ATLAS Upgrade for High Luminosity LHC

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LHC and HL-LHC plans

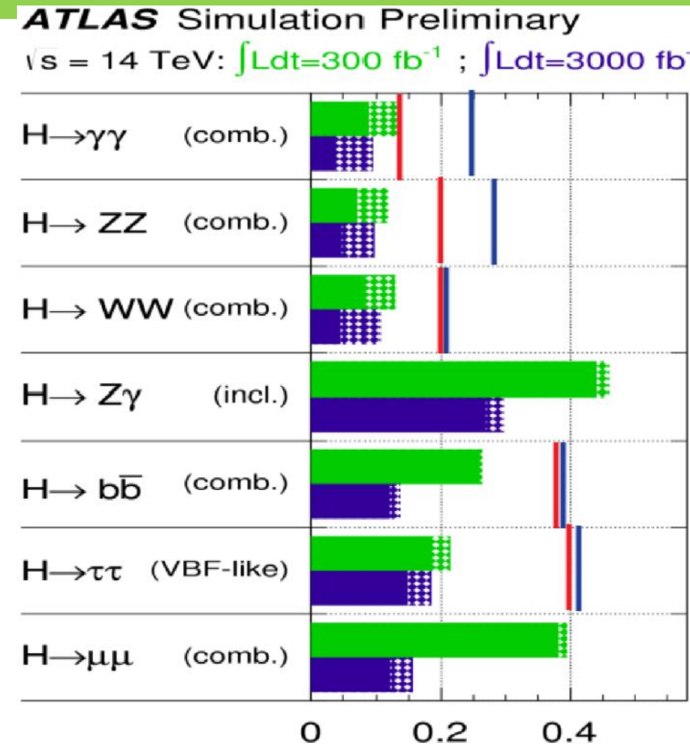
https://project-hl-lhc-industry.web.cern.ch/content/project-schedule

❖ Long Shutdown 3 from 2024 to mid-2026 will bring major upgrades to LHC and the experiments

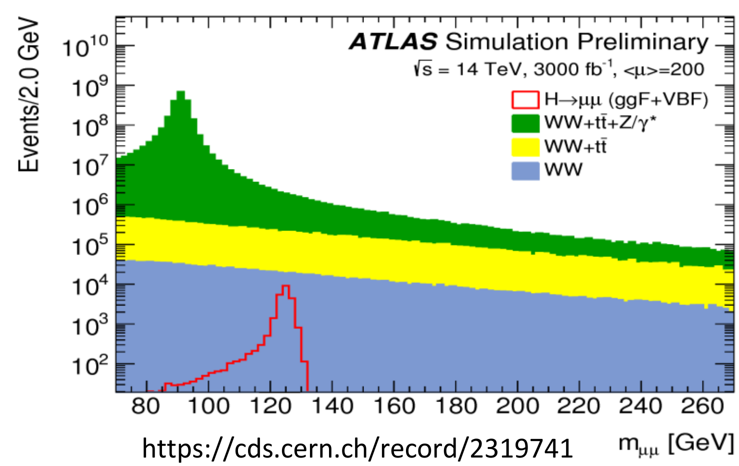
❖ HL-LHC significantly improves upon LHC and top priority is an exploitation of its full potential

Physics prospects: SM and beyond

- **Precise SM and Higgs sector measurements**
  - Higgs boson μ values , access to rare Higgs processes
  - Higgs boson couplings will be measured with precision of 2-10%
  - Higgs self-coupling in SM accessible at HL-LHC
  - Weak boson scattering
- **Beyond Standard Model physics**
  - Searches for new massive states on HL-LHC will extend mass reach by ~20%
  - SUSY particles searches significantly extended
  - High mass gauge bosons, tt resonances, quark and lepton substructure, extra dimensions, dark matter candidate, …
- **Update of the physics projections with a new CERN Yellow Report as input to the European Strategy group by the end of 2018.**



http://cds.cern.ch/record/2630602



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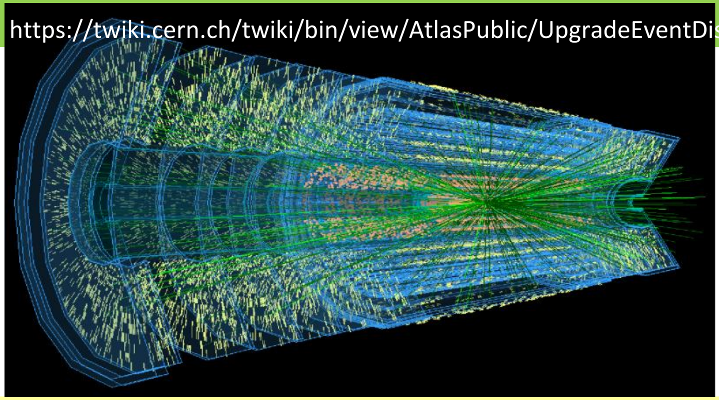
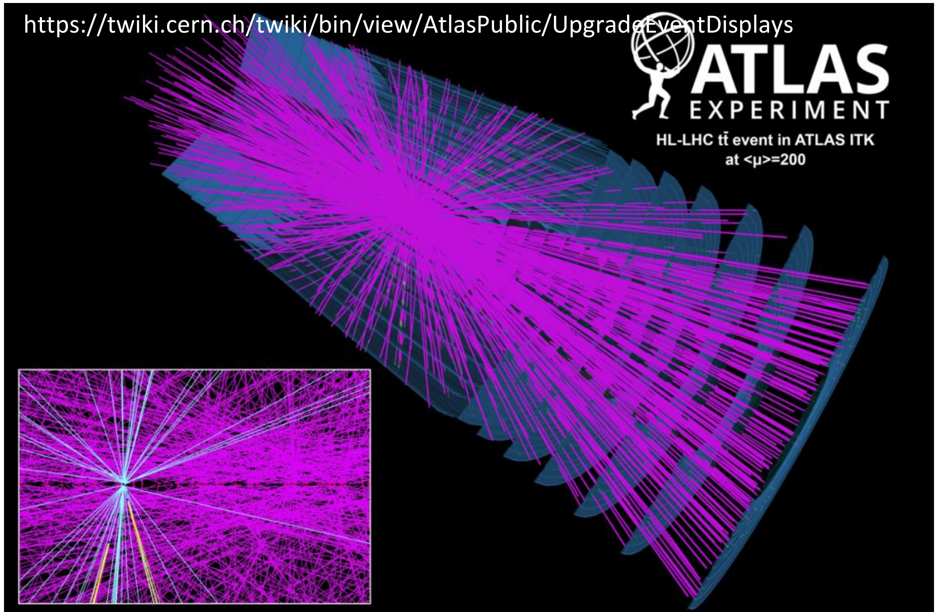
Detector challenges and upgrades

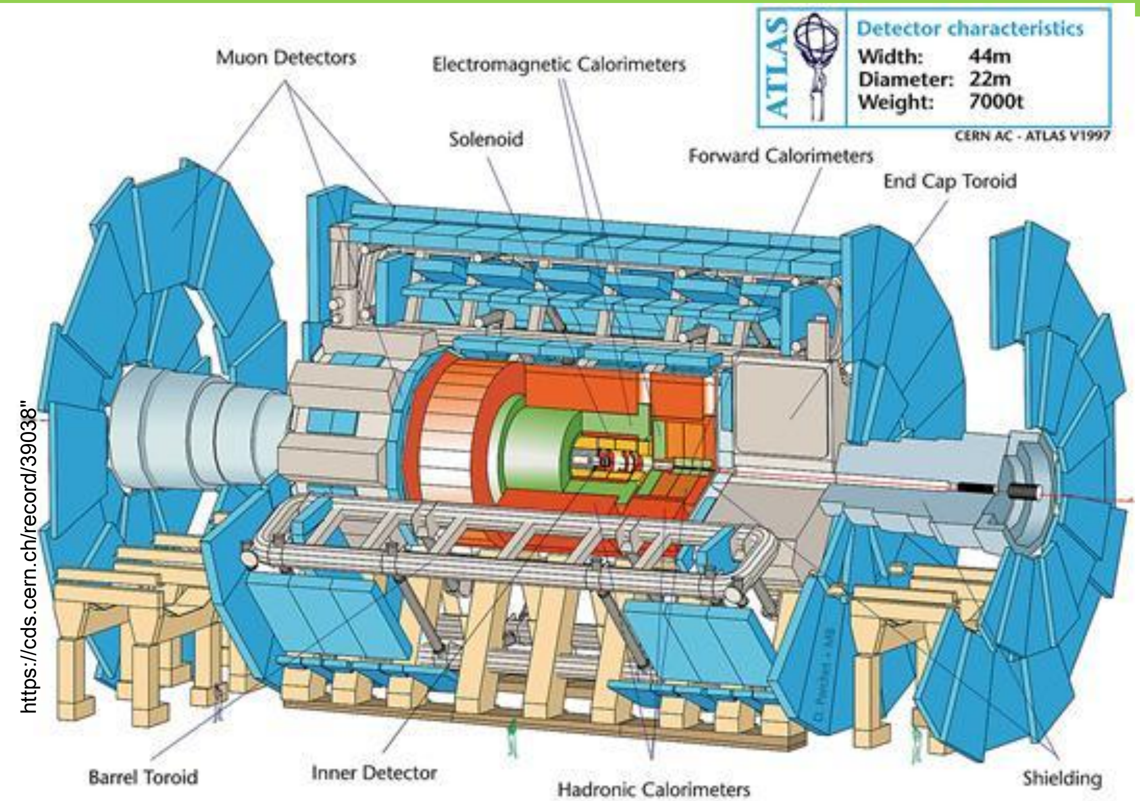


HL-LHC expected performance:
- Centre of mass energy: **$\sqrt{s}$ = 14 TeV**
- Instantaneous **L = 5.0 × 10^{34} cm^{-2} s^{-1}**
  – Ultimate L = 7.5 × 10^{34} cm^{-2} s^{-1}
- Integrated **L 3000 fb^{-1}**
  – Ultimate integrated **L 4000 fb^{-1}**
- Average interactions per bunch crossing: **<μ> = 200**



