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ATLAS Upgrade for the HL-LHC: meeting the challenges of a five-fold increase in collision rate

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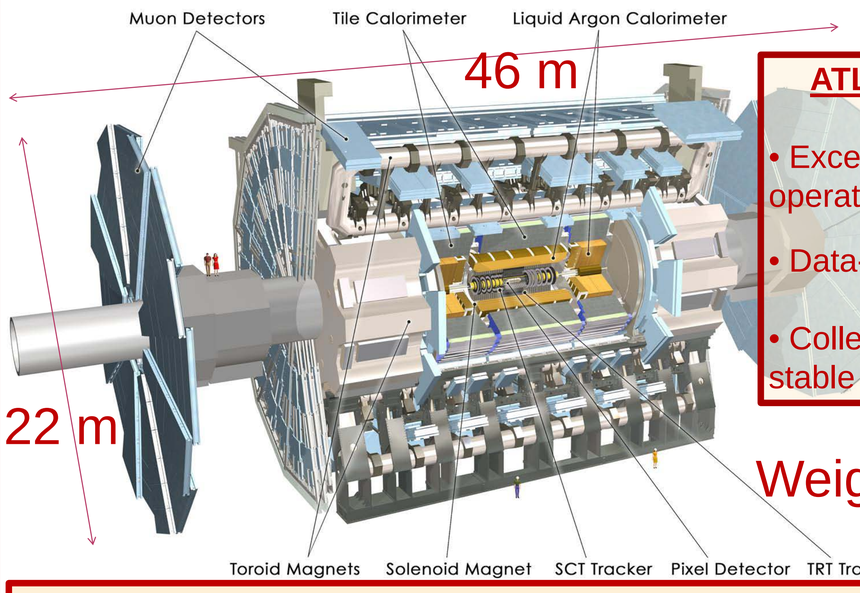
On behalf of the ATLAS Collaboration

ATLAS Experiment



Weight: 7000 t

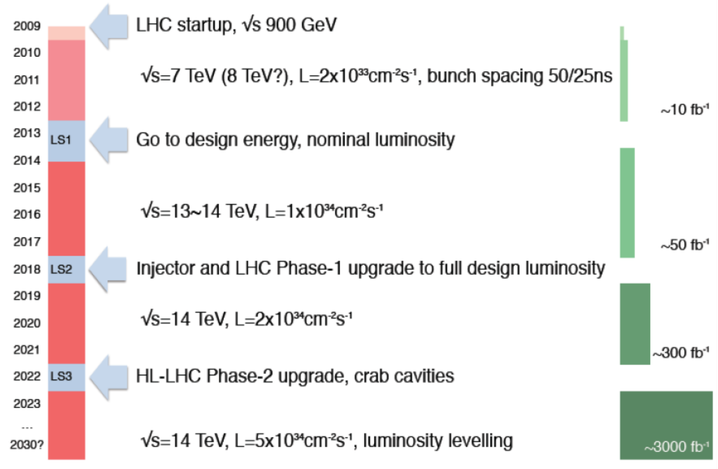
ATLAS status, Nov'2011

- Excellent performance and operation
- Data-taking efficiency ~94%
- Collected over 5 fb^{-1} with stable p-p beams at $\sqrt{s}$=7 TeV

- The largest ever built HEP experiment, operating at LHC, CERN
- Designed to explore the $\sqrt{s}$=14 TeV p-p collisions at L= 10^{34} cm^{-2} s^{-1}
- Basic subsystems:
  - * *Inner Detector, ID* (Pixel Detector, SCT, TRT) within solenoid of B=2T
  - * *Calorimeters* (Liquid Argon and Tile (scintillating tiles))
  - * *Muon Spectrometer*, using toroidal magnetic field of B=0.5T

HL-LHC & ATLAS Upgrade(s)

- High-Luminosity LHC (HL-LHC or sLHC) → 5 times increase of the instantaneous luminosity, i.e. L_{sLHC}=5·$10^{34}$$cm^{-2}s^{-1}$. The goal is to extend the data set from about 300 fb^{-1} proposed for LHC running, to 3000 fb^{-1} by ~ 2030.
- Physics goals/motivations:
  - SUperSYmmetry (discovery, spectroscopy)
  - Higgs physics (rare decay modes, Higgs couplings)
  - New forces, new gauge bosons(W', Z' extending searches to higher limits)
  - Quark substructure, …



