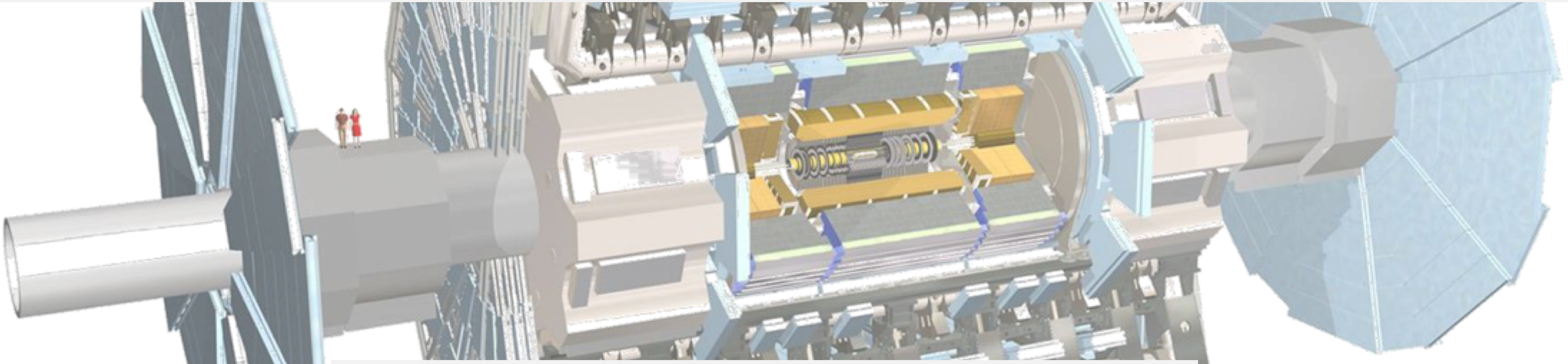
The ATLAS Experiment upgrades: present status and the future at the High Luminosity LHC



Sandra Leone (INFN Pisa)

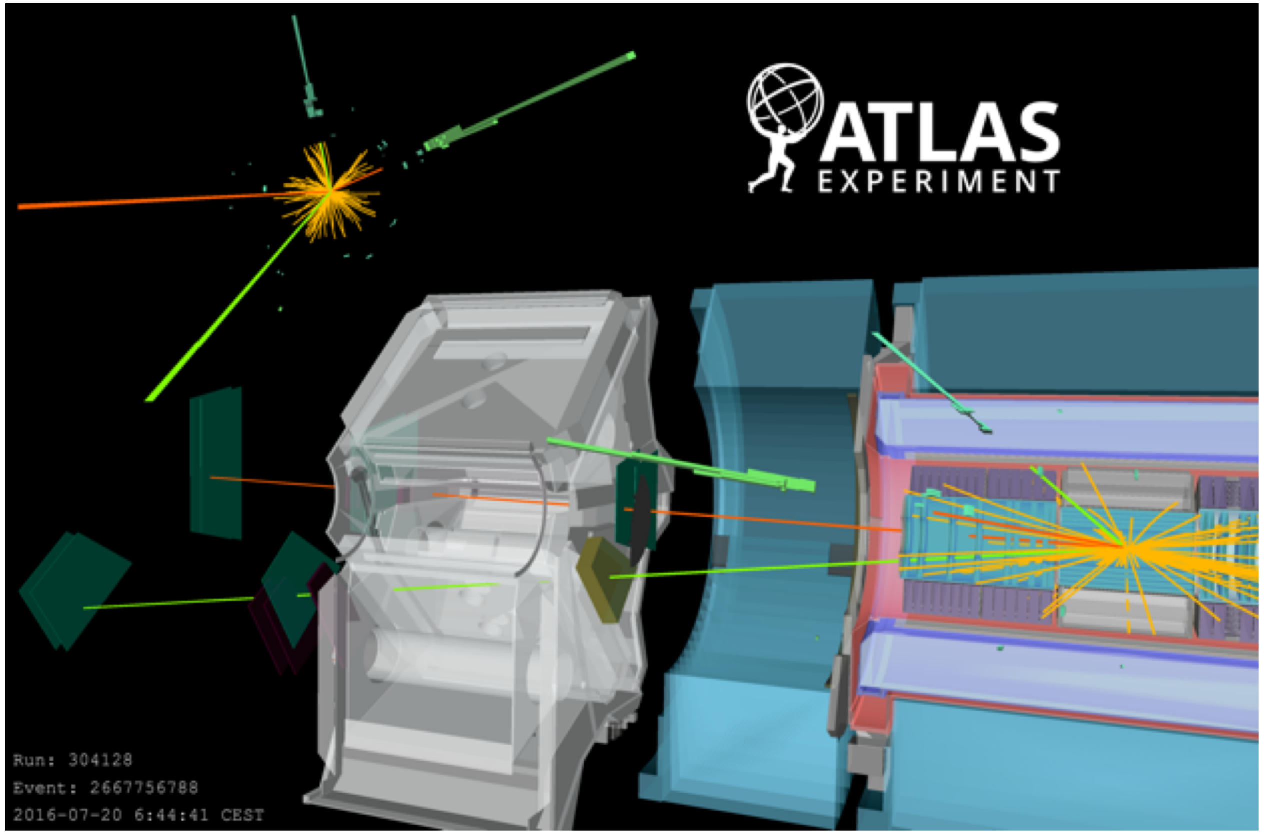
on behalf of the ATLAS Collaboration

19th International Conference on Hadron Spectroscopy and Structure (HADRON2021) July 28, 2021

Physics motivation for High Luminosity LHC

High luminosity is needed to extend the reach of LHC physics program:

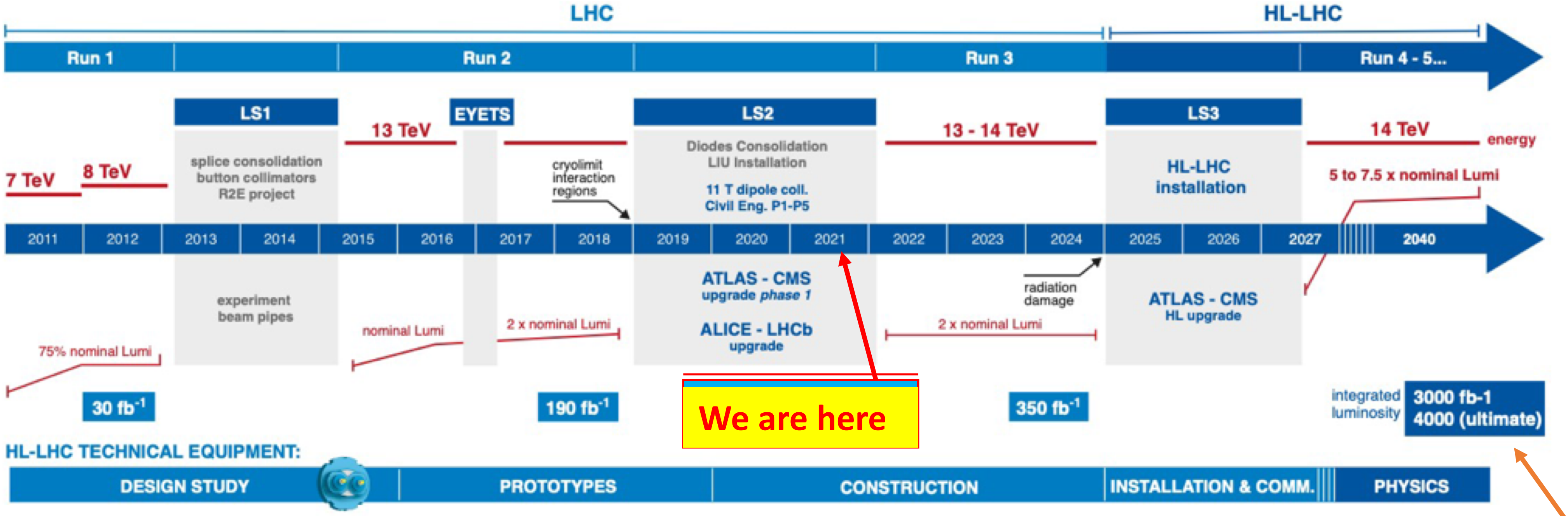
- Pursue exploration of Electroweak Symmetry Breaking in the Standard Model
  - Precision measurements (e.g. Higgs couplings and self-coupling)
  - Search for SM rare processes (e.g. $H \rightarrow \mu\mu$, vector boson scattering, etc.)