Detector challenges:
- Higher particle fluxes, larger event sizes, higher trigger rate
  - ➢ trigger challenge
- Higher detector occupancy
  - ➢ readout limitations
  - ➢ increasing reconstruction complexity
- Increasing fluences, close to beam pipe up to 10^{16} n_{eq} $/cm^{-2}$
  - ➢ increased radiation damage
  - ➢ increased activation of materials

ATLAS Detector upgrades phase II



https://cds.cern.ch/record/39038"

Muon system upgrade. New chambers in the Inner barrel region.

Upgraded Triger and Data Aquisition System

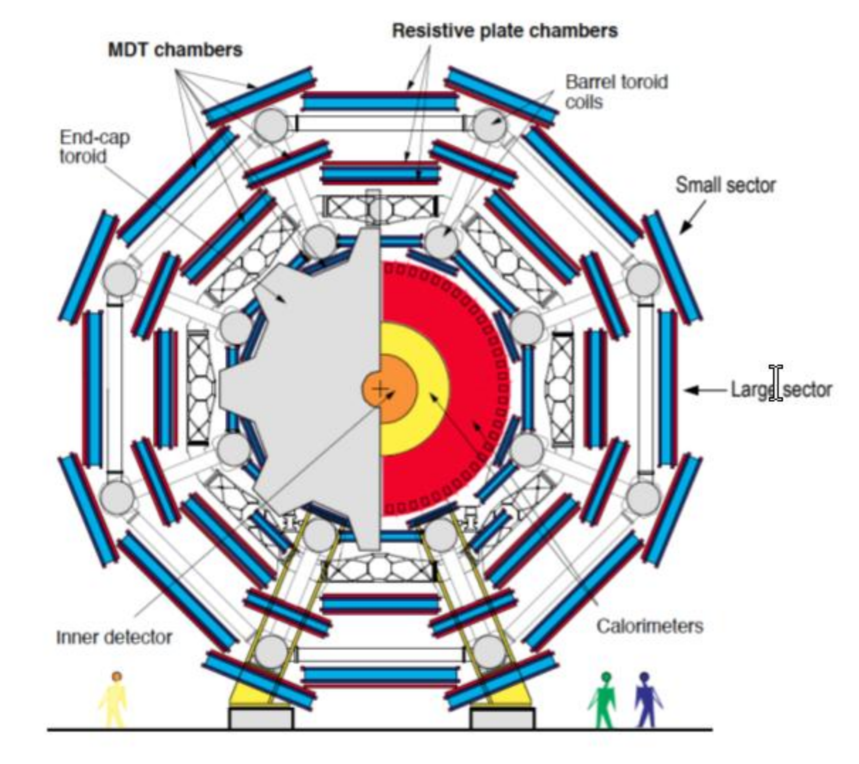
All new Inner Tracking Detector: Strips and Pixels

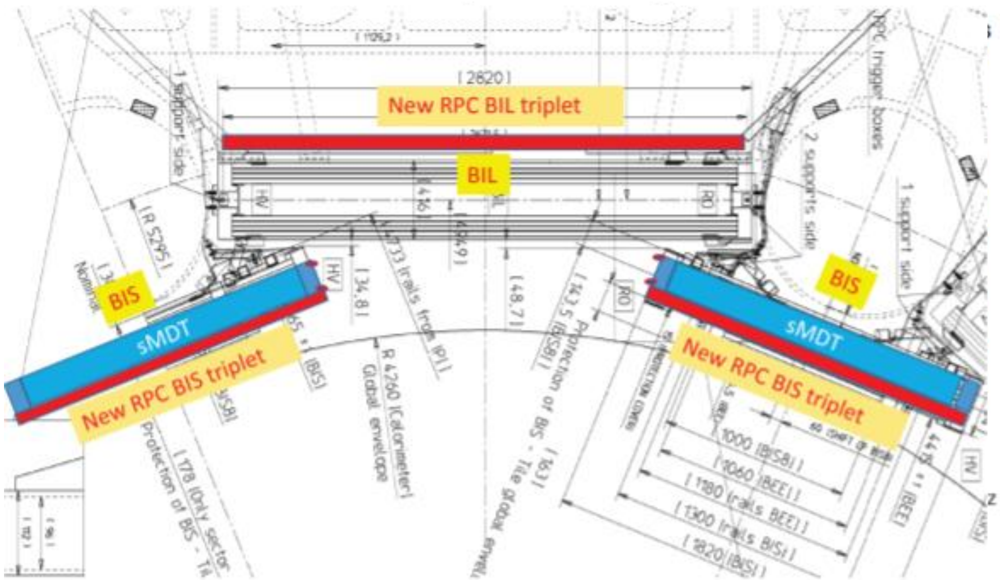
High Granularity Timing Detector

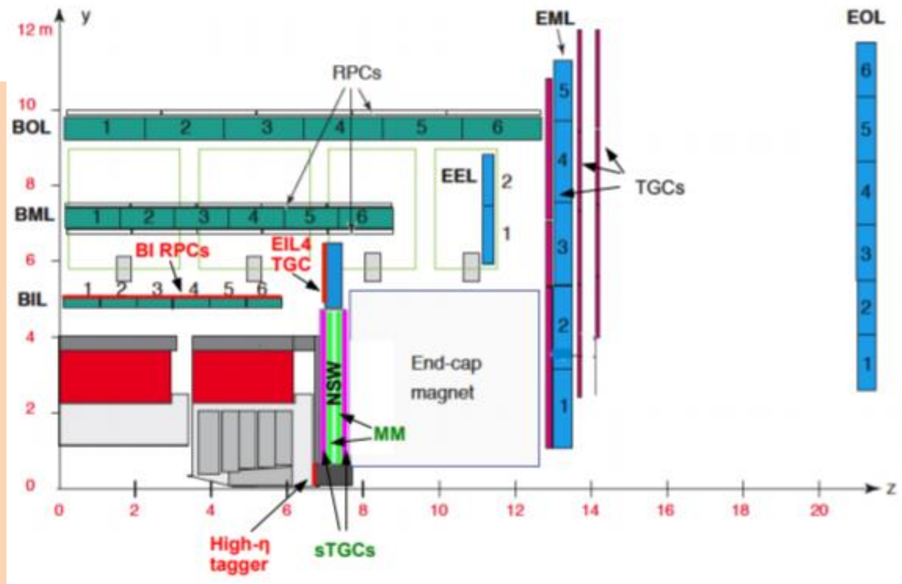
Major electronics upgrades in various subsystems and continuous efforts in consolidation, eg. new cooling systems, improved electronics and power supplies, shielding additions…

Muon Spectrometer Upgrade

CERN-LHCC-2017-017





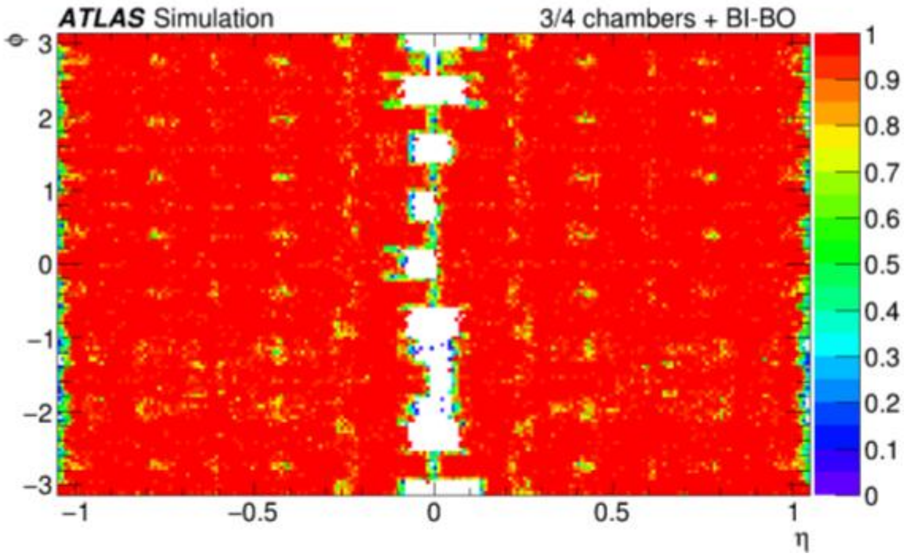


- Replacement of all frontend on- and off-detector readout and trigger electronics. All data streamed off-detector at 40 MHz.
- Major improvement in trigger capability, robustness, background suppression and increased acceptance by adding new detectors: **BI RPC, sMDT, EIL4 TGC**