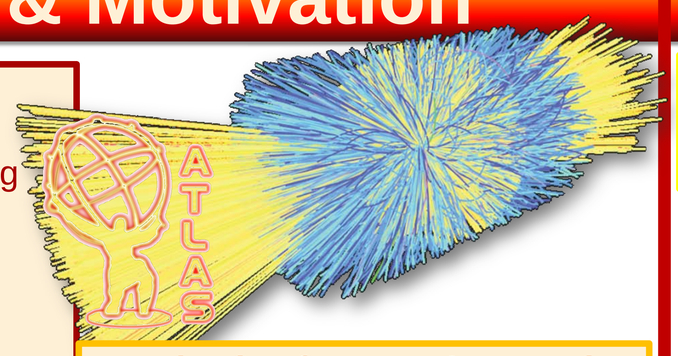
ATLAS Upgrade Plans

- **Phase-0** (LS1), 2013-2014
  - *New Insertable pixel B-Layer (IBL) → approved*
- **Phase-1** (LS2), 2018
  - *Fast TracK trigger (FTK) → approved*
  - *New Muon small wheels*
  - *Improved L1 Calo granularity*
  - *Bring in "topological" triggers*
- **Phase-2** (LS3), 2022-2023
  - *Full tracker replacement*
  - *Calorimeter upgrades*
  - *Trigger upgrades*

Challenges & Motivation

sLHC Environment

- ~ 200 interactions per bunch crossing
- Higher particle fluxes
- Increased detector occupancy and larger event sizes
- Harsher radiation environment



Limitations of current detector

- Radiation damage
  - Inner Detector
  - Calorimeter electronics
- Readout limitations for Pixel and SCT
- Too high occupancy in the TRT
- Too large energy flow in the FCal
- High hit-rate from Cavern background for Muons
- Trigger capacity (higher rates, event sizes)

Motivation for ATLAS Upgrade

✓ New detectors, adequate to the sLHC conditions, designed and built using the newest technologies available

✓ Replacement of the aged components

Requirements

Excellent performance in:
- Tracking & b-tagging
- Lepton identification
- Forward(central)-jet tagging(veto)

ATLAS Upgrade: Phase-0

❑ **2013-2014,** L=1·$10^{34}$$cm^{-2}s^{-1}$
❑ **Detector consolidation**
❑ **Installing new pixel layer**

→ Insertable B-Layer (IBL)

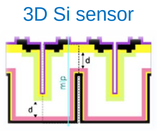
CERN-LHCC-2010-013 ATLAS Insertable B-Layer Technical Design Report TDR

- Insertion of an additional, 4th pixel layer b/w the innermost pixel (B-)layer and the beam pipe
- A beam-pipe with smaller radius needed, r = 29 mm → 25 mm
- Compensate for defects in existing B-layer
- Improves vertex resolution, secondary vertex finding, b-tagging

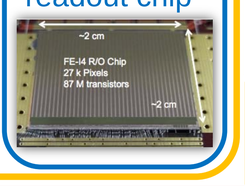
IBL technology

Planner Si sensor

3D Si sensor

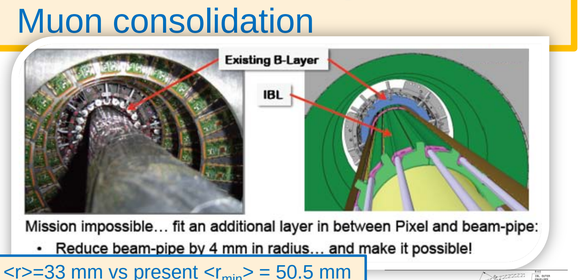


New readout chip



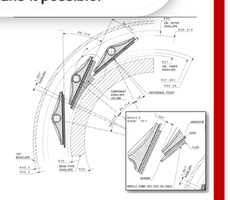
→ Detector consolidation

- New ID cooling system
- New beam pipe: steel → Al
  - 10-20% background reduction
- Calorimeter consolidation (e.g. low voltage PS)
- Removal of Min.-Bias Trigger Scint.
- New neutron shielding
- Muon consolidation

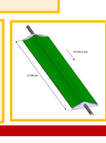


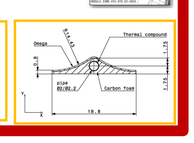
- <r>=33 mm vs present <r_{min}> = 50.5 mm
- z coverage = 60 cm, |η| < 2.5
- 14 staves with φ overlap
- No η overlap of modules on stave

Main challenges for IBL:
- Higher particle fluxes
- Increased amount of material



- New stave design with carbon foam material
- low material budget
- excellent heat path to cooling pipe

