https://atlas.cern/

ATLAS Upgrades for the High-Luminosity LHC

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Representing the ATLAS Collaboration

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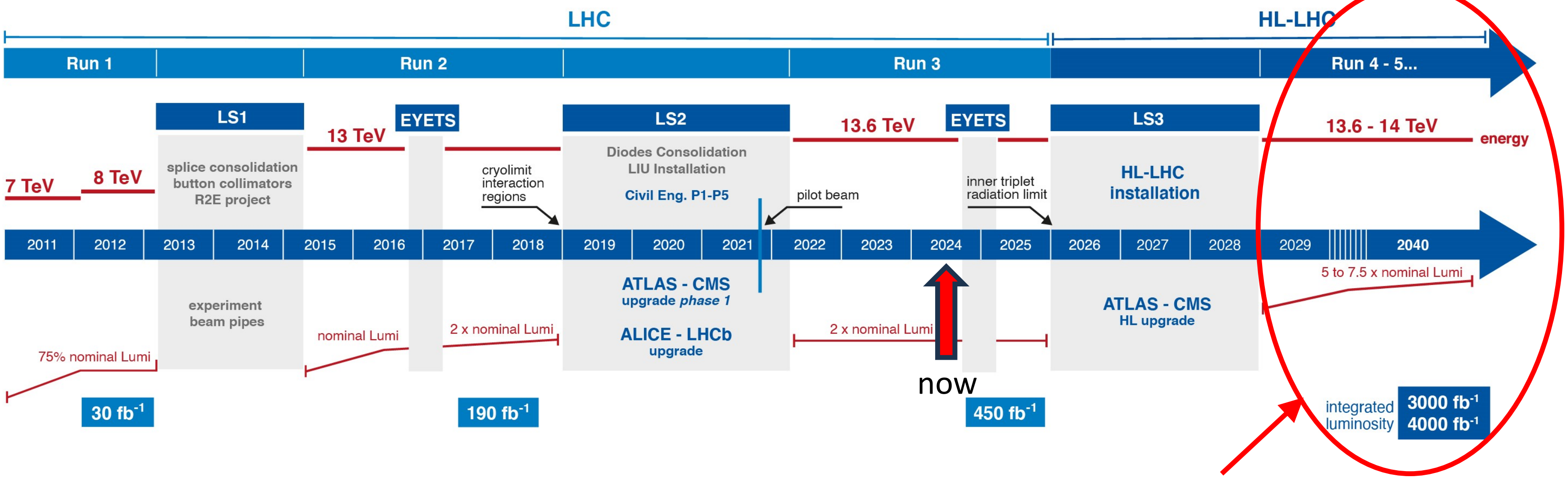
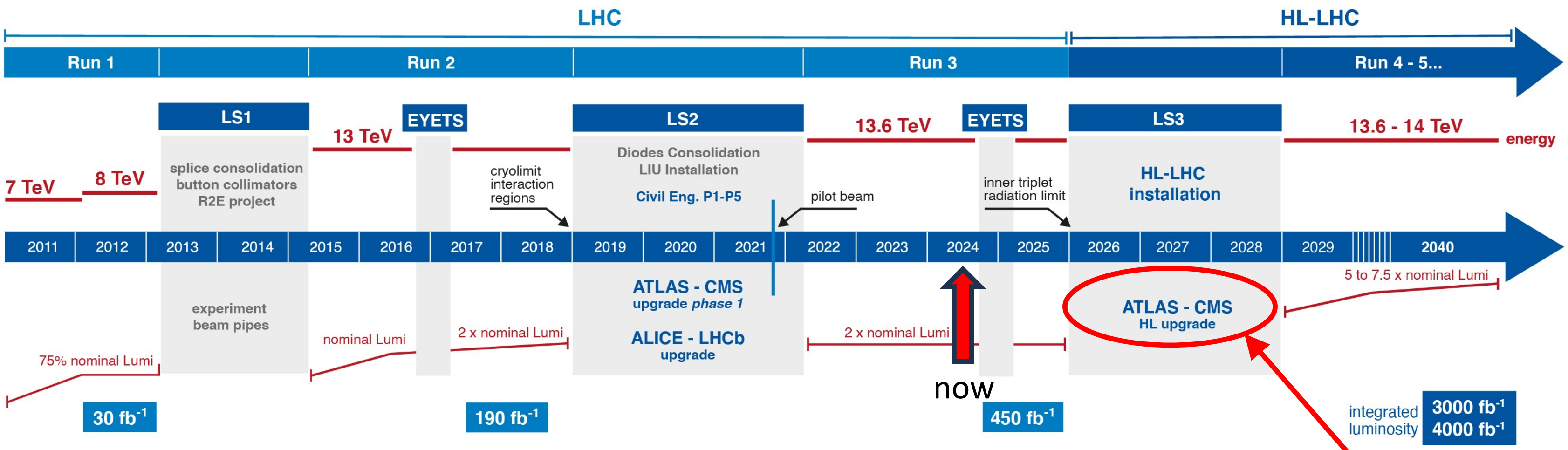
The High-Luminosity LHC



- Most of the data expected for the LHC physics program will only be delivered during the HL-LHC phase.
- > 3000 fb^{-1} of data at $\sqrt{s} \simeq 14$ TeV will allow precision measurements to constrain the Standard Model in yet-unexplored phase spaces, in particular in the Higgs sector.