Muon Spectrometer Upgrade

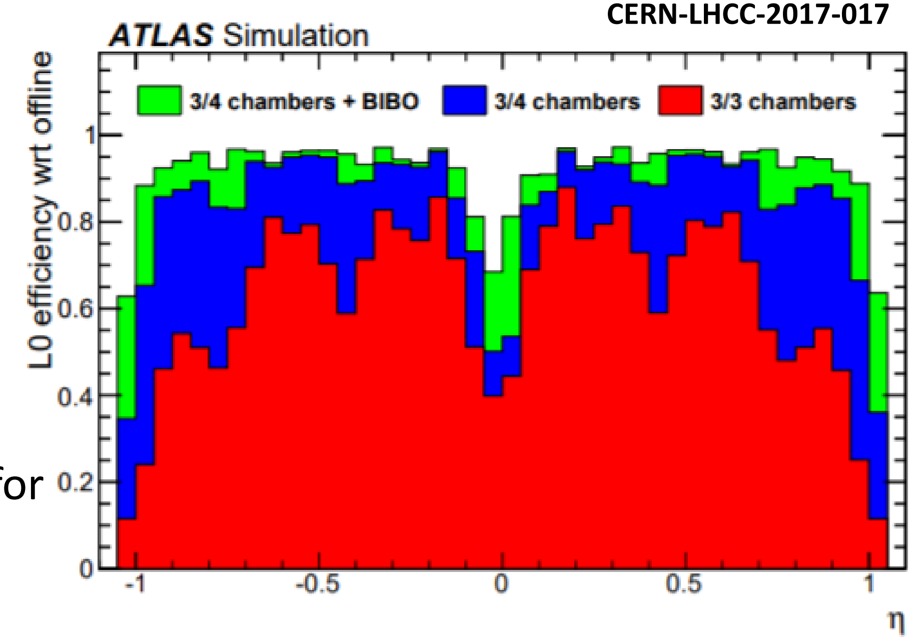
CERN-LHCC-2017-017

- Present MS has three RPC layers.
- Addition of fourth RPC layer (triplet) => major improvement in robustness!



Geometrical acceptance of the L0 barrel trigger with respect to reconstructed muons.

CERN-LHCC-2017-017

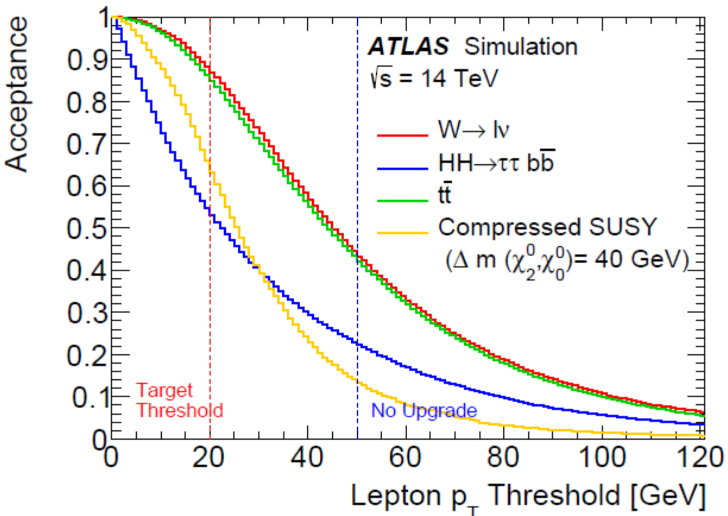


Efficiency times acceptance of the L0 barrel trigger with respect to reconstructed muons.
Plot assumes worst-case RPC aging scenario for original chambers (only 65% single-hit efficiency).

TDAQ upgrade physics motivation

CERN-LHCC-2017-020

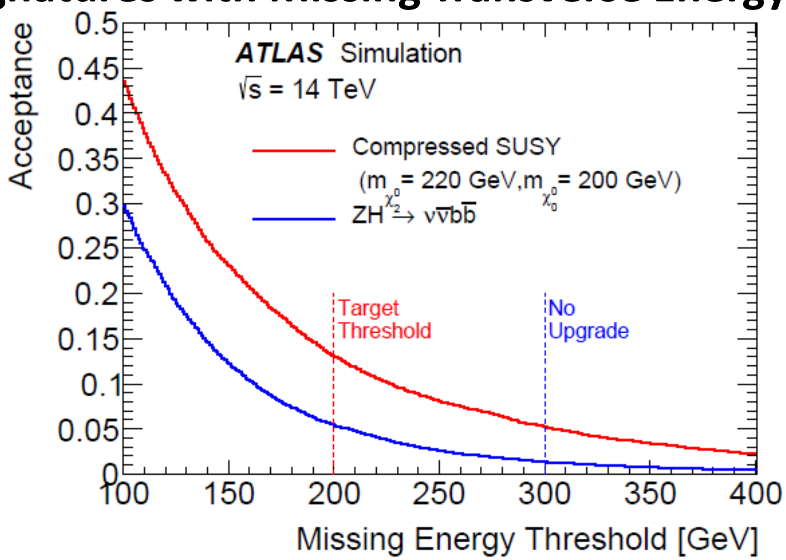
Signatures with Single-Electron and Single-Muon Triggers



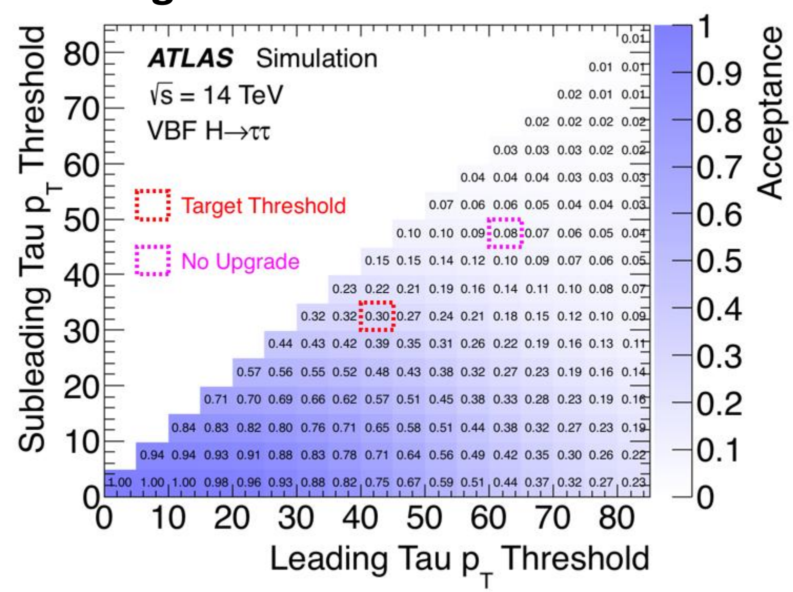
Physics searches require keeping the p_T of the various trigger objects as low as possible:

- Electroweak scale requires low p_T leptons
- Searches for new physics with e.g. low Δm too
- HH measurements requires low p_T jets/b-jets