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/EventDisplayRun2Physics#Exotics_Full_Run2_event_displays

- Search for Beyond Standard Model physics in new regions of phase space:
  - SUSY and exotic benchmarks significantly extended
  - Rare processes and resonances: search for new massive states
  - Exploration of the dark sector

Luminosity and energy increase at the LHC

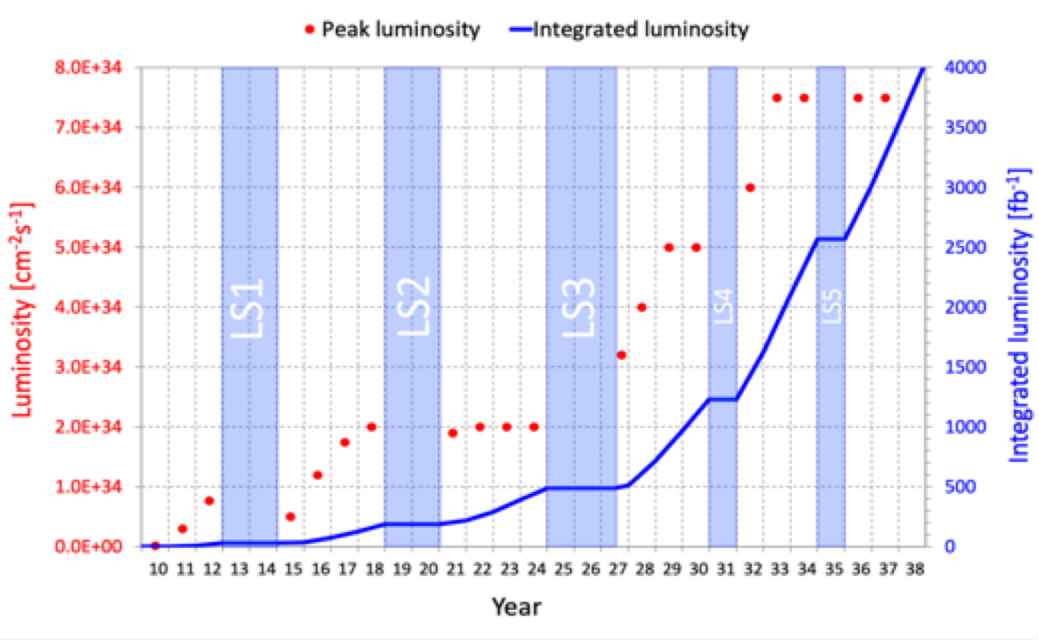


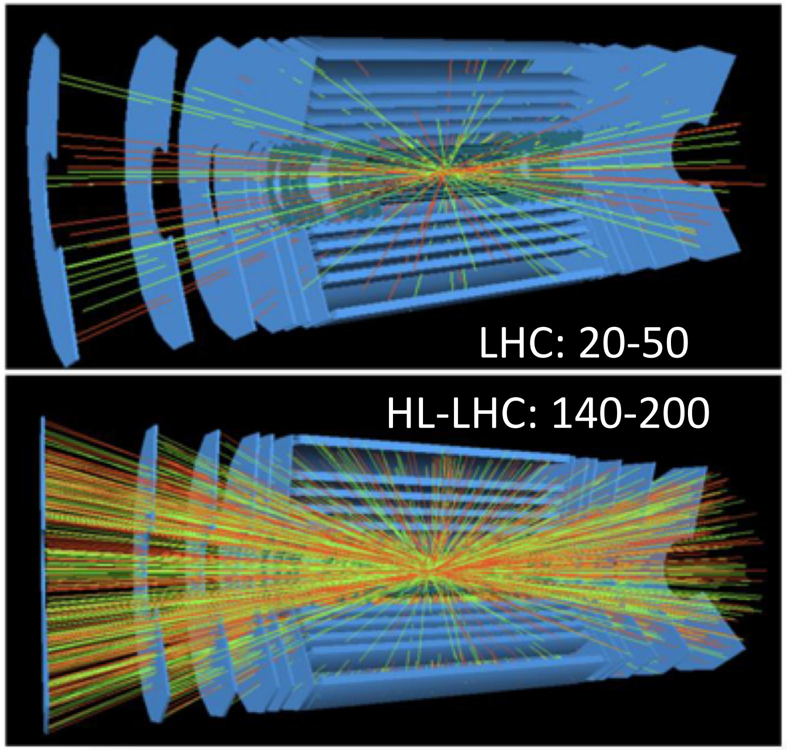
4000 fb^{-1} ultimate

- Long Shutdown 2 (Phase-1 upgrade) preparing for Run 3
  – Luminosity leveling at 2 x 10^{34} $cm^{-2}s^{-1}$, possible increase to √s=13.5 or 14 TeV
  – Expecting accumulation of 300 fb^{-1} during Run 3
- Long Shutdown 3 (Phase-2 upgrade) to prepare for HL-LHC
  – The HL-LHC era with luminosity of 7.5 x $10^{34}$$cm^{-2}s^{-1}$ at √s=14 TeV
  – Large data samples (up to 4000 fb^{-1}) and major experimental challenges

HL-LHC impact and challenges for ATLAS detectors

- The HL-LHC challenges the detectors and detector electronics



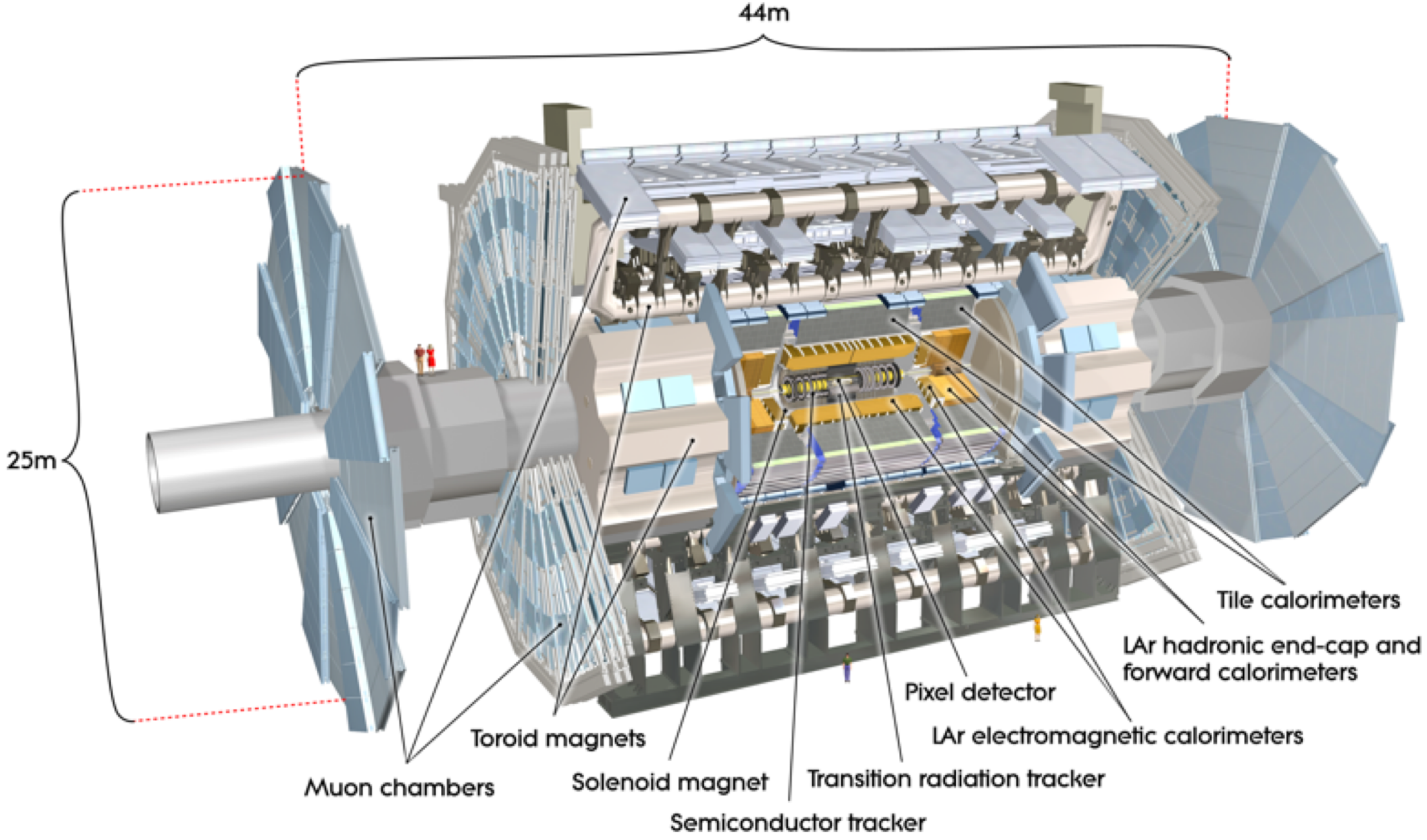


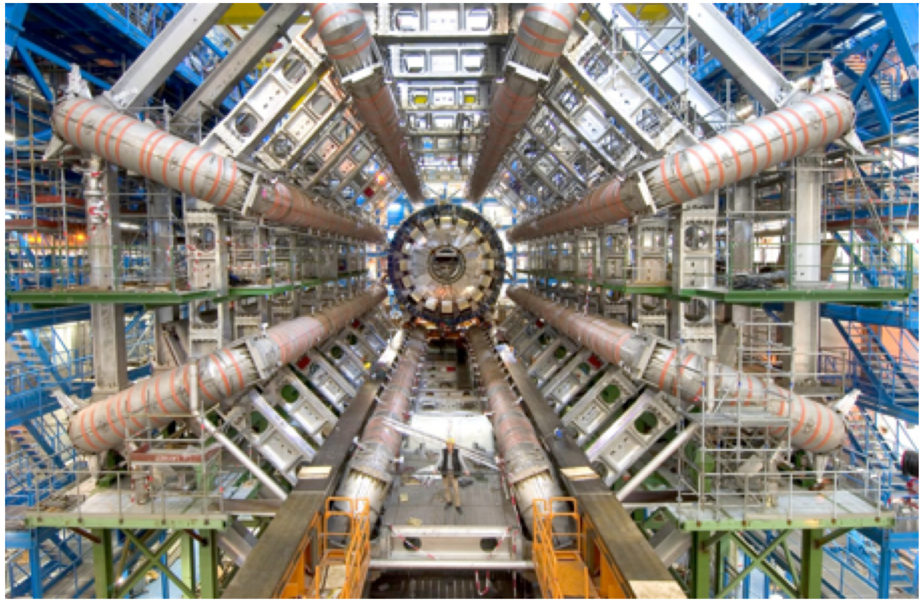
- High luminosity: from 2x 10^{34} $cm^{-2}s^{-1}$ up to 7.5x10^{34} $cm^{-2}s^{-1}$
- High trigger rates from 100 kHz Level1 to 1 MHz in ATLAS
- High pile-up (ie detector occupancy) conditions → from <μ> = 20 for LHC design up to <μ> =200 for HL-LHC
- Increased radiation dose → increased radiation damage and activation of materials
- Long term operation → 15 additional years on top of the original 15 (was designed for 10)