LHC → HL-LHC: Challenges for Detectors



- Instantaneous nominal luminosity x 5-7 over current, integrated luminosity x 10
  - → New radiation-hard components, complete new tracker, finer sensor granularity everywhere.
- Increase of overlapping p-p events (“pileup”) x 4-5 over current
  - → More energy in calorimeters, more jets especially in the forward region, high hit rates.

→ Increased readout rate required: x 10 over current

- new front-end and/or back-end electronics for many sub-detectors
- new DAQ and trigger system to cope with increased complexity and bandwidth

“Phase-II” Upgrades:

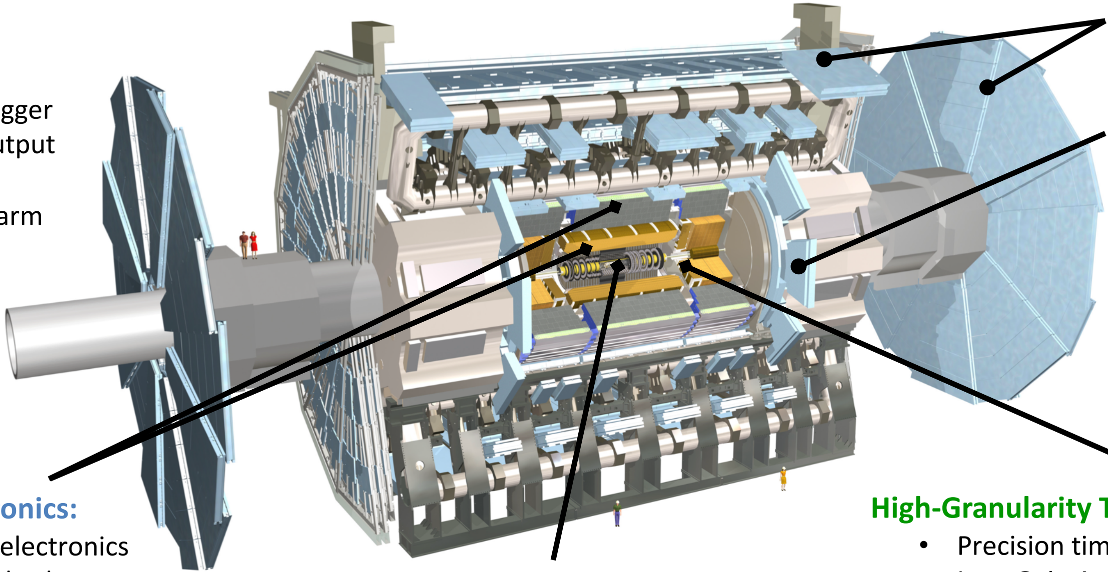
- R&D since ~2010
- Currently largely in production
- Completion, Installation, and Commissioning during LS3

ATLAS Phase-II Upgrades at a Glance

New and improved detectors:

Trigger and DAQ Upgrade:
- Single-level trigger with 1 MHz output (x10 current)
- Faster event farm

Muon Chambers:
- New Inner-Barrel chambers
  - Improved trigger efficiency and momentum resolution
  - Reduced fake rate
- Upgrade of the detector electronics for the new T/DAQ



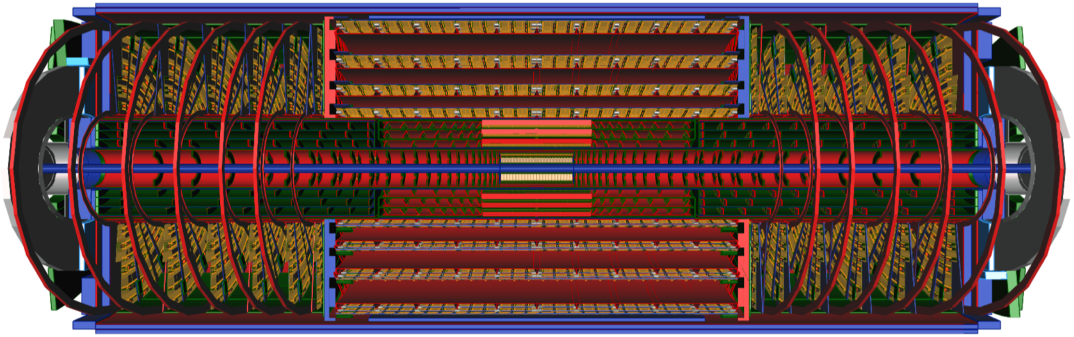
Calorimeter Electronics:
- On-detector electronics upgrades for both LAr and Tile Calorimaters

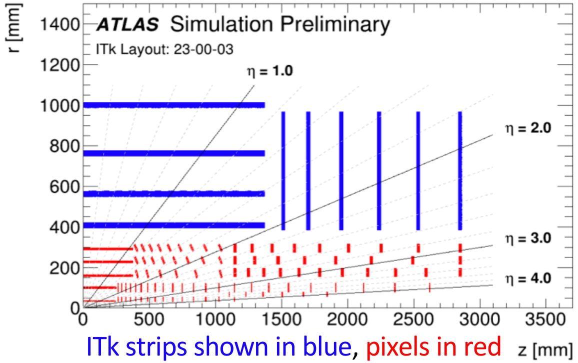
→ 40MHz readout for triggering

Inner Tracker (ITk):
- Replacement for Inner Detector
- All-silicon, 9 layers up to $|\eta|=4$
- Less material, finer segmentation → improved vertexing, tracking, b-tagging

