (FELIX)**



FELIX card Prototype: FLX-182

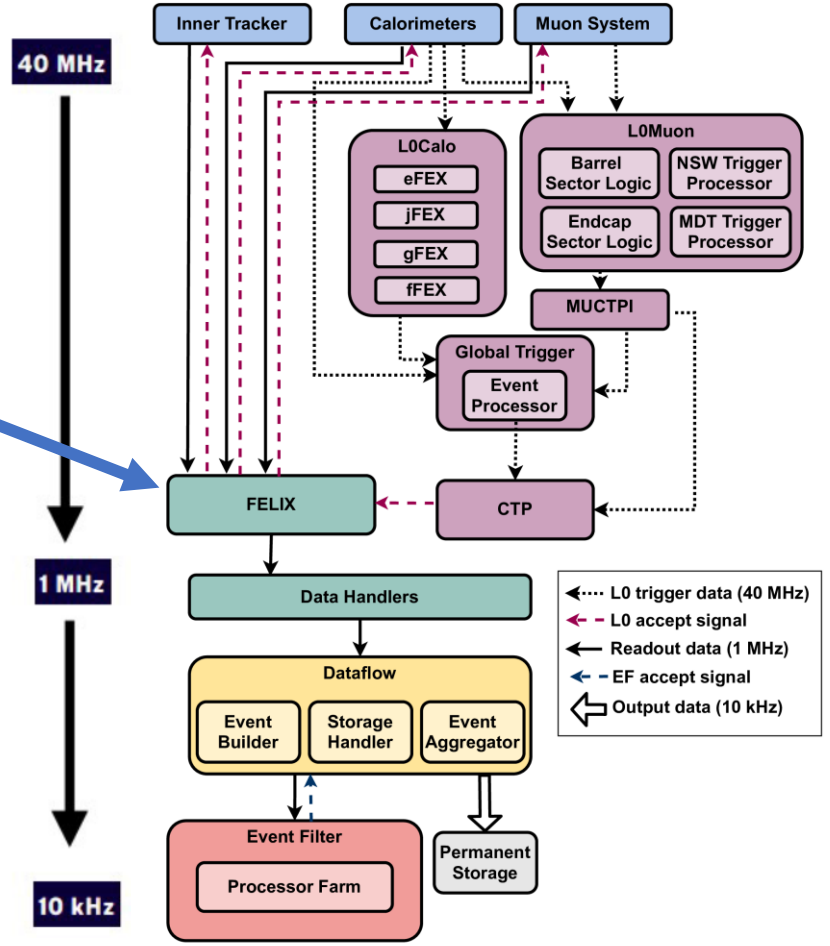
Trigger:

Hardware based Level-0:

- Trigger data input at 40 MHz from Calorimeters and Muons
- Output Rate 1 MHz (currently 100 kHz), latency 10 μs
- Exploits full detector granularity with new **Global Trigger component**

Software based Event Filter:

- Output rate 10 kHz (currently 3 kHz)
- Extended tracking range fully exploiting ITk, improves muon trigger efficiency
- Accelerators (GPU), Machine Learning (ML) and Neural Networks (NN) for online reconstruction



New TDAQ architecture

Summary

- ATLAS has an ambitious upgrade program to fully exploit the physics potential of HL- LHC
- Upgrades are underway to provide better performance in a challenging environment such as high radiation doses and high pile-up
- New detectors and read-out electronics are being developed to ensure the high efficiency and high-quality data taking in HL-LHC era
- Many projects are entering pre-production or production phase
  - Schedule will also be a challenge, both for construction, as well for a compact installation during the next long LHC shutdown

With all these upgrades in place, ATLAS will be well prepared for many years of data taking at the high luminosity LHC!