- Detector and electronic upgrades are underway to ensure high efficiency and high quality data-taking and maintain good physics performance in HL-LHC era

Atlas detector overview…

- 44m long and 25m high, ~7000 tons
- ~ 3000 km cables and ~110 million channels
- Eight superconducting coils 25m long and 5m wide.
- 2T/1T magnetic field delivered by solenoid/toroid magnet





Atlas detector overview… and phase I Upgrade

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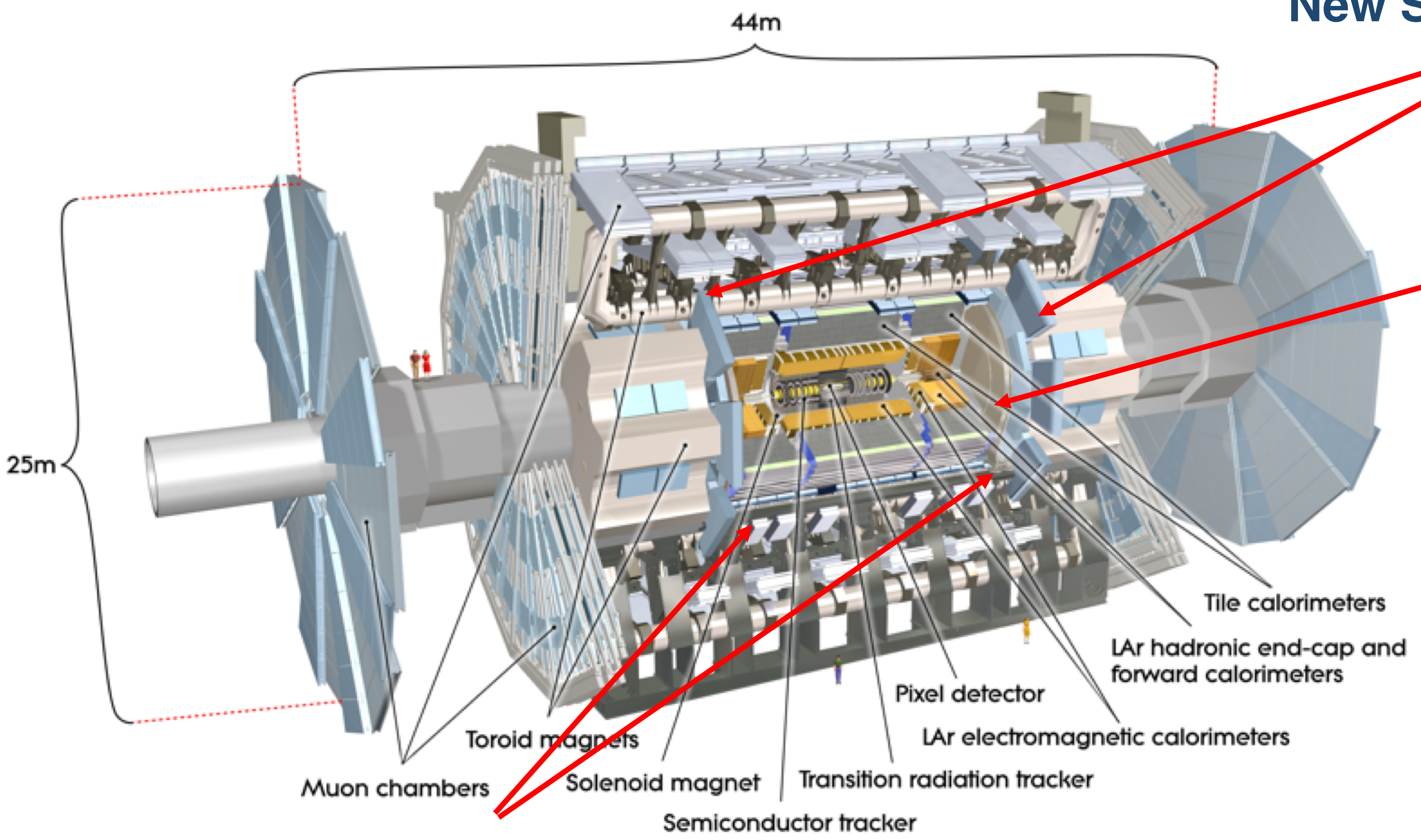
New Small Wheel detector

LAr new front-end electronics



Trigger / DAQ off detector electronics:

New L1 hardware trigger → Improved trigger capabilities
→ Higher purity e/γ triggers
→ Lower forward muon fake rate

New **Muon RPC** detector (BIS78)

S. Leone (INFN Pisa)

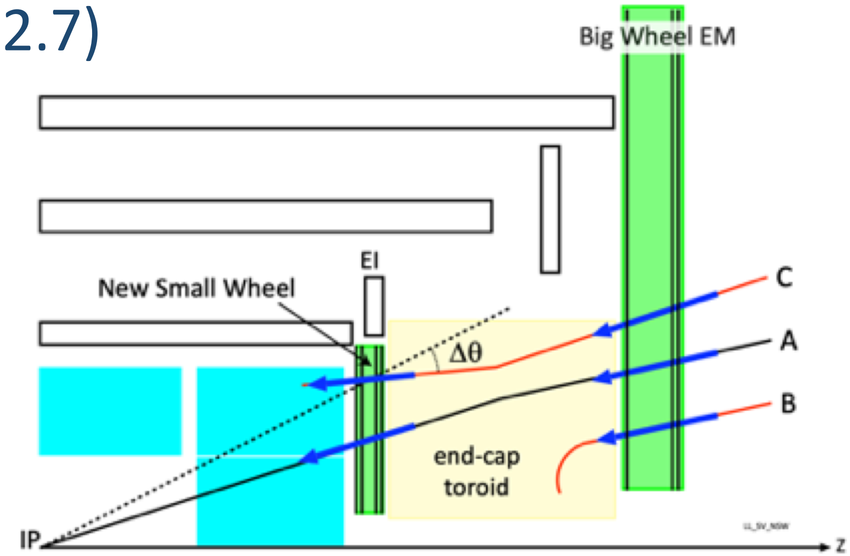
ATLAS-TDR-023

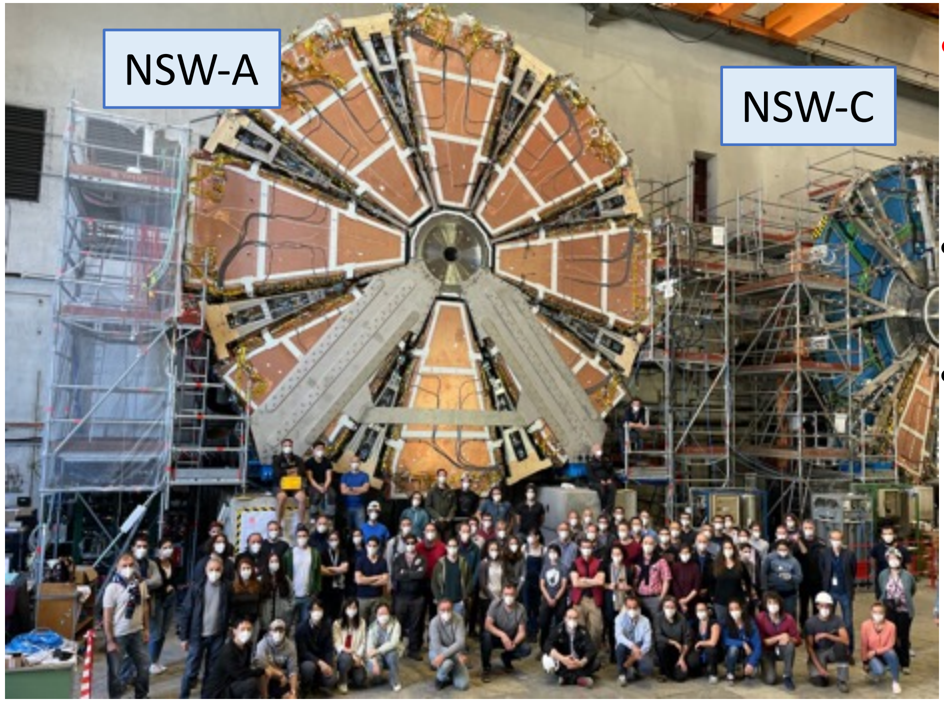
Phase I Upgrade: New Small Wheel status

Two 5m radius wheels in the inner end-cap region (1.3 < |η| < 2.7)