High-Granularity Timing Detector:
- Precision time reconstruction (30ps) with Low-Gain Avalanche Detectors (LGADs)
- Improved pile-up rejection in the forward region
- Also bunch-by-bunch luminosity

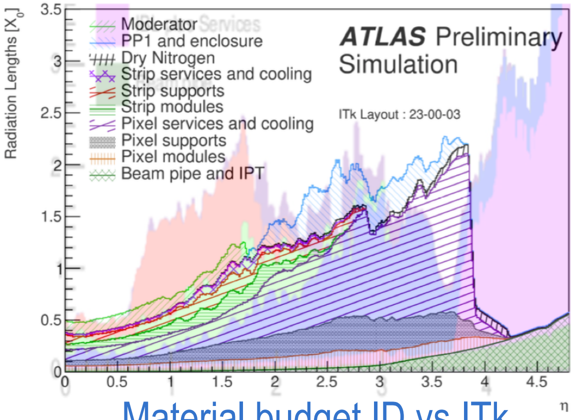
The Inner Tracker ("ITk") - Overview





ITk strips shown in blue, pixels in red
(only the active Silicon is shown)

- Complete replacement of the current Inner Detector
  - All-silicon: 168 m^2 of strips, 13 m^2 of pixels
  - Rad-hard design up to 10^{16} n_{eq}/cm^2 on innermost layers
- Improved performance:
  - Increased coverage: $|\eta| < 2.5 \rightarrow |\eta| < 4.0$
  - > 9 space points per track
  - Reduced material budget, finer segmentation
- Many parts currently in production

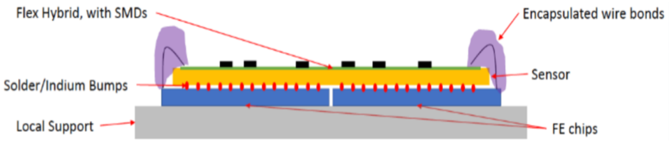


Material budget ID vs ITk

ATL-PHYS-PUB-2021-024

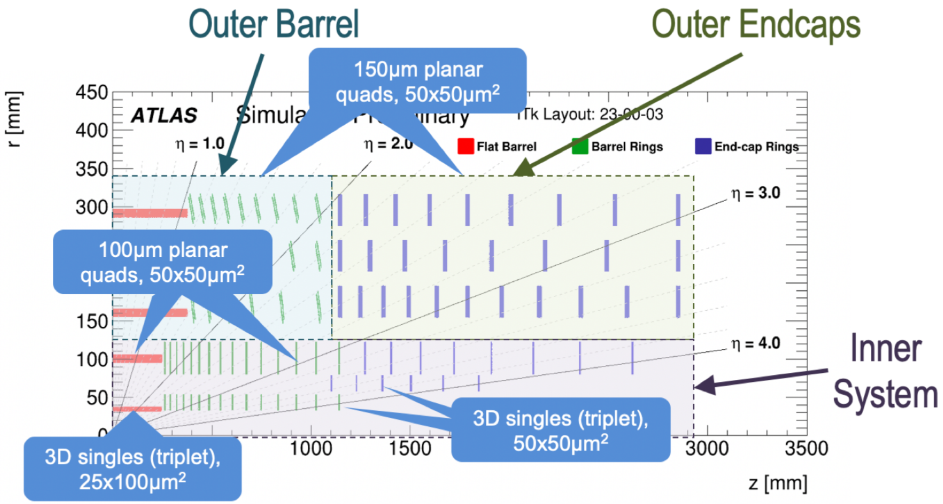
ITk Pixels: Overview and Modules

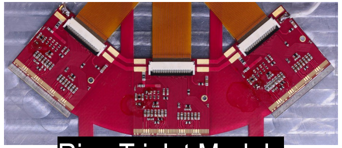
- 5-layer pixel system
  - 3 subsystems with complementary designs: Outer Barrel, Outer Endcaps, Inner System
- A total of ~10'000 hybrid Silicon modules
  - Front-end ASIC by RD53 (joint development for ATLAS and CMS)
  - 3D and planar sensors bump-bonded to ASICs (industrial process) to produce 'bare modules'
  - Cu-Kapton flex hybrids glued to sensors and wire-bonded to ASICs

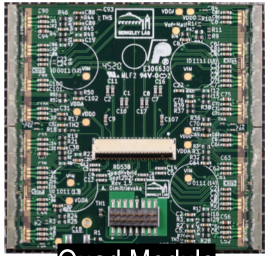


Hybrid Module Concept

- Several region-dependent module designs
  - "quads": four ASICs bonded to one planar-Si sensor
  - "triplets": three single-chip assemblies (3D silicon sensors) glued to specially-shaped hybrids
- Serial powering to reduce cable mass
  - Up to 14 modules in a single serial-power chain




Ring Triplet Module

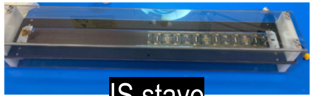

Quad Module

ITk Pixels: Supports, Services, Status

- Support structures are made of carbon-based materials (low mass, high stability, high thermal conductivity) and cooled by evaporative CO_2 in thin-walled Ti pipes.