Signatures with Missing Transverse Energy



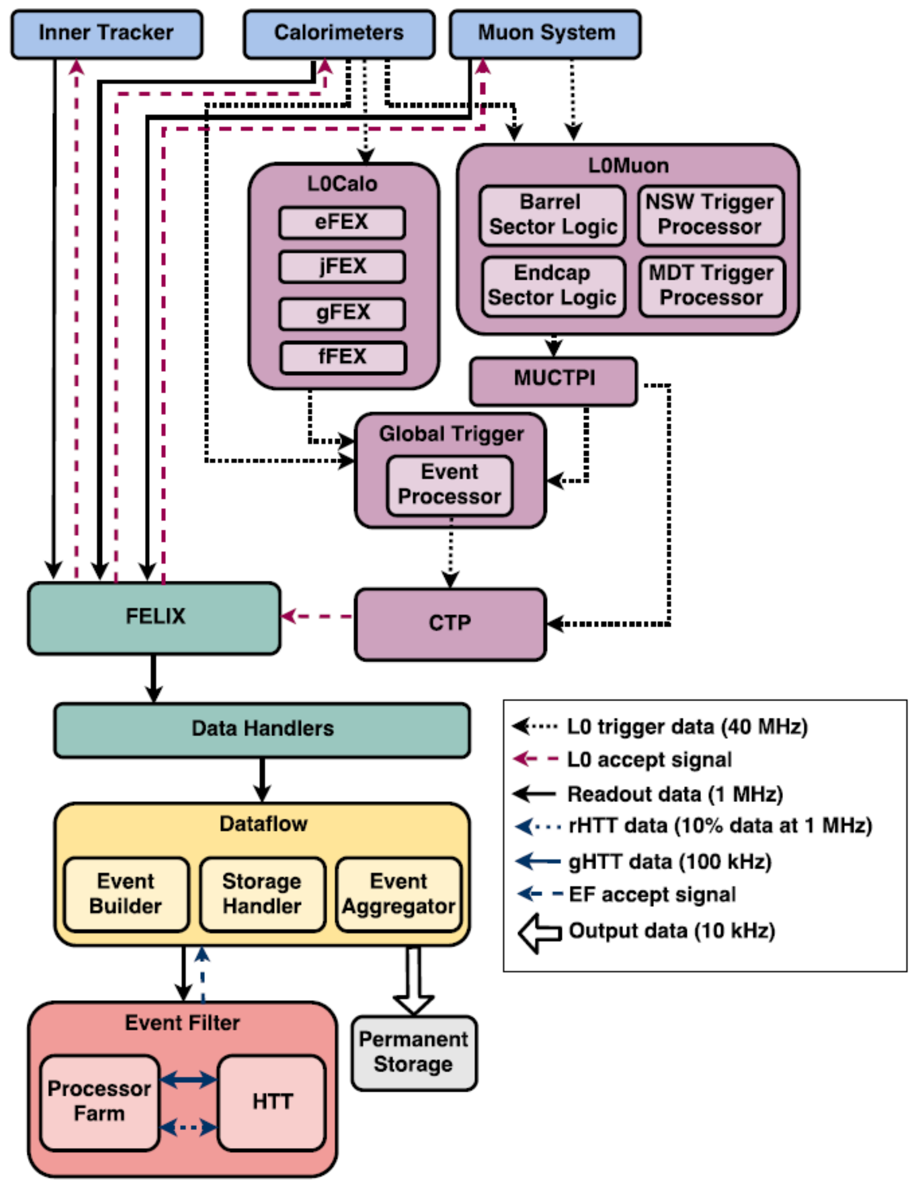
Signatures with Jets



TDAQ system in Phase-II

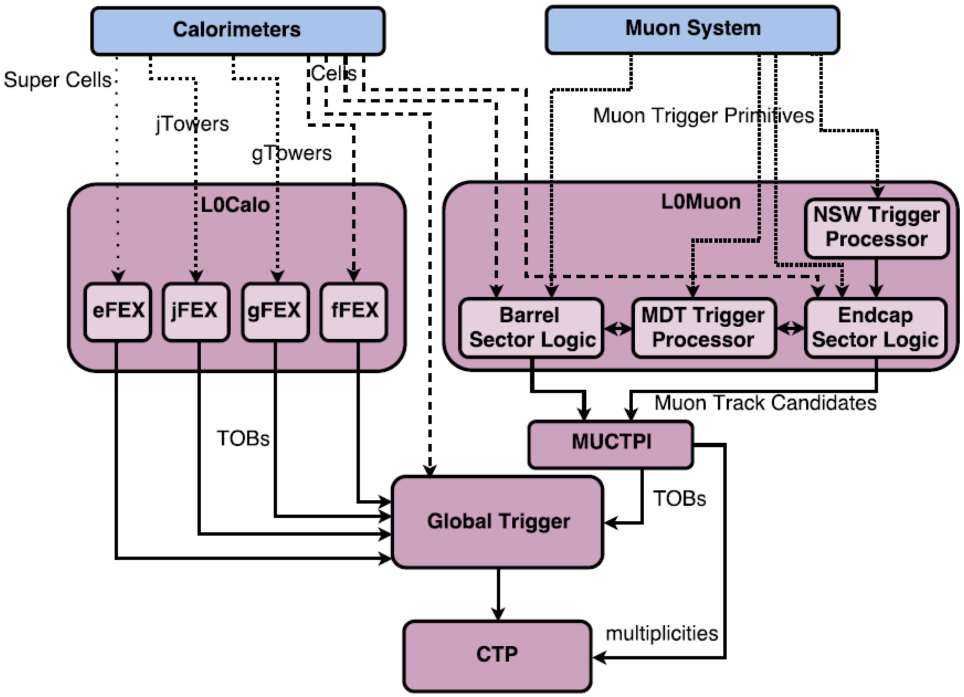
CERN-LHCC-2017-020

- Two-level trigger architecture:
  - L0
  - tracking data is used High Level Trigger(HLT) customized hardware
- L0 Trigger Rate 1 MHz
  - was 100 kHz
- L0 latency/rate < 10 µs
  - was 2.5 µs
- HLT output rate: 10 kHz
- Considers an evolution system with all the „hooks” allowing scaling TDAQ later if demanded be physics/HL-LHC performance.



ATLAS Level-0 architecture

CERN-LHCC-2017-020



Level-0 upgrade:

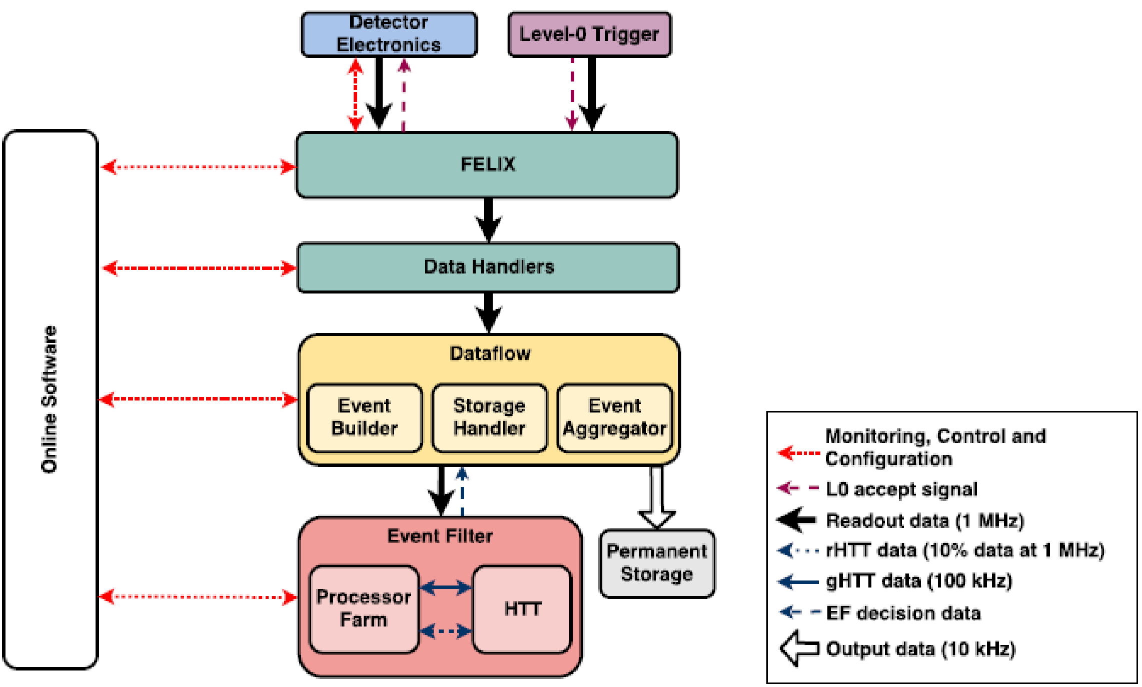
- Added Info from Muon and Calorimeters
- **L0calo** new in Phase I and extending Feature Extraction (**FEXs**) in Phase II for fwd EM and jets
- **L0Muon** inclusion data from MDT, New Small Wheel (extend |eta|<2.6) to improve the muon trigger coverage.
- **Global Trigger** new subsystem of the Level-0 Trigger, will perform offline-like algorithms on full-granularity calorimeter data and make topo

- **Central Trigger –** new Central Trigger Processor; new Muon-to-CTP Interface

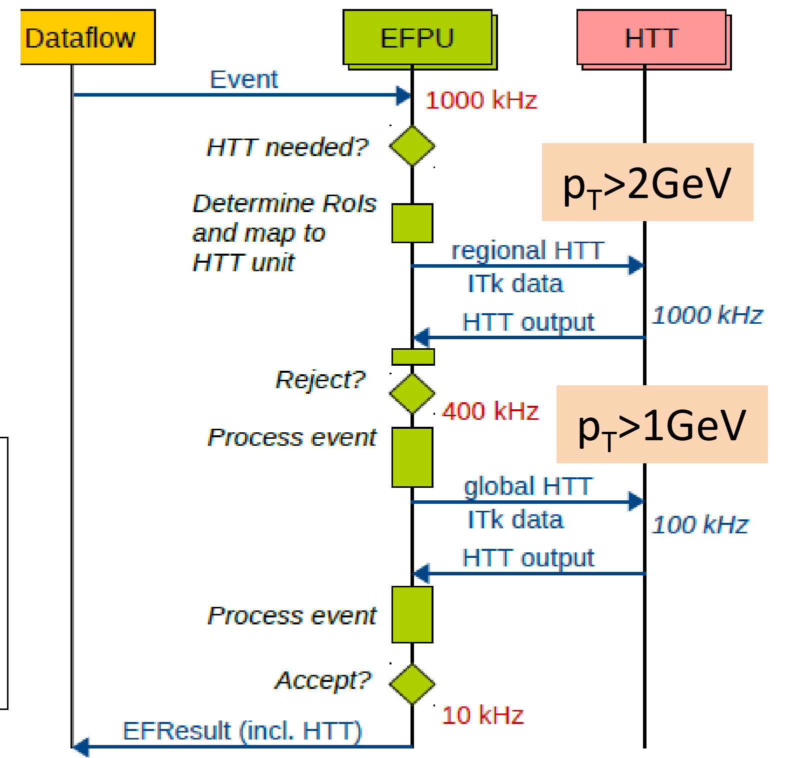
TDAQ Upgrade DAQ and HLT

CERN-LHCC-2017-020

- **DAQ** system based on FELIX universal network-based interface for TTC and all DAQ functions.
- **Event Filter** consists of Hardware-based Tracking for the Trigger (**HTT**) (based on Associative Memory technology for track finding and FPGAs for track fitting) and processor farm for sophisticated HLT event selection.
- **Regional HTT** runs on 1 MHz event stream and reduce rate to ~400 kHz output. **Global HTT** runs at ~100 kHz to find all tracks with $p_T > 1$ GeV and reduce final output to the required 10 kHz.