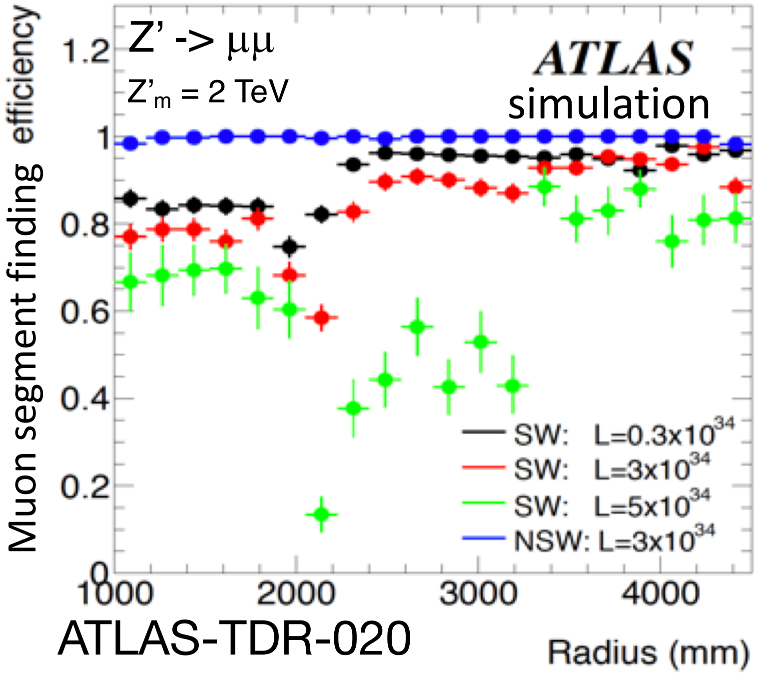
Needed to reduce fake muon triggers in the end-cap region, thanks to the coincidence endcap-NSW

- Each wheel is formed by:
- 2 external small-strip Thin Gap Chambers sTGC wedges (trigger, bunch crossing identification + tracking with < 1 mrad resol.)
- 2 internal MicroMega wedges (mainly tracking, spatial resolution <100 µm)





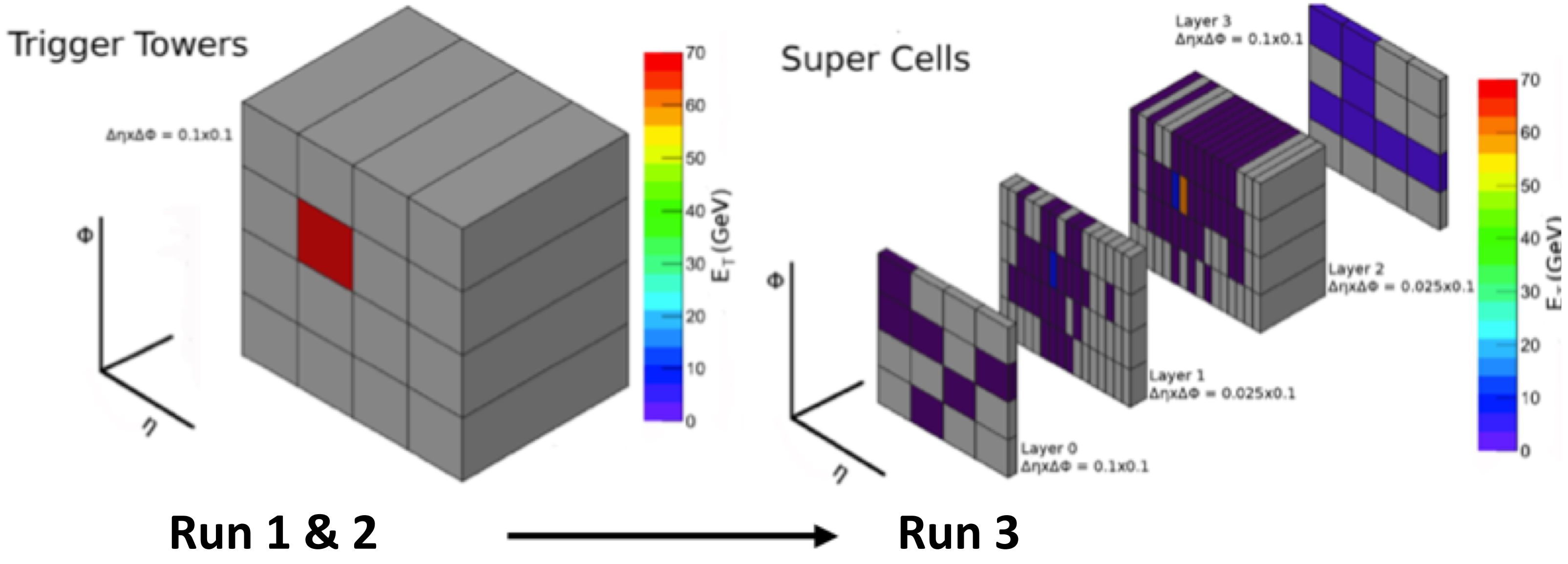
- News on 12 July 2021:
  NSW-A was lowered 100 meters underground
- Second wheel will follow in October 2021
- 2022 will be crucial for commissioning and integration in ATLAS of the 2 wheels

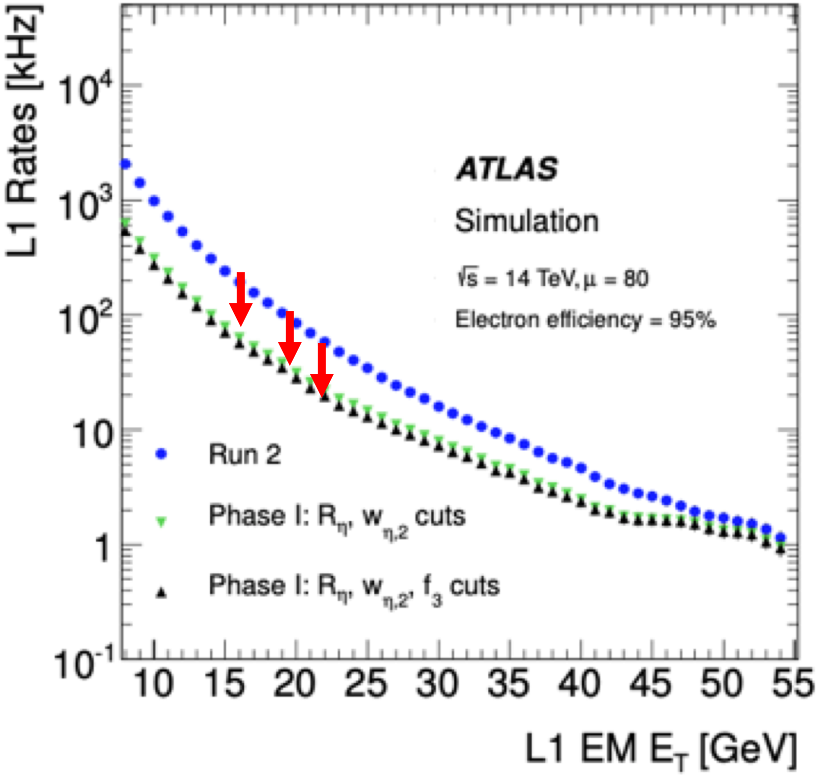


ATLAS-TDR-020

S. Leone (INFN Pisa)

Phase I Upgrade: LAr calorimeter





CERN-LHCC-2013-017

- LAr new front-end and back-end boards
- Trigger electronics with higher granularity

(increased trigger tower granularity $\Delta\eta \times \Delta\phi = 0.025 \times 0.1$ and longitudinal shower information)