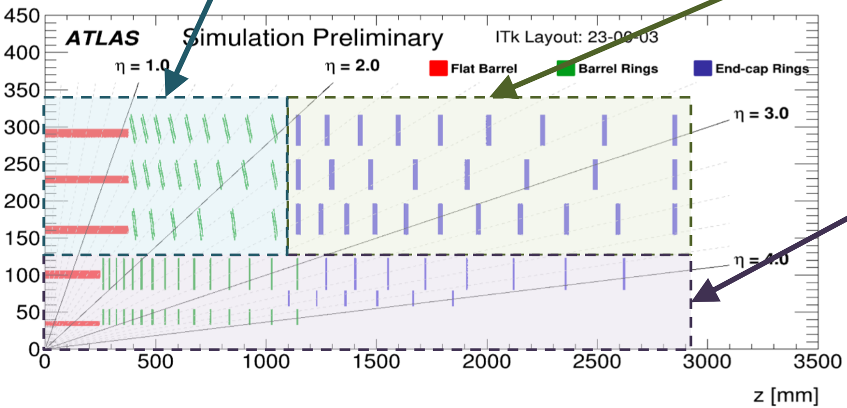

OB inclined half-ring

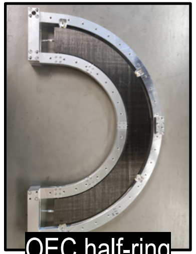

OB longeron

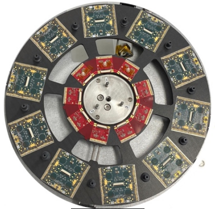

IS stave

Outer Barrel

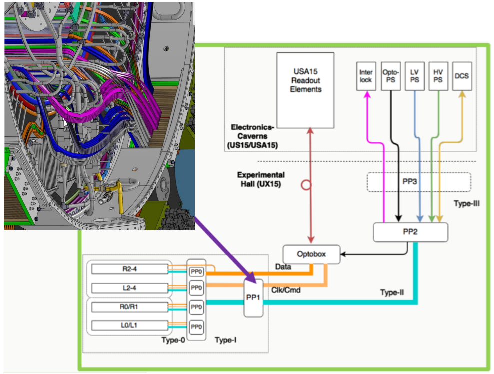
Outer Endcaps




OEC half-ring


IS ring

Inner System

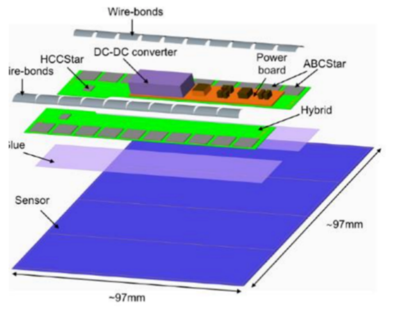


- A system of patch panels and electrical cables of increasing size carry power, monitoring, commands, and data between the detector and the services caverns.
  - System test comprising a 'slice' of all detectors scheduled for later this year
- Status: FE chips; all sensors; some hybridization, supports and services currently in production. All else in pre-production or late design phase.

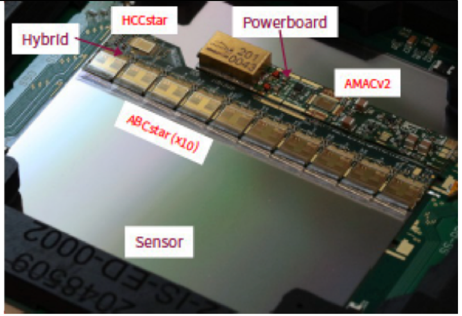
ITk Strips

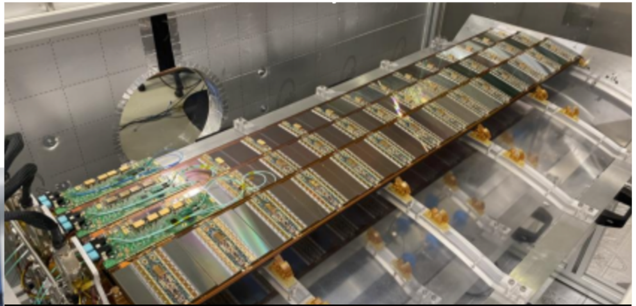
- Organized as two subsystems
  - 4 Barrel layers, 6 Endcap disks
  - See earlier slide for R-z layout
  - Coverage to | η | < 2.7
  - ~18’000 modules
  - 3x larger than current SCT, 5x as many modules
- Planar Si strip sensors are wire-bonded to flex hybrids
  - Strips are 75.5μ pitch; ~5cm long in inner layers, ~10cm long at higher R
- Supports, cooling, services are analogous to pixels
  - Carbon-based, CO_2 cooled
- Status:
  - ASICs: production finished, testing nearly done
  - Sensors and electronics in production
  - First staves/petals are loaded
  - Thermal-cycling programme of modules underway
  - Layer-2 and Layer-3 supporting cylinders have arrived and are being integrated in CERN cleanroom