ATLAS Event Filter selection process with HTT



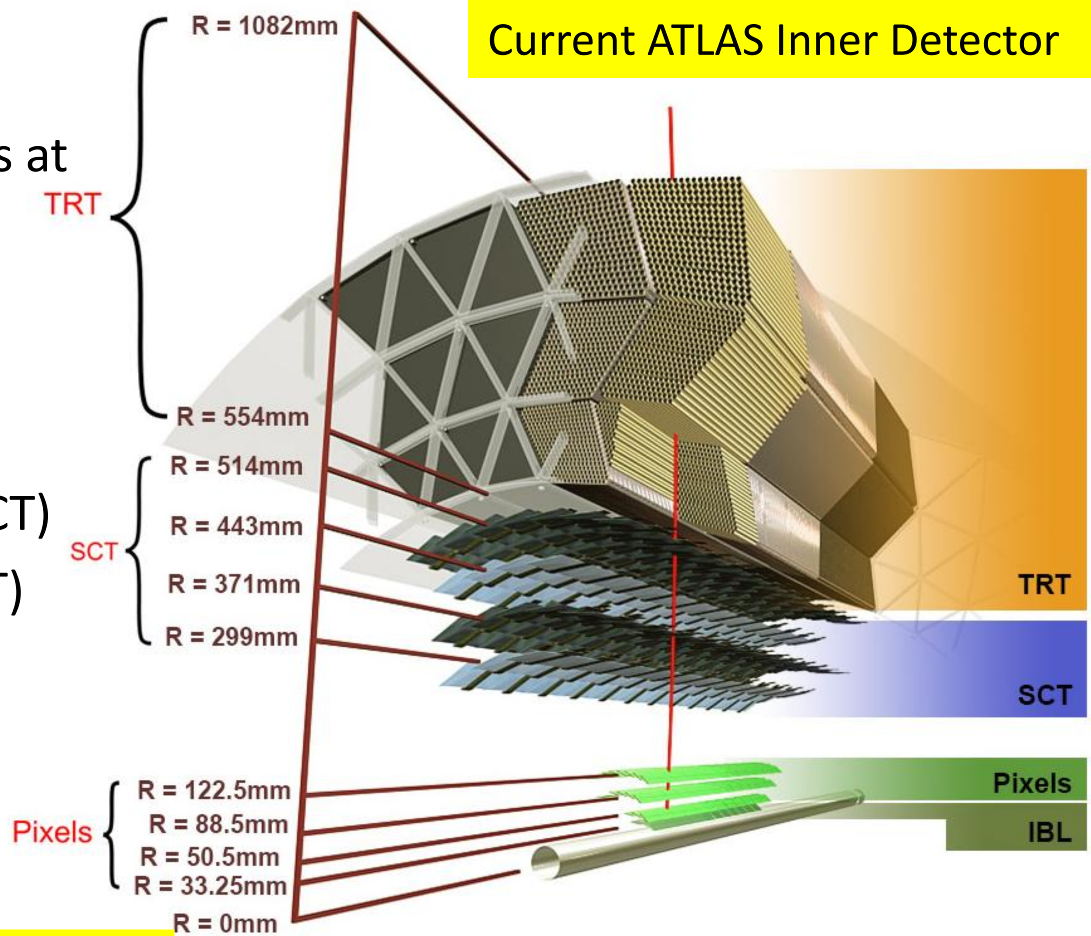
Inner Tracker (ITk) Overview

- Current ATLAS Inner Detector designed to operate for 10 years at L=1x10^{34} cm^{-2} s-1 with <μ>=23, @25ns, L1=100kHz

Limiting factors at HL-LHC

- Bandwidth saturation (Pixels, SCT)
- Increased occupancies (TRT, SCT)
- Radiation damage (Pixels (SCT) designed for 400 (700) fb^{-1})

Current ATLAS Inner Detector



Complete replacement of Inner Detector with all-Silicon Inner Tracker

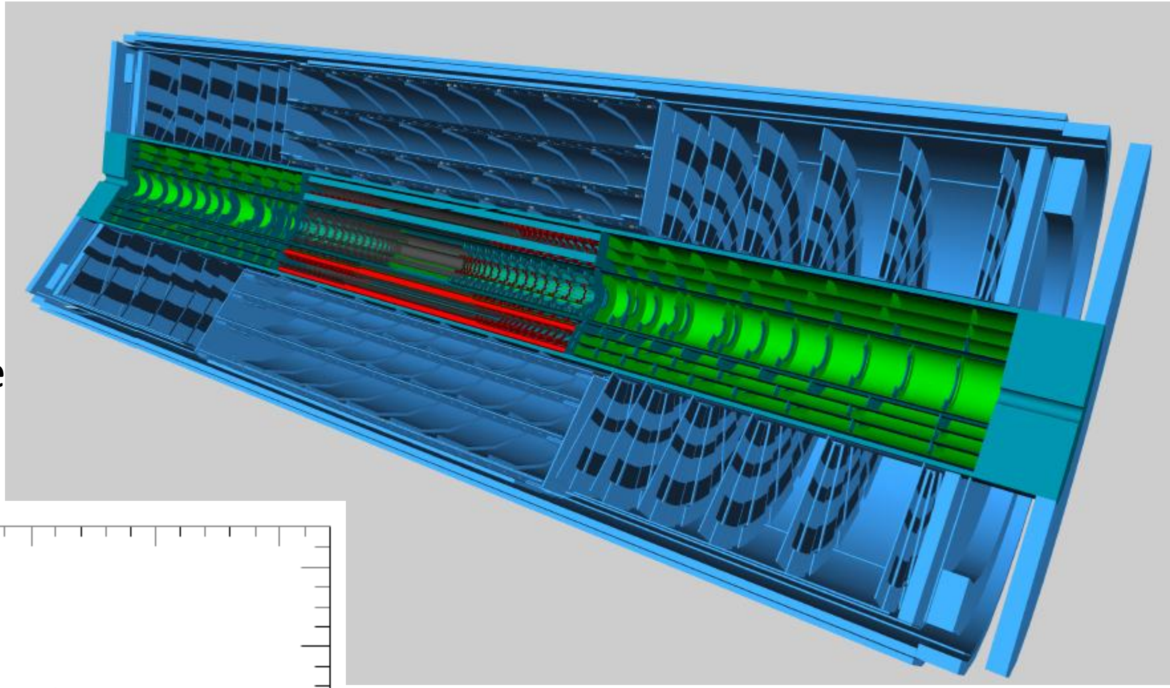
Inner Tracker Overview

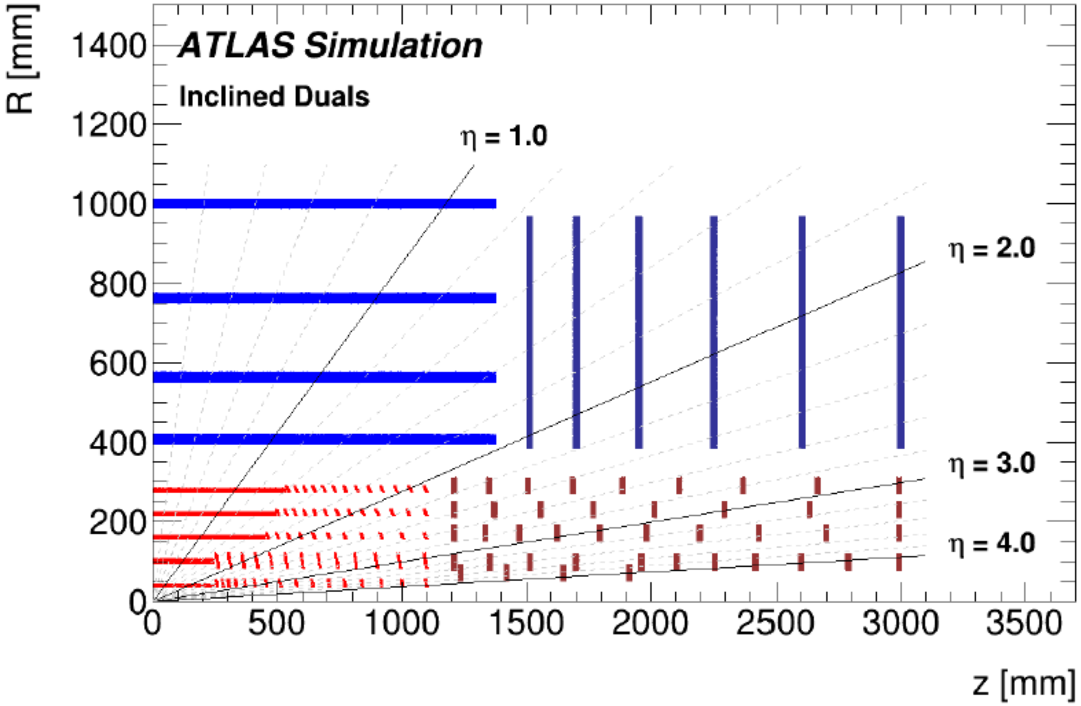
CERN-LHCC-2017-021

- **Strips**: 4 barrels and 6 disks .