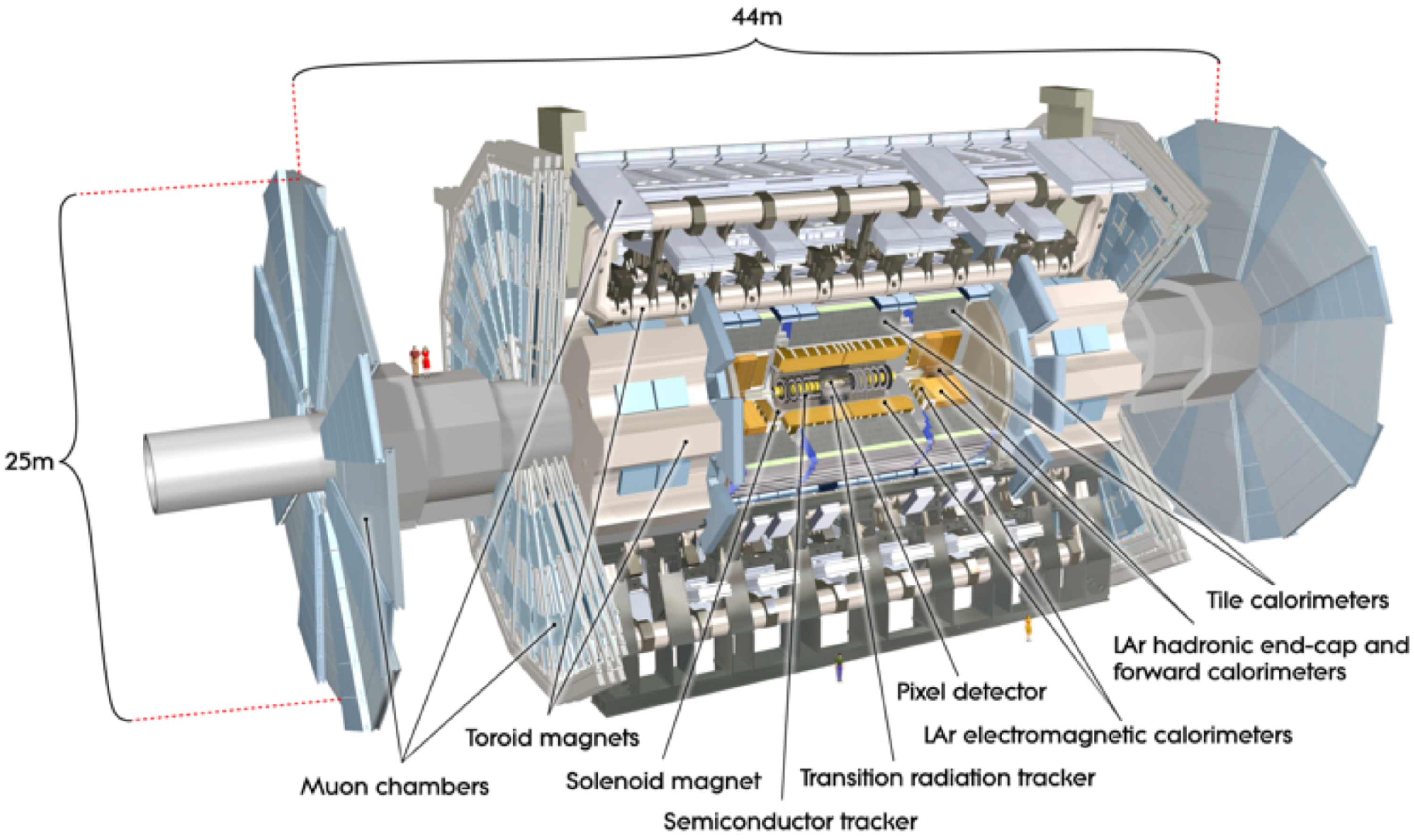
- More refined processing of electromagnetic calorimeter information at higher granularity

→ Electrons: high efficiency & reduced trigger rate

→ Jets: Improved resolution

→ allows ATLAS to maintain lower EM trigger thresholds in Run 3

Atlas detector overview… and phase II Upgrade

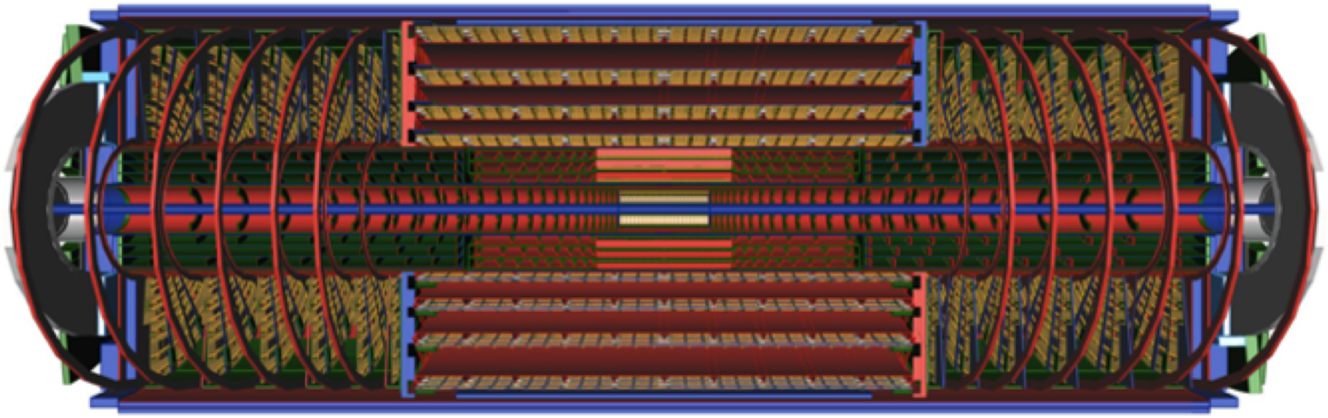


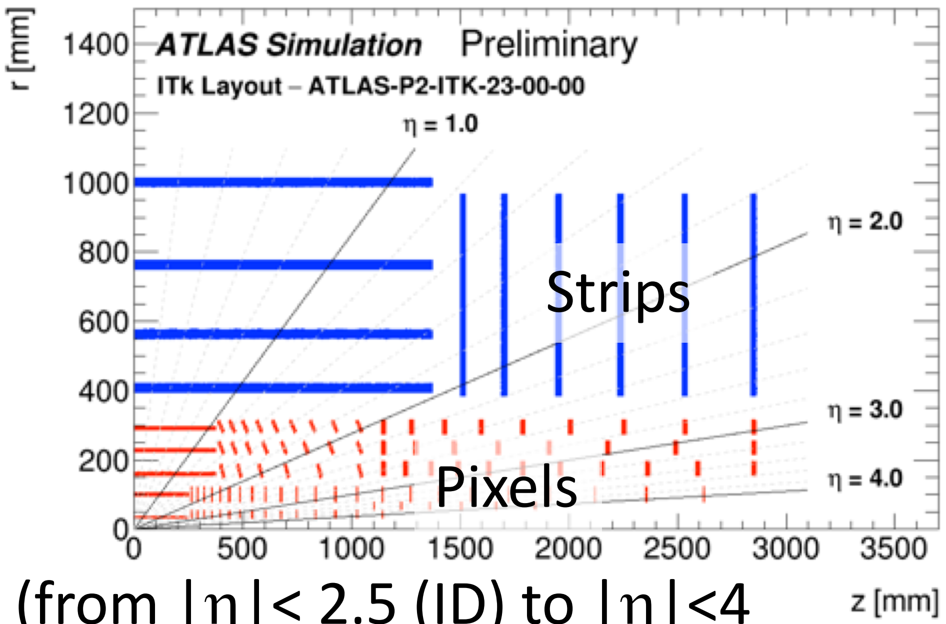
	Phase-2 Upgrade
Tracking	Completely new Inner Tracker (ITk) with $\lvert\eta\rvert<4$ and Pixel and Strip subdetectors
Calorimeters	Front-end and back-end electronics replacement for 40MHz readout
Timing	New high-granularity timing detector
Muons	New muon chambers in barrel inner region, and upgraded electronics for 40MHz readout

Global number of readout channels from 100 millions to 15 hundred millions!

CERN-LHCC-2012-022
ATL-PHYS-PUB-2019-005

Inner tracker (ITk) for Phase II





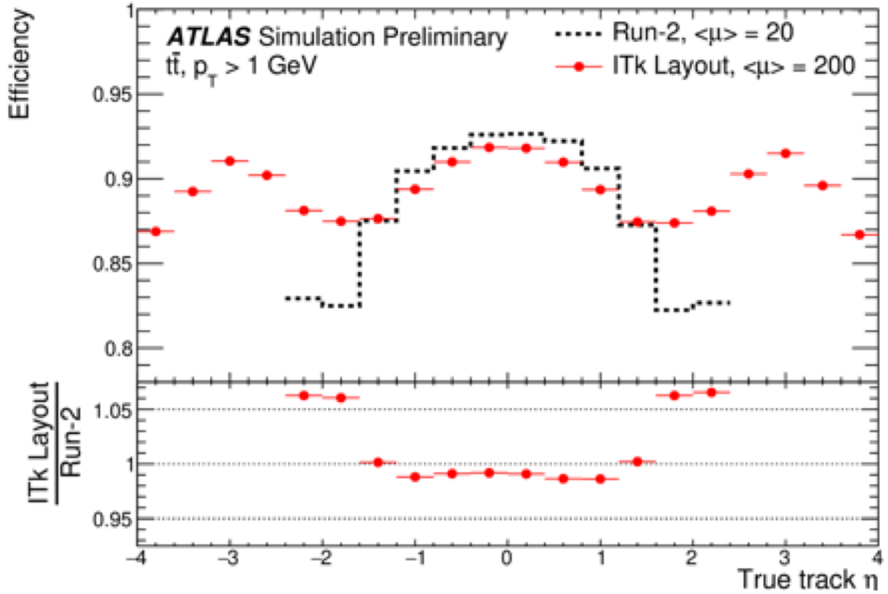
- New all-silicon inner tracker with increased acceptance (from |η|< 2.5 (ID) to |η|<4 (ITk)) and increased pile-up rejection
- Inner part made of 5 barrel layers and barrel+end-cap rings of **pixel** detector
  - Covering |η|< 4.0. Active area: 12.7 m^2. # of channels: ~5x10^9
- Outer part made of 4 barrel layers and 6 end-cap disks of **strip** detectors
  - Covering |η|< 2.7. 165 m^2 of Silicon. almost 60 million channels
  - Silicon microstrip modules with small stereo angle provide 2D measurements
- Improves tracking and b-tagging performance compared to existing detector thanks to:
  - high track reconstr. efficiency over 90% (comparable to current Inner Detector (ID))
  - low rate of fake tracks (one order of magnitude reduction compared to ID)