Module Concept

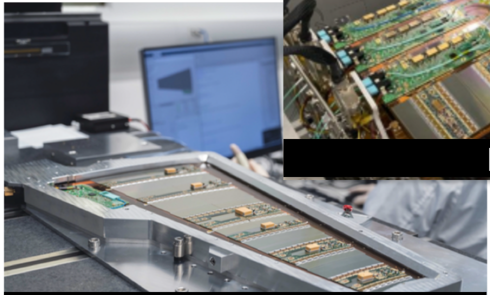


A Barrel Module





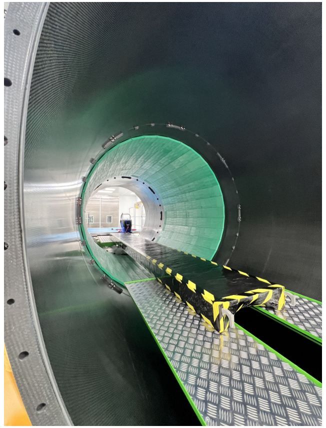
Barrel System Test



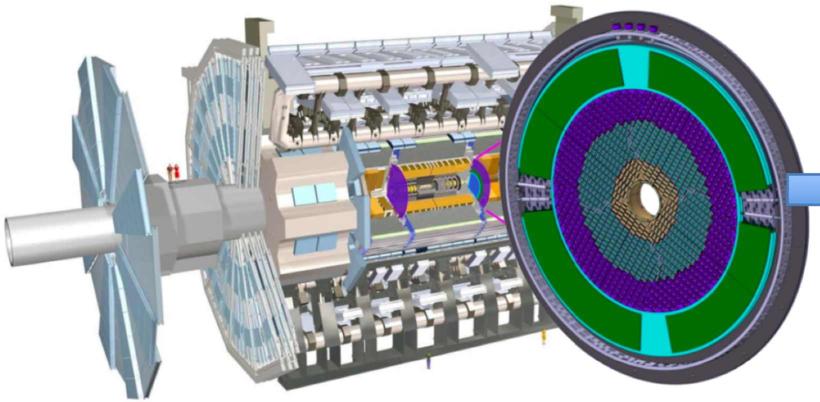
Endcap Petal

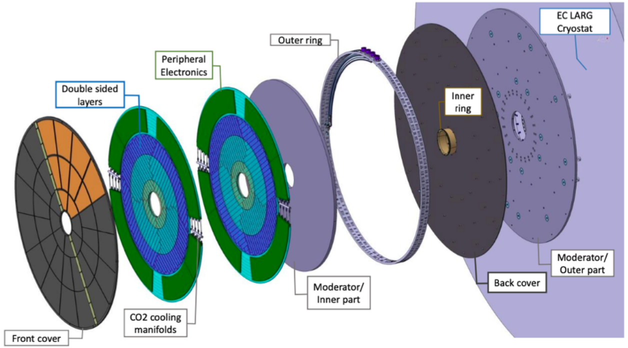
ITk – Putting it All Together

- ITk components are being made at many sites worldwide.
- Final assembly at CERN is starting already:
  - Outer Cylinder is at the ATLAS site, polymoderator (neutron shielding) has been installed
  - Two Strips supporting cylinders are currently being integrated

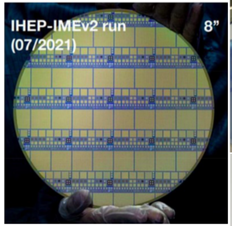


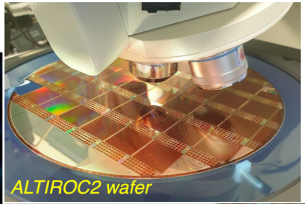
The High-Granularity Timing Detector (HGTD)





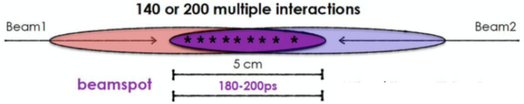
LGAD Sensor wafer





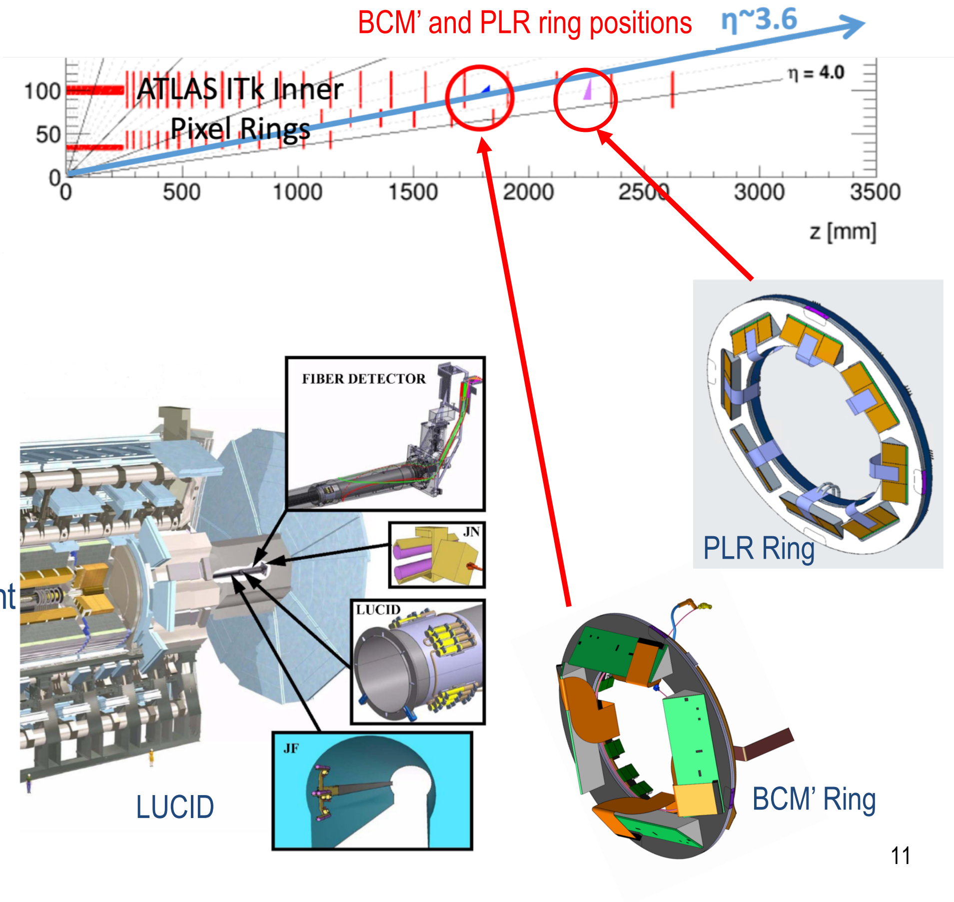
Full size Peripheral Electronics Board (PEB) prototype