- **Pixel**: 5 flat barrels at small η, inclined layout at intermediate η, and ring geometry at large η.

•Layout is still evolving for a few more months. Will be based on quad modules





- Acceptance extended from |η|<2.5 to |η|<4.0

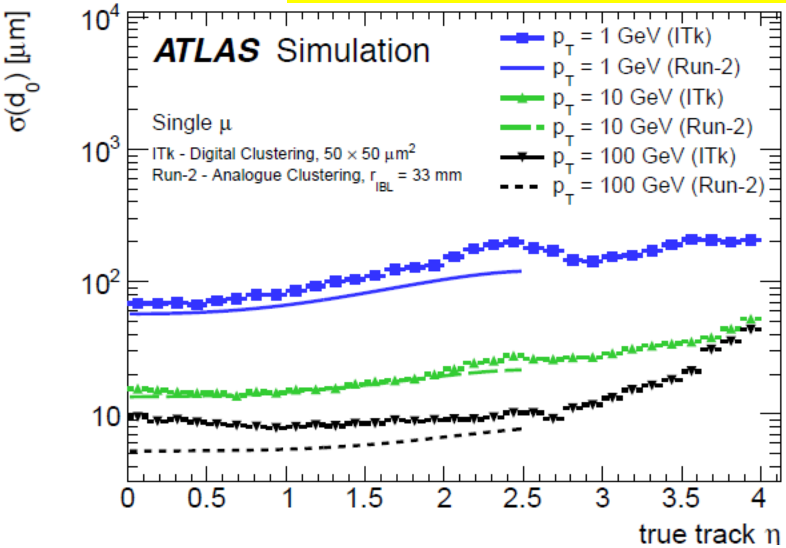
- Number of hits in barrel ~ 13
2 hits/strip module)
In forward regions at least 9 pixel hits

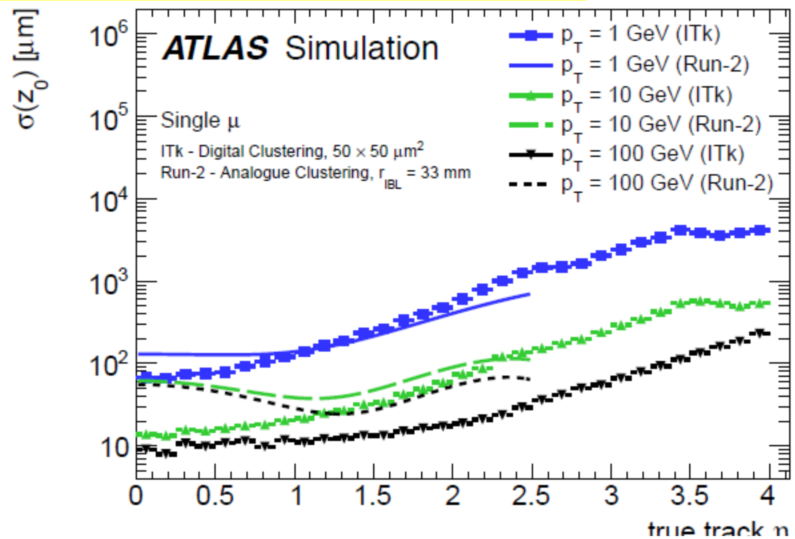
- Minimizes silicon area and material.

Inner Tracker Performance

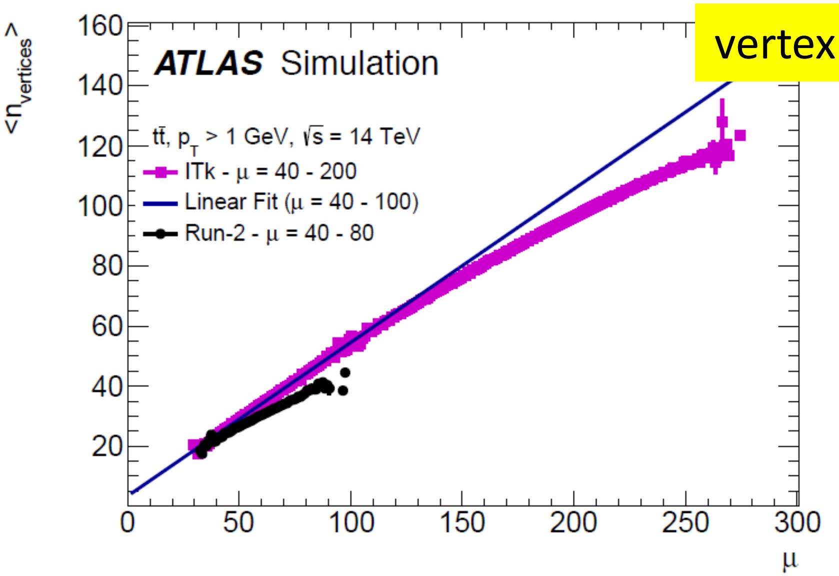
CERN-LHCC-2017-021

Transverse and longitudial impact parameter resolution

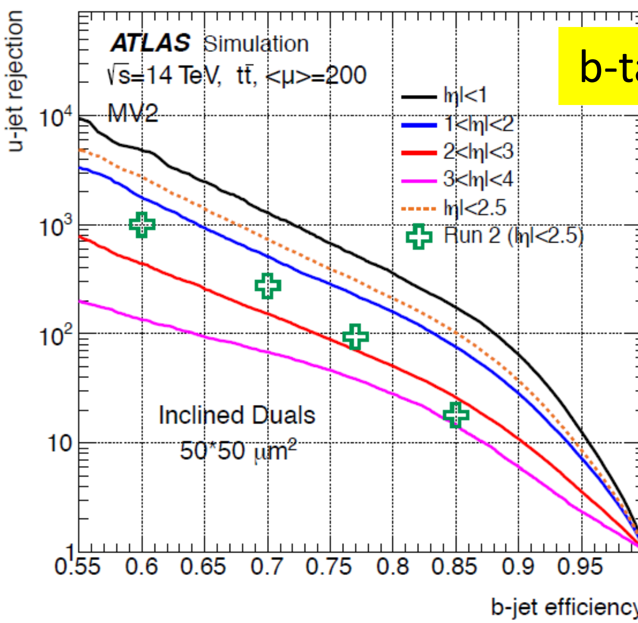




vertexing



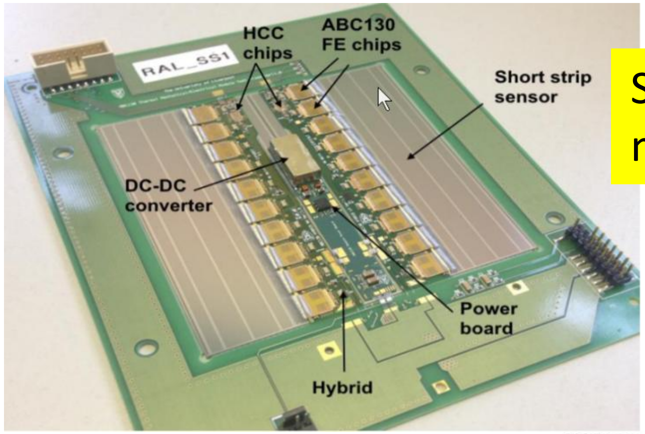
b-tagging



Inner Tracker - Strip System

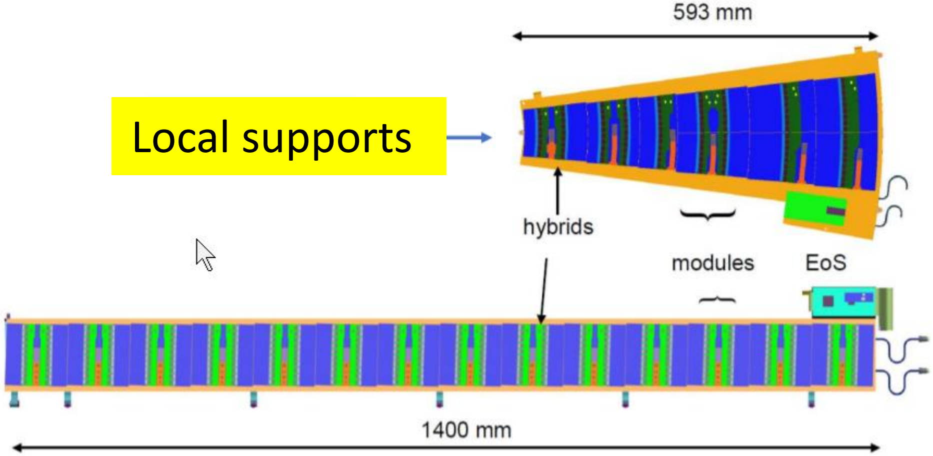
CERN-LHCC-2017-005

- ~18K Modules, each n-in-p sensor about 100 cm^2
- Strip width about 75 µm,
  resolution 22 µm rms.
- Stereo angle between pairs of sensors on either side of cooled support gives second coordinate to about 0.7 mm
- 59.87 million channels
- 165 m^2 of Silicon