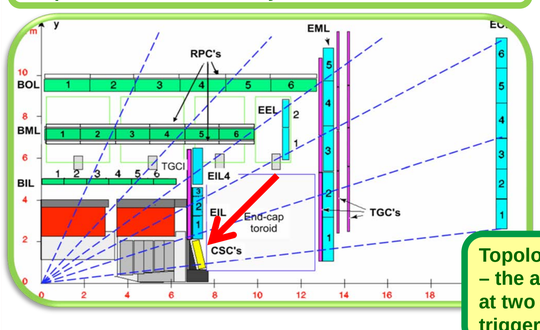




ATLAS Upgrade: Phase-1

❑ **2018,** L=2·$10^{34}$$cm^{-2}s^{-1}$
❑ **New Muon Small Wheels**
❑ **Fast Track Trigger**
❑ **Topological trigger**
❑ **Improved L1Calo granularity**

▪ **Current Muon Small Wheel won't be able to cope with luminosities beyond the nominal.**



Topological triggers: – the ability to look at two or more trigger objects at L1

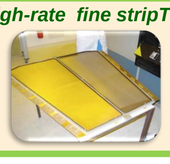
→ New Muon Small Wheels

- Replacement of 1st endcap station (CSC's) with New Small Wheel
- Must ensure:
  - efficient tracking at high particle rate and large |η|; pos. resolution < 100 μm
  - trigger improvement, integration in L1
- Candidate technologies under study:

Smaller drift tubes (sMDT) — sMDT 30mm→15mm Ar:CO_2 93:7

+ RPC or TGC

High-rate fine stripTGC's



MicroMEGA's

→ Improved L1 Calo granularity

- Introducing a high-granularity calorimeter L1-trigger readout interface
- Installation of independent digital trigger data links in limited area (Δη x Δφ = 0.4 x 0.4), for both LAr and Tile, in Phase-0

→ Fast Tracker Trigger (FTK)

- A dedicated hardware-based track finder
- Tracking at beginning of LVL2
- Fast track fit (~1fit/ns on FPGA), provide helix parameters to L2
- Improvement for b-tagging, τ-identification, lepton isolation

ATLAS Upgrade: Phase-2

❑ **2022-2023,** L=5·$10^{34}$$cm^{-2}s^{-1}$
❑ **New ID tracker**
❑ **Calorimeter upgrades**
❑ **Trigger upgrades**

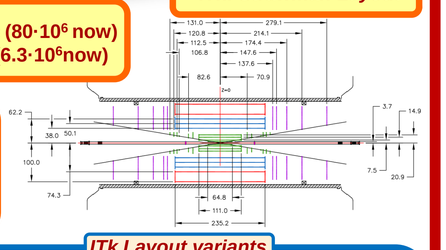
ITk: Strawman Layout

400·10^6 pixels (80·10^6 now)
45·10^6 strips (6.3·10^6now)

→ New Inner detector Tracker (ITk)

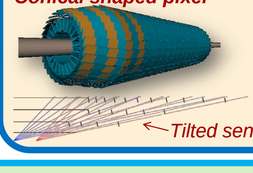
- All new tracker, completely made of silicon, no TRT
- Higher granularity
- Improved material budget
- Baseline: Layers of pixels and micro-strips

Strips: 5 barrel layers
- 3 Inner layers, short strips, 24mm
- 2 outer layers, long strips, 96 mm
- 5 double sided disks each end-cap
Pixels: 4 pixel layers, 6 pixel disks

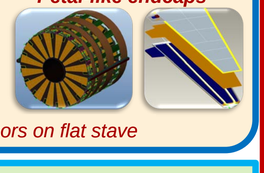


ITk Layout variants

Conical shaped pixel



Petal-like endcaps



Tilted sensors on flat stave

Pixel R&D
- Planar sensors
- 3D sensors with active gap
- Diamond sensors (more radiation hard)

Si-Strip R&D
- Single-sided modules in STAVE structure
- Double-sided super-modules

→ Calorimeter upgrades

- Replace cold electronics (preamplifiers) inside LAr Hadronic endcap
- Replacement of all on-detector readout electronics for all calorimeters (LAr and Tile)
- Potentially upgrade the FCal with either a warm Mini-FCal detector or with a LAr FCal featuring small size

→Trigger upgrades

- Higher event rates → higher rejection needed
- Track Trigger at L0/L1
- Full granularity of calorimeter at L1
- Improved muon trigger coverage