- New detector between ITk and endcap calorimeter
- Two double-sided disks per side
  - Low-Gain Avalanche Detector (LGAD) arrays with 1.3x1.3 mm^2 pixels…
  - …bump-bonded to ALTIROC ASICs
  - Readout electronics surround modules
- Disentangle pileup in the forward region with timing information
  - Assigning a high-resolution time to tracks allows better vertex reconstruction
  - Timing resolution: 70 ps per hit, 30-50 ps per track
- Also provides precision bunch-by-bunch luminosity measurements



Luminosity Measurement

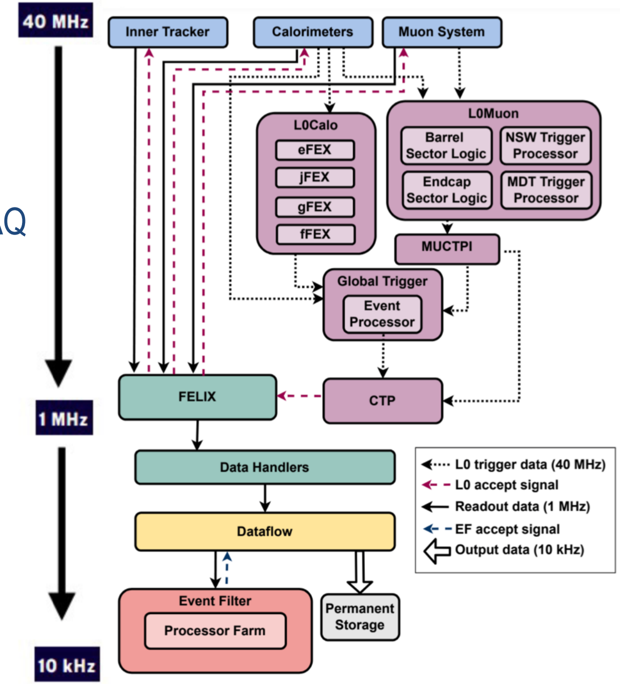
- Stable and precise luminosity measurement provided by a system of forward detectors:
  - HGTD
    - between the ITk and the endcap colorimeter (previous slide)
  - Inside the ITk-Pixel Inner System:
    - BCM’: new 3D-diamond-based Beam Conditions Monitor
      - may also provide luminosity measurement
    - Pixel Luminosity Rings (PLRs)
  - LUCID3:
    - Upgraded Cherenkov Integrating Luminosity Monitor (hit counting)

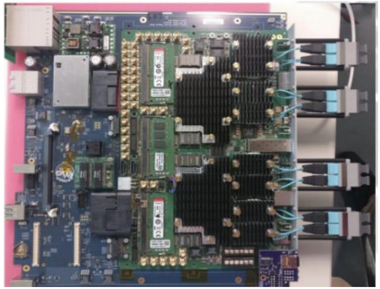


Trigger and DAQ Upgrade

- Move to 1 MHz single-level hardware trigger for all systems
  - Hardware-based Level 0:
    - 1 MHz (currently 100 kHz), ~5 TB/s, latency 10 μs
  - Software-based Event Filter (high-level trigger):
    - 10 kHz (currently 3 kHz), ~5 GB/s
  - Exploits improved detector granularity and extended tracking range, improved muon trigger efficiency
- Front-end electronics linked via FELIX (custom PCIe FPGA cards) readout to DAQ
  - Replaces VME-based readout boards
- System is currently in prototype and testing phase, with system-level integration tests ramping up
  - Final Event-filter demonstrator phase later this year