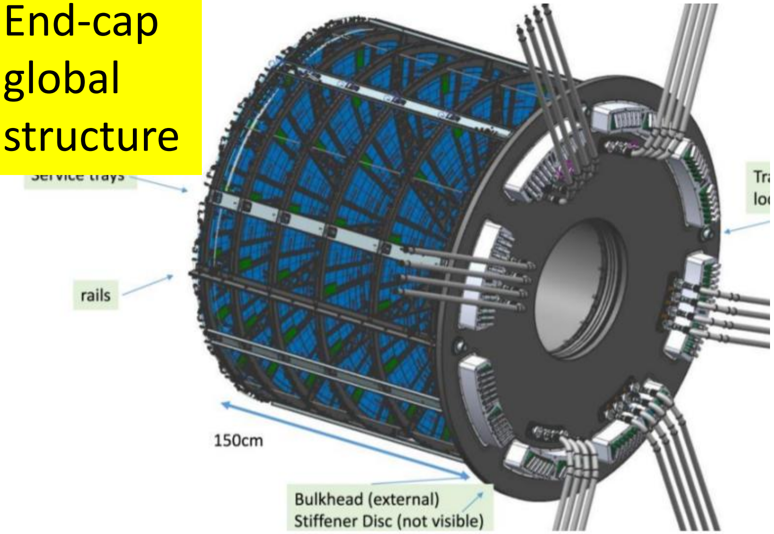


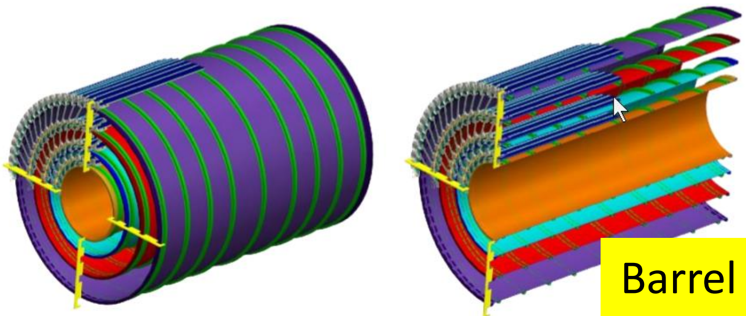
Strip barrel module

Local supports



End-cap global structure





Barrel cylinder

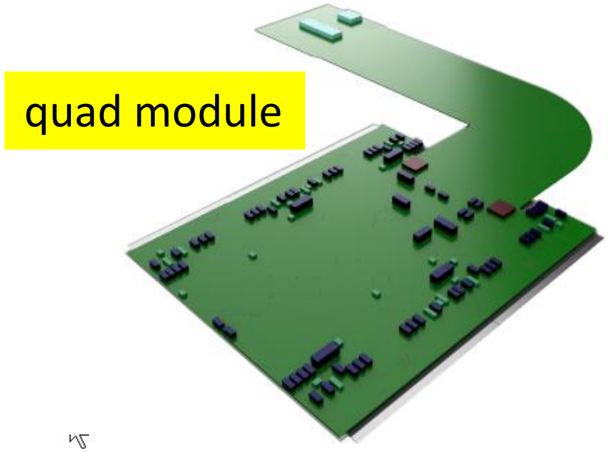
Inner Tracker - Pixel System

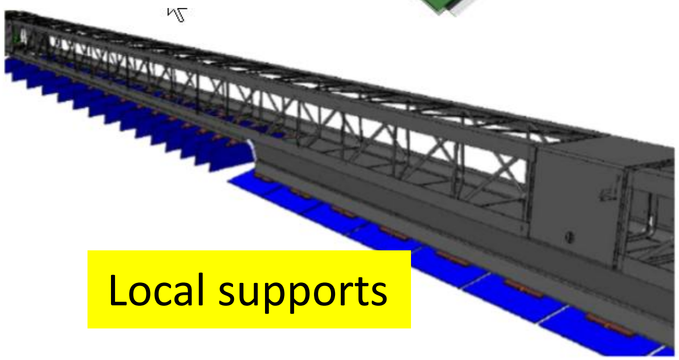
CERN-LHCC-2017-021

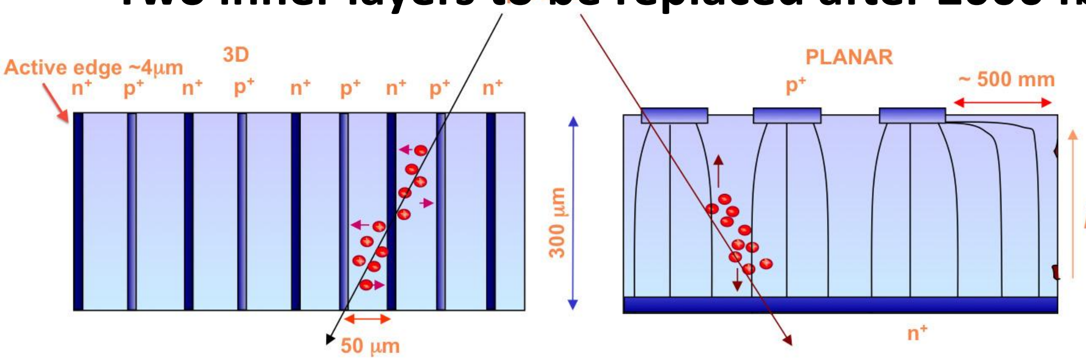
- Active area: 12.7 m^2
- Pixel size: 50x50 (or 25x100) μm^2
- 10276 modules;
- 33184 FE chips ;
- # of channels: ~$5x10^9$
- Radiation tolerance up to: $1.3x10^{16}$ n_{eq}/cm^2
  TID 9,9MGy

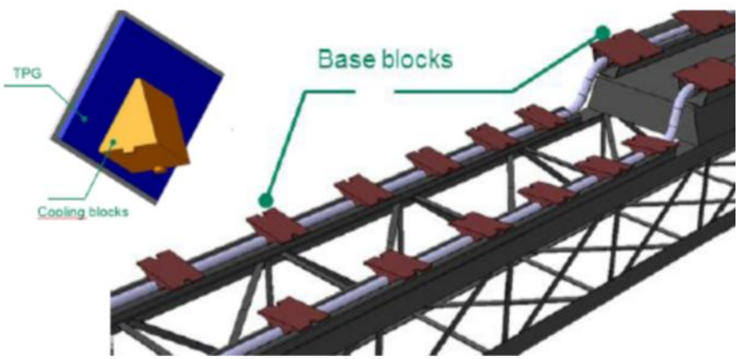
Pixel sensor technologies:

- 3D sensors in the innermost layer
- Planar sensors
- **Two inner layers to be replaced after 2000 fb^{-1}**