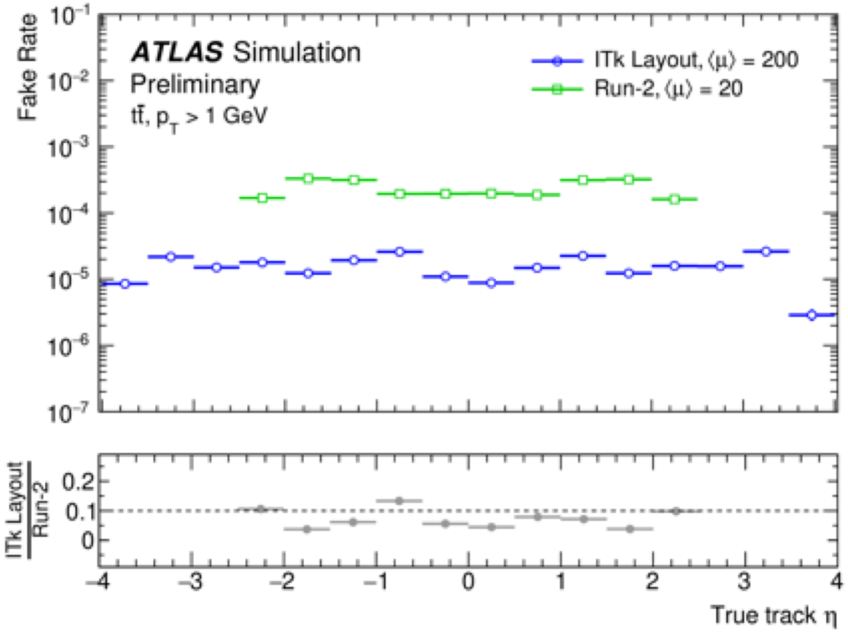
Inner tracker (ITk)

A lot of progress, despite of pandemic situation

Entering preproduction stage

Pixel module on automated machine





ATL-PHYS-PUB-2019-014

At least 9 hits are guaranteed for all particles with $p_T > 1$ GeV

Overall significant improvement thanks to:

- Reduced material budget ➔ minimize material interactions
- Increase in overall hit counts ➔ tighter track selection
- Improved hermeticity ➔ more hits, fewer holes

Electromagnetic calorimeter (LAr)

LAr calorimeters sensing components inherently radiation hard

→ expected to perform reliably at HL-LHC

Readout electronics full replacement is required:

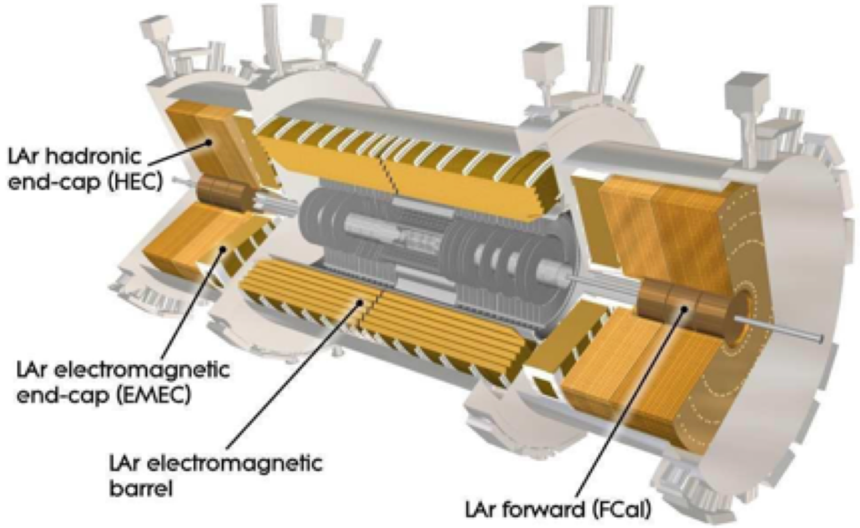
→ Current electronics is not compatible with phase-II requests (latency and trigger rate)

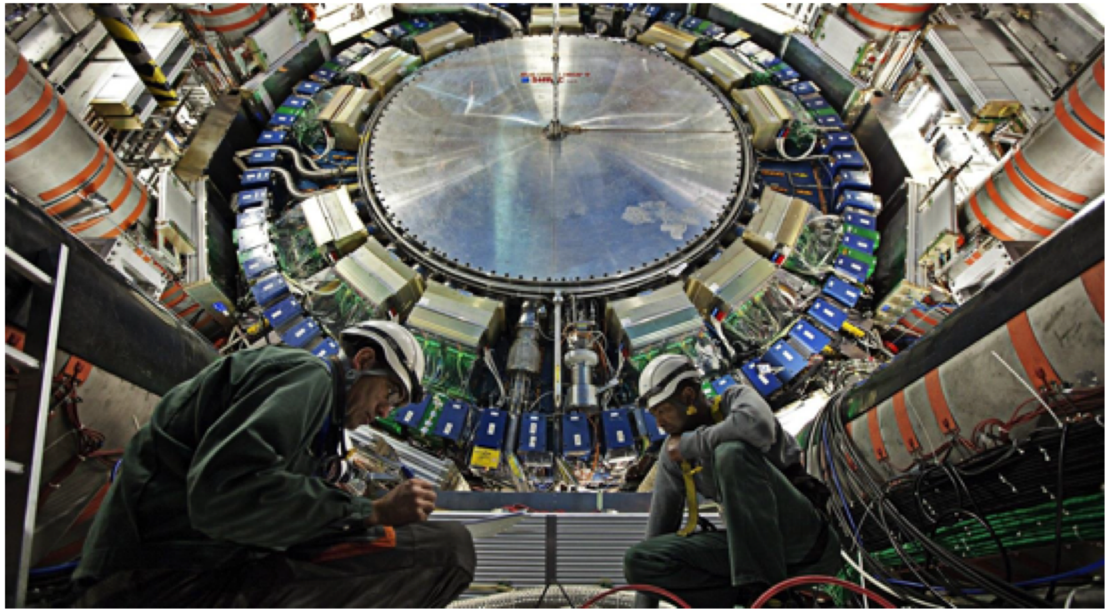
→ Radiation hardness requirements are above original design

• new front-end, calibration boards and all back-end electronics will be replaced

• new LV power supplies

• full granularity calorimeter signals will be digitized and sent off-detector at 40 MHz

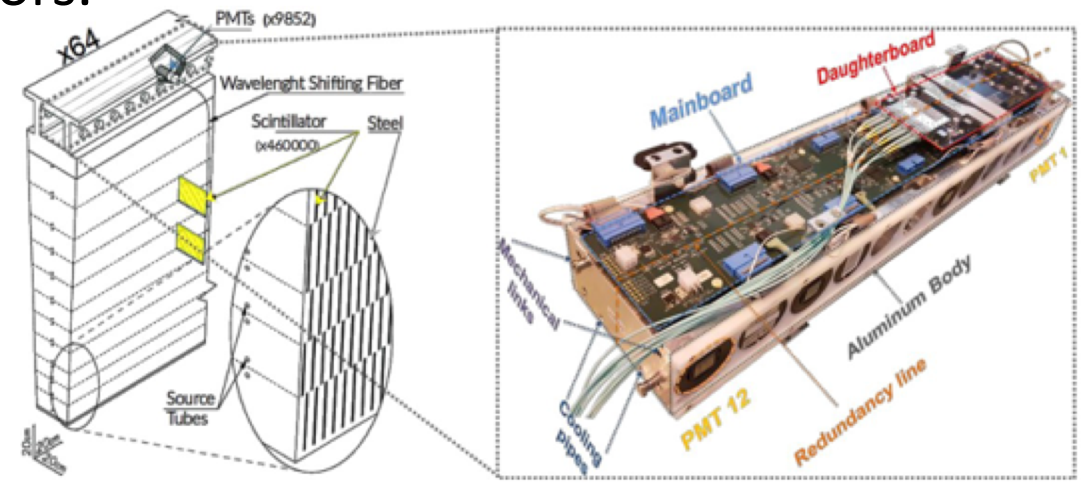


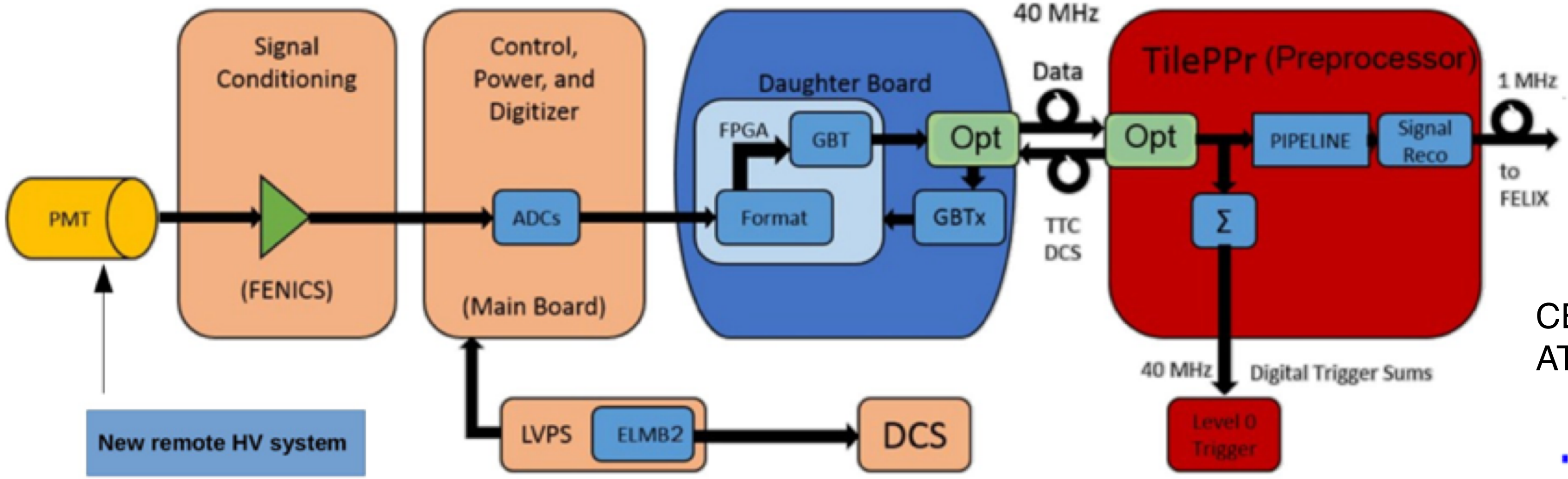


CERN-LHCC-2017-018 ; ATLAS-TDR-027.