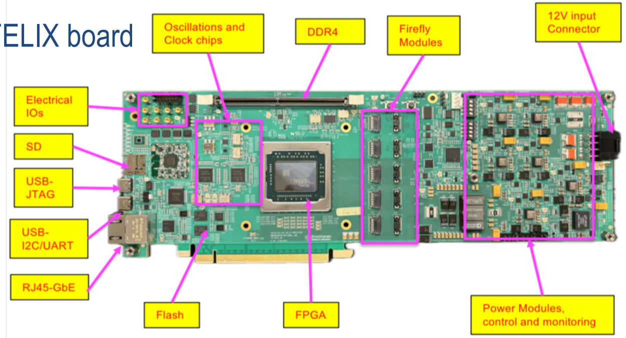
Phase-II TDAQ





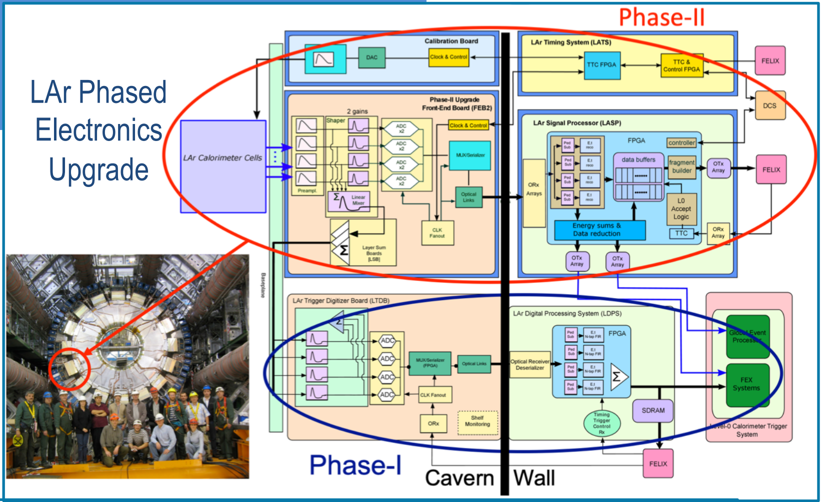
L0 muon trigger prototype

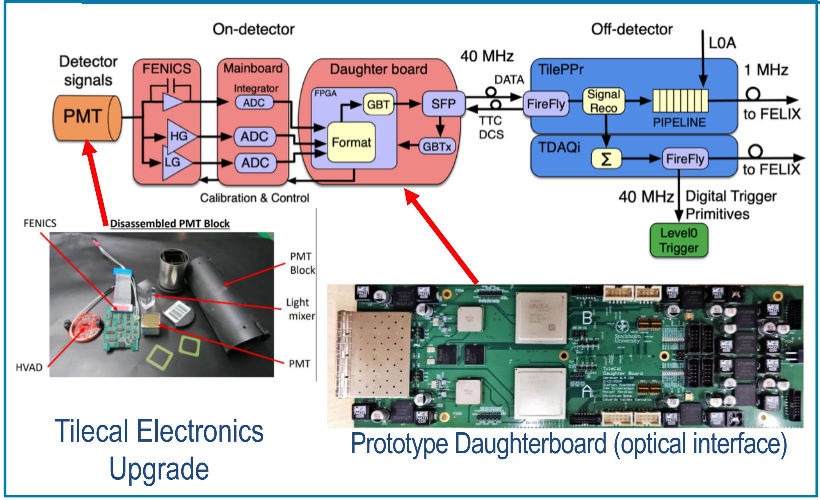
FELIX board



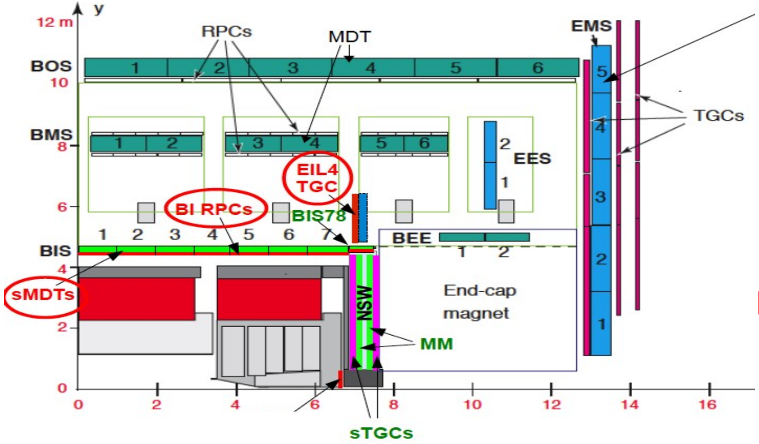
Calorimeters

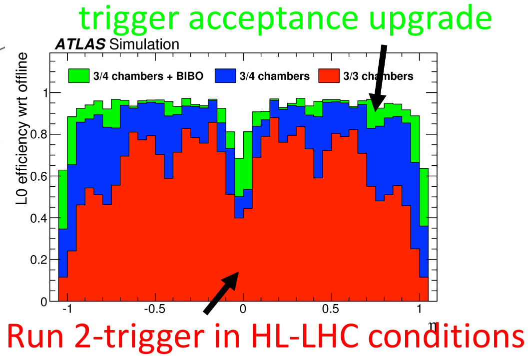
- All calorimeter electronics are being upgraded
  - Improved radiation hardness
  - Upgrade to match Phase-II readout and trigger specifications
  - compatibility with the new TDAQ architecture
- LAr (electromagnetic) calorimeter:
  - Phased:
    - new phase-I installed digitization and processing is in operation
    - Phase-II: calibration, digitization, signal processing for energy reconstruction
  - On-detector:
    - New high-precision front-end electronics aimed at 16-bit dynamic range and linearity better than 0.1%
    - New ASICs (ADC, calibration DAC, pulser)
  - Off-detector:
    - ATCA boards for waveform feature extraction (energy, time)
    - Total bandwidth 345 Tbps
- Tilecal (hadronic):
  - Replacing on- and off-detector electronics
    - Improved precision and range
  - Replacing ~1000 of the most-exposed PMTs
  - Replacing HV and LV power systems to cope with new electronics and higher radiation environment
  - → Compatibility with new TDAQ, improved redundancy / reliability
- In production in many areas