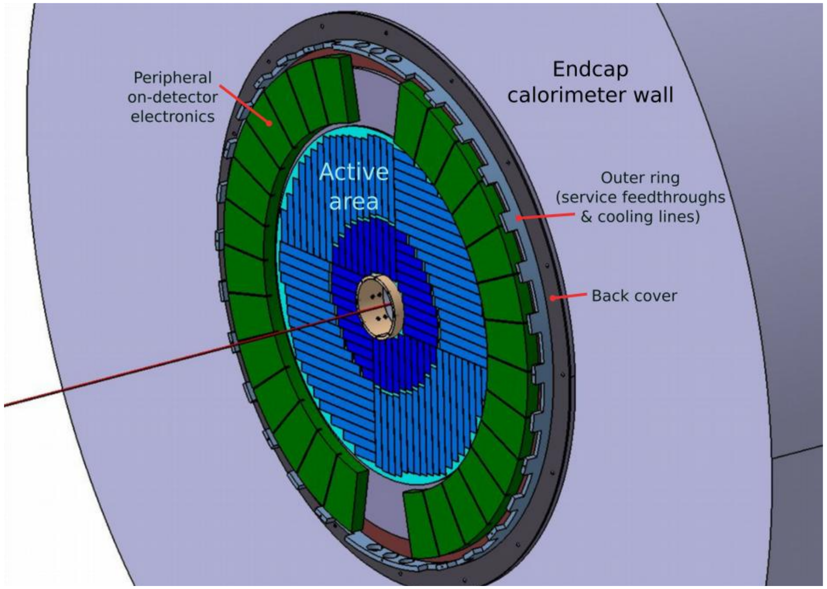


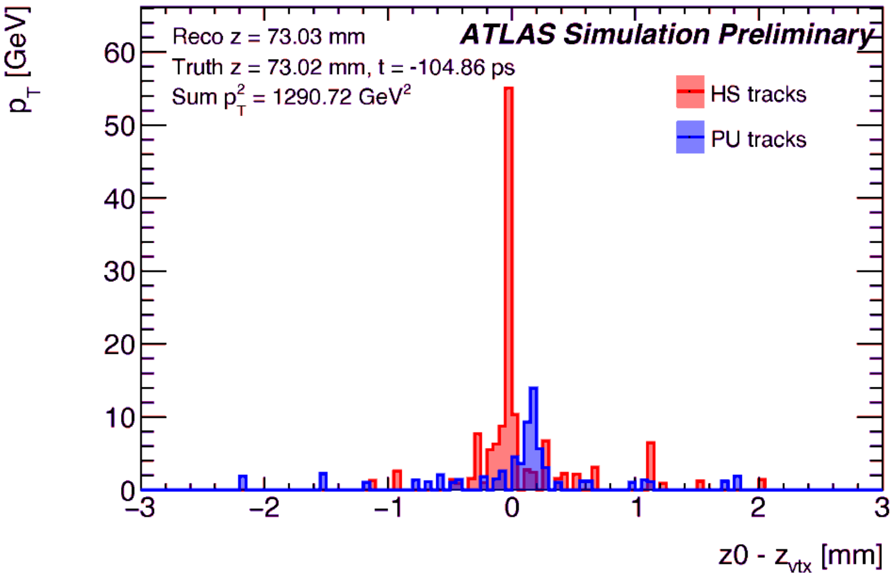


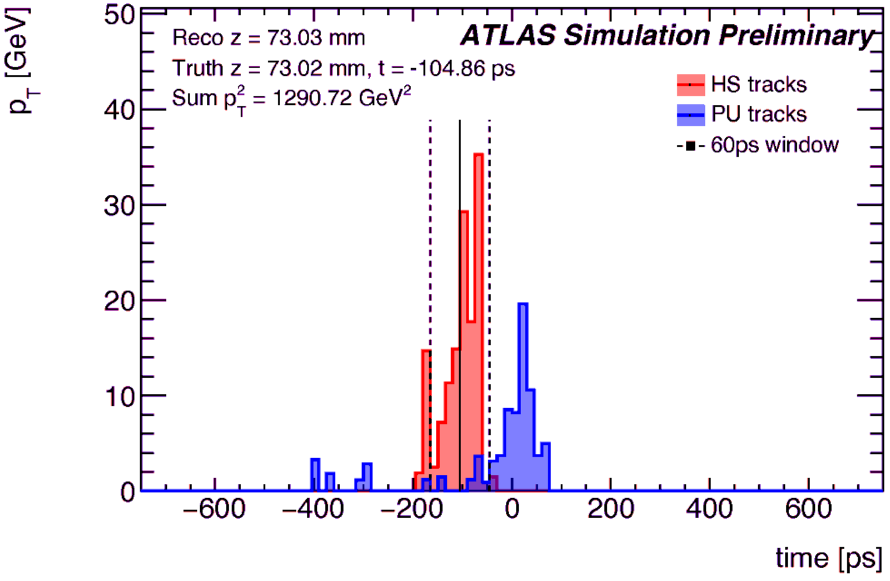
High Granularity Timing Detector

CERN-LHCC-2018-023

- Timing detector could be used in addition to track ID z_0 to separate vertices from different pp interactions in a high pileup environment
- ~4 layers of low-gain avalanche detectors with 30-50 ps time resolution, installed in space between ID and calorimeter end-caps



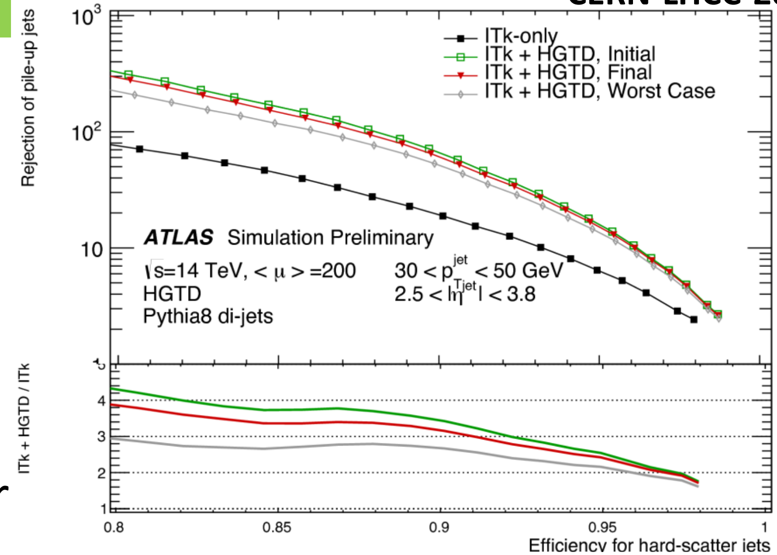


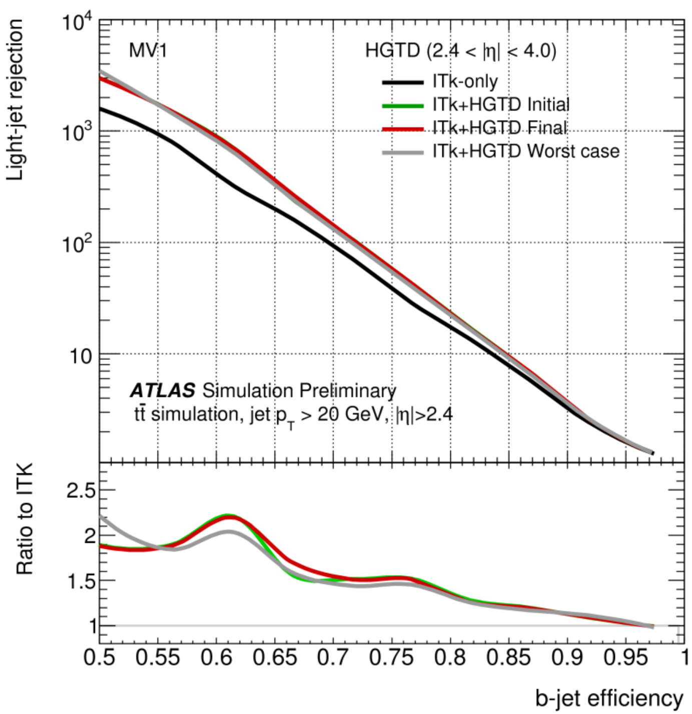


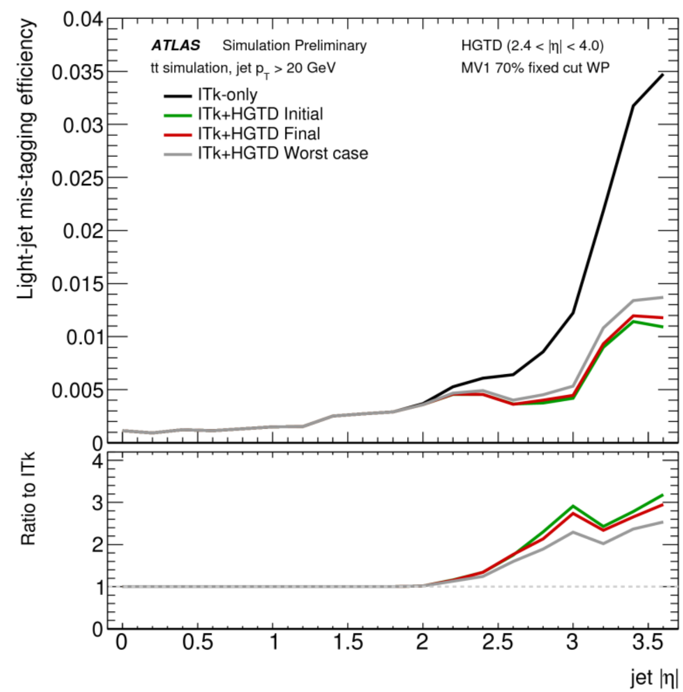
High Granularity Timing Detector

CERN-LHCC-2018-023

- Improvements in selection of hard-scatter jets, b-tagging and lepton isolation:
  - pileup jet rejection in region covered by HGTD by factor 5-10 additional rejection
  - factor 1.5-2 for tagging, factor 2-3 for







Summary

- The HL-LHC will provide hundreds of fb^{-1} per year, allowing unprecedented precision measurements of SM and Higgs properties , exploration of extremely rare processes or searches beyond SM physics

- ATLAS Upgrades will allow full exploitation of the very high luminosity from the HL-LHC in 2026

- Work on all the major upgrades is well advanced and documented in TDRs. More detailed information can be found there: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/WebHome#Upgrade_Projects_and_Physics_Pro