Hadron calorimeter (TileCal)

- New readout for front-end and back-end electronics
  - → To provide fully digital data to the trigger processors.
  - → More radiation hard.
- New mechanical structure to host the electronics
  - → easier access for maintenance
- New HV for PMT → individual channel for each PMT
- New LVPS → will be more radiation tolerant
- Upgraded calibration systems (Cesium and Laser)
- PMTs reading out the most exposed cells will be replaced (about 10% of the total 10K PMTs)
- Project in very mature state. Entering production phase in many areas

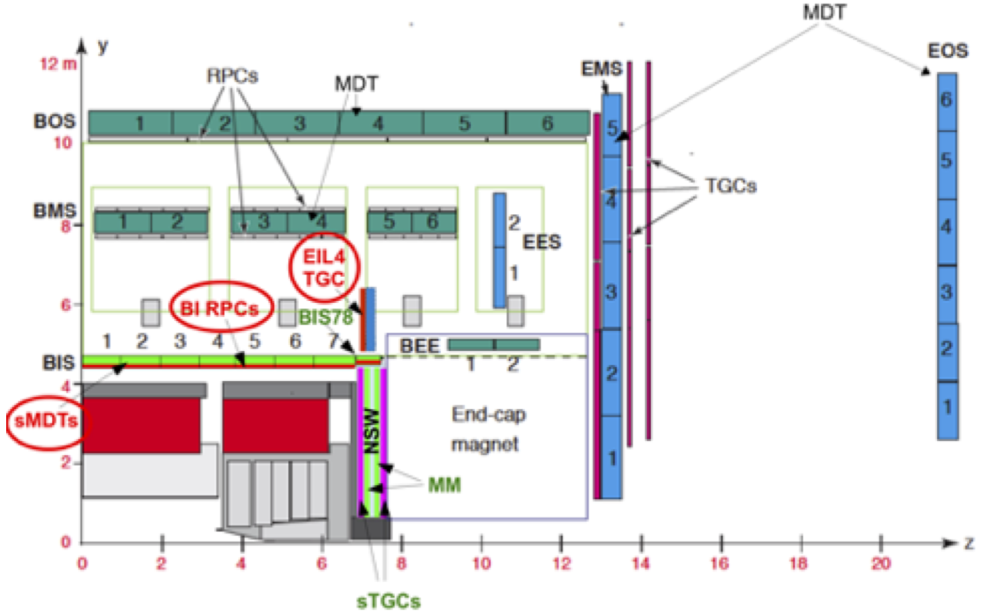




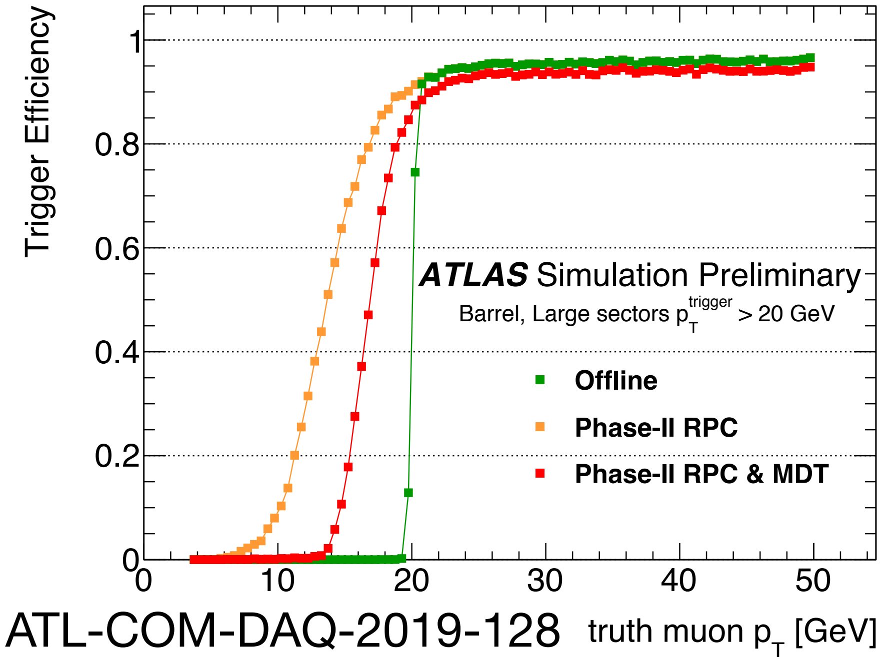
CERN-LHCC-2017-019
ATLAS-TDR-028

Muon detectors

- Muon system is made of different types of gaseous detectors in the outer part of ATLAS (barrel+end-cap)
- <u>Requirements for Phase-II:</u>
  →reduce the trigger fake rate in barrel and end-cap regions (combine NSW-TGC trigger info)
  → increase geometrical coverage in the barrel
- <u>New detectors:</u>
  - barrel inner RPC + sMDT:
  - old BIS MDT replaced by new (sMDT + RPC)
  - new RPC mounted on top of existing BIL MDT
  - TGC EIL4 (from doublet to triplet + finer granularity)
- New front-end, trigger and readout electronics, new power system
- Transmitting all data @ 40MHz, for both trigger and readout: no buffering on detector
- Use MDT for trigger → Improvement in trigger momentum resolution



R-Z views of the Phase-II ATLAS muon spectrometer layout



ATL-COM-DAQ-2019-128

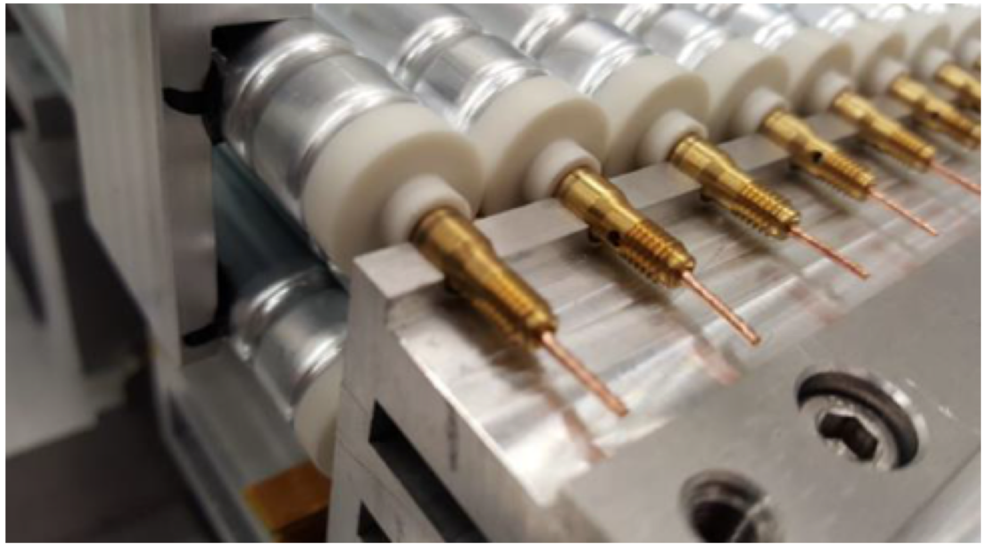
MDT: Muon Drift Chamber – RPC: Resistive Plate Chamber - TGC: Thin Gap Chambers

Muon detector chambers

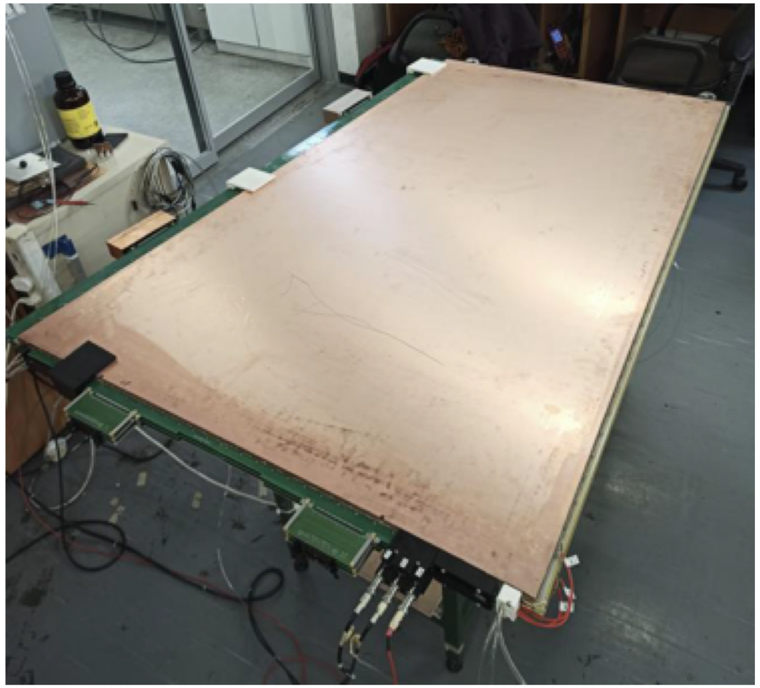
Most of the projects in prototyping phase
Huge activity from the electronics side (ASIC prototyping and production)

- sMDT
  - → Production underway
  - → High precision and performance of the first chambers
  - → New electronics allows for better performance than legacy
- RPC
  - → Prototypes are being built
  - → Mechanics design progressing well
- EIL4 TGC
  - → First prototype available
  - → Test ongoing

CERN-LHCC-2017-017
ATLAS-TDR-026.



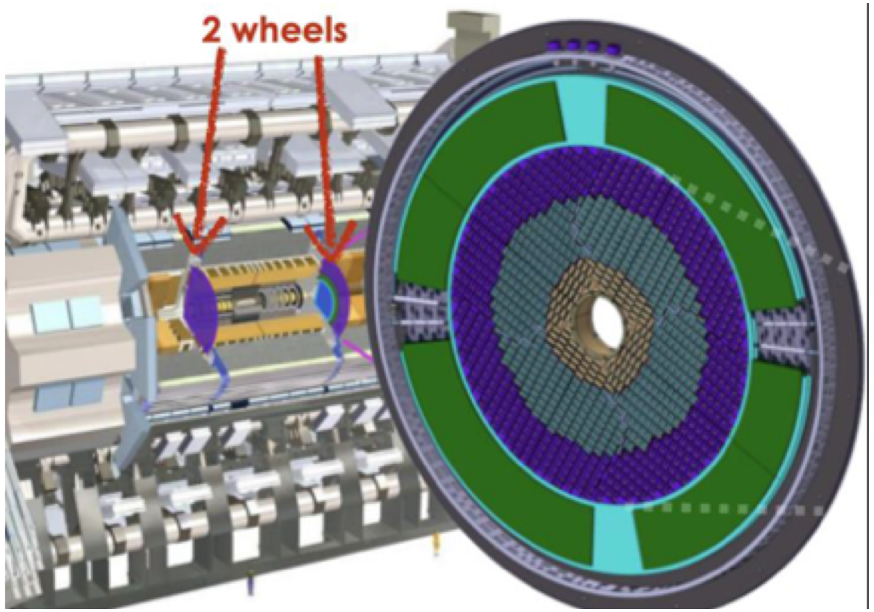
New sMDT chamber tubes

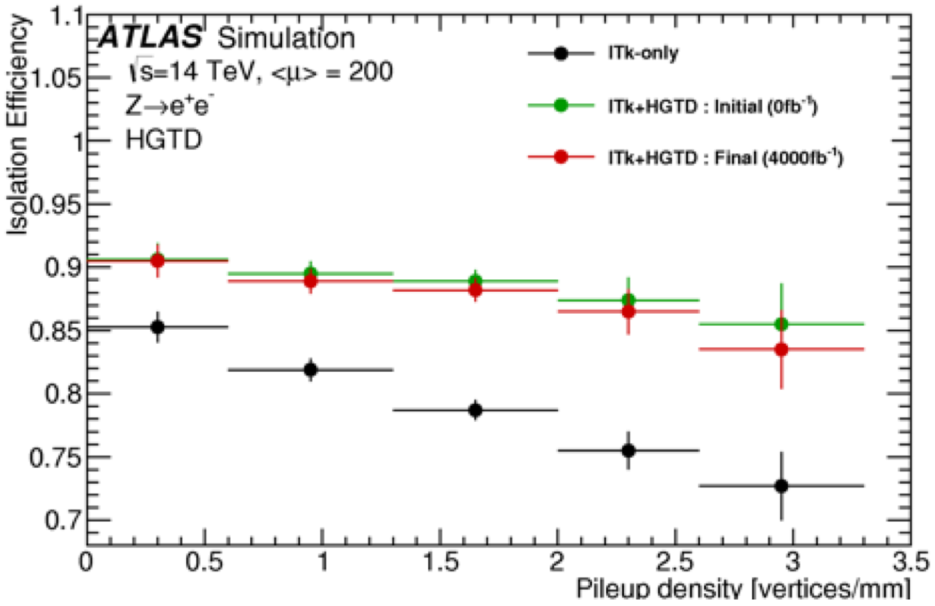


TGC EIL-4 chamber first prototype

High granularity timing detector

- HGTD designed to improve performance in the forward region in the HL-LHC high-pileup environment
  →Use high-precision timing information to distinguish between collisions close in space but well-separated in time.
- installed in space between inner detector and calorimeter end-caps at z = ±3.5m
  → constrained by limited available space
- Two instrumented double-sided layers per end-cap
- $2.4 < \eta < 4.0$; R_{min}= 12 cm; R_{max} = 64 cm
- based on silicon Low Gain Avalanche Detector (LGAD) technology
- Required time resolution: Δt = 30-50 ps/track
- Allow precision luminosity measurement bunch-by-bunch
- Improves pileup rejection by a factor of ~ 1.5

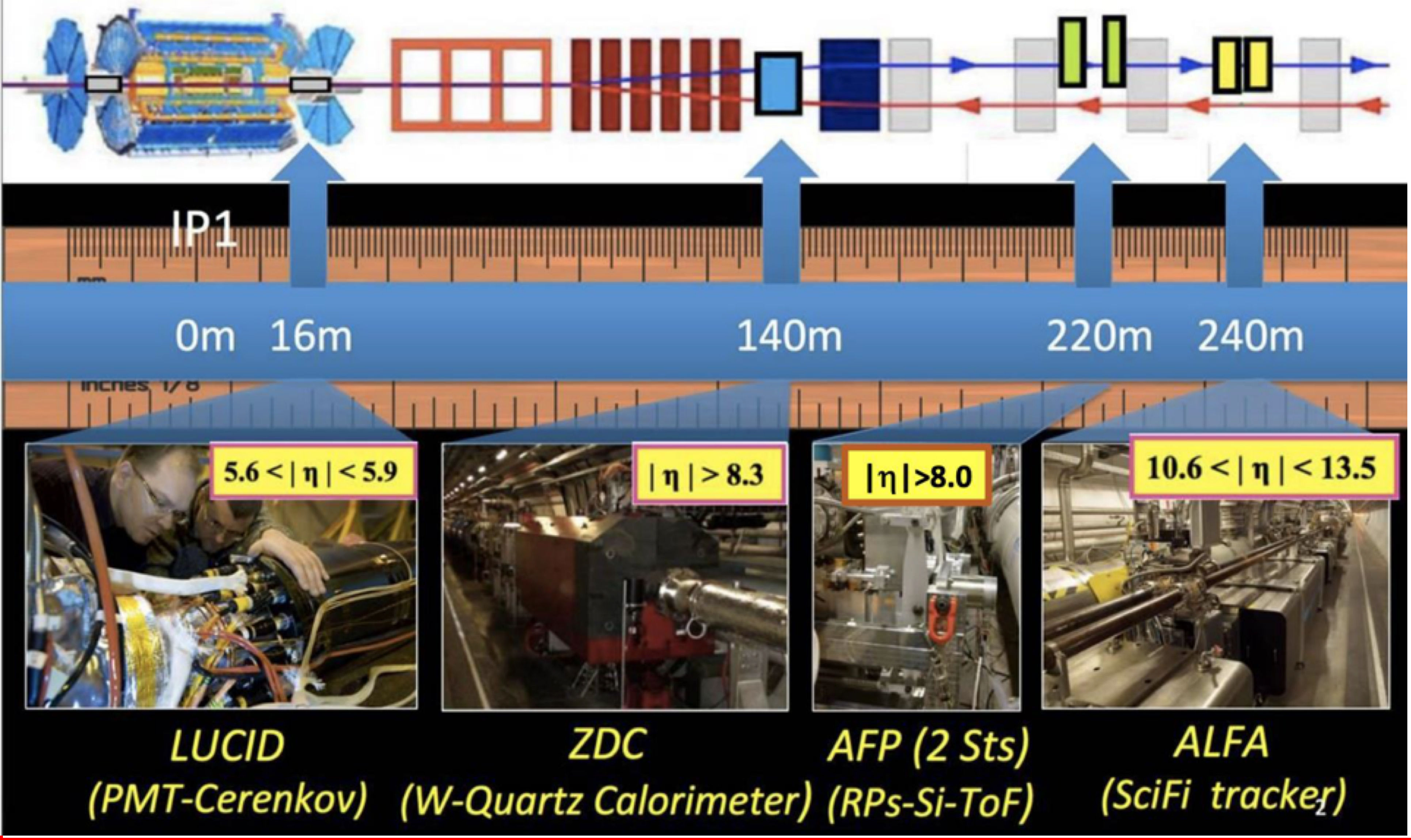




CERN-LHCC-2020-007 - ATLAS-TDR-031

Forward detectors

HL-LHC program requires stable and precise luminosity measurement and foresees a rich program of forward and heavy ions physics