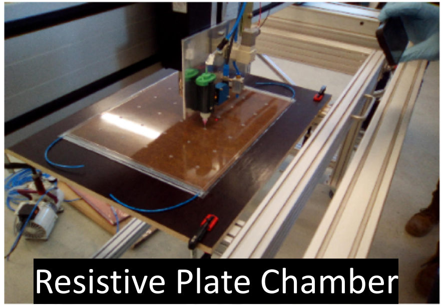


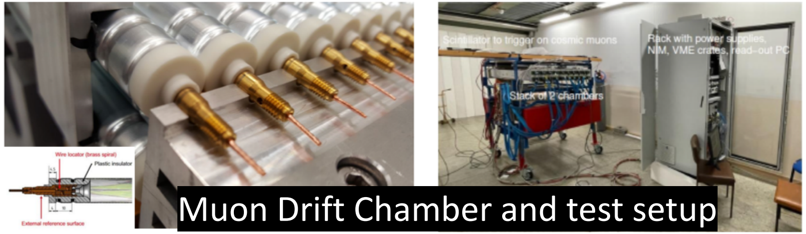


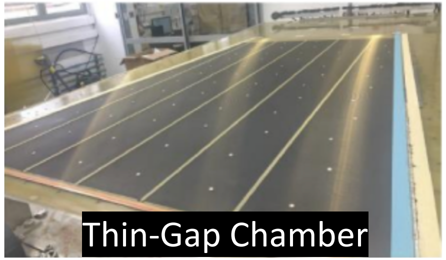
Muon System






Resistive Plate Chamber


Muon Drift Chamber and test setup


Thin-Gap Chamber

- Additional inner barrel layers being added:
  - To improve trigger coverage and rejection
  - In production, many chambers finished
- Update readout/trigger electronics everywhere:
  - All hit data is sent off-detector to trigger logic boards with L0 trigger rate 1 MHz and latency 10μs.
  - Production started.

Summary

- The ATLAS detector is undergoing major upgrades to fully exploit the potential of the HL-LHC:
  - New subdetectors / components:
    - ITk for improved central tracking with less material, more coverage, and finer segmentation
    - HGTD to resolve increased pileup with precise timing
    - Upgraded forward / luminosity detectors
    - New inner-barrel muon chambers
  - An upgrade of the trigger and readout system → increased readout rates
  - Upgraded electronics for existing calorimeters and muon system
- All these activities are currently in (or near) production with some components already delivered to CERN.
  - Still some technical problems remaining, and schedule is challenging, but all is moving forward thanks to focused and dedicated community.

Lots of detailed talks later this week…!

For More Information…

Inner Tracker

F.Muñoz Sanchez: ATLAS ITk Pixel Detector Overview – Thursday 11:54; Operation, Performance and Upgrades
Y.Tian: Characterization with test beams of ITk pixel detectors for the upgrade of the ATLAS Inner Detector – Thursday, Poster Session 1
Z.Tao: The ATLAS ITk Strip Detector System for the Phase-II LHC Upgrade - Thursday 12:12; Operation, Performance and Upgrades
J.J.Teoh: Summary of the ATLAS ITk strip tracker module pre-production – Thursday, Poster Session 1
R.Privara: Performance study of ATLAS ITk strip endcap modules using charged particle beams – Thursday, Poster Session 1
Z.Tao: The ATLAS Inner Tracker Strip Detector system tests - development of DAQ and DCS – Thursday, Poster Session 1
B.Stelzer: Automated Assembly of Petals and Staves for the ATLAS ITk Strip Detector – Thursday 18:00, Technology and Industrial Applications
K.G.Wraight: ATLAS ITk Production Database usage – Friday, Poster Session 2
H.Hayward: Expected performance of the ATLAS ITk detector for HL-LHC - Thursday 14:30; Operation, Performance and Upgrades
M.-T.Pham: A geometric deep learning algorithm for charged-particle track reconstruction in the ATLAS ITk – Friday 17:02, Computing and Data Handling

Forward

A.Leopold: The High-Granularity Timing Detector for ATLAS at HL-LHC - Thursday 17:00; Operation, Performance and Upgrades
X.Yang: Testbeam performance of ALTIROC3 hybrid assemblies with LGAD sensors for the ATLAS HGTD Upgrade – Friday, Poster Session 2
J.Lindon: LUCID3: the upgrade of the ATLAS Luminosity detector for High Luminosity LHC – Thursday, Poster Session 1
C.Ohm: Towards an ATLAS luminosity measurement at HL-LHC – Friday 18:12; Operation, Performance and Upgrades
Y.Guo: ATLAS ZDC for Run3 and Run4 – Saturday 11:39; Operation, Performance and Upgrades

Calo

T.Barillari: Development of the ATLAS Liquid Argon Calorimeter Readout Electronics for the HL-LHC – Friday, Poster Session 2
A.Da Silva Gomes: Upgrade of the ATLAS Tile Calorimeter for the High Luminosity LHC – Saturday 09:36; Operation, Performance and Upgrades

Muons

A.Rocchi: Production and test of BI-RPC detectors for ATLAS Phase II upgrade – Thursday 17:45, Technology and Industrial Applications
A.Wada: Integration test of a new inner-station TGC system for the ATLAS experiment at HL-LHC – Thursday, Poster Session 1
J.Ge: Upgrade of the ATLAS Monitored Drift Tube detector for the HL-LHC – Thursday, Poster Session 1
E.Yamashita: A comprehensive firmware validation machinery for the Level-0 Endcap Muon trigger for LHC-ATLAS Phase2 upgrade – Thursday, Poster Session 1
E.Ballabene: The ATLAS RPC Phase II upgrade for High Luminosity LHC era – Saturday 18:15; Operation, Performance and Upgrades

Thank you for your attention,
and have a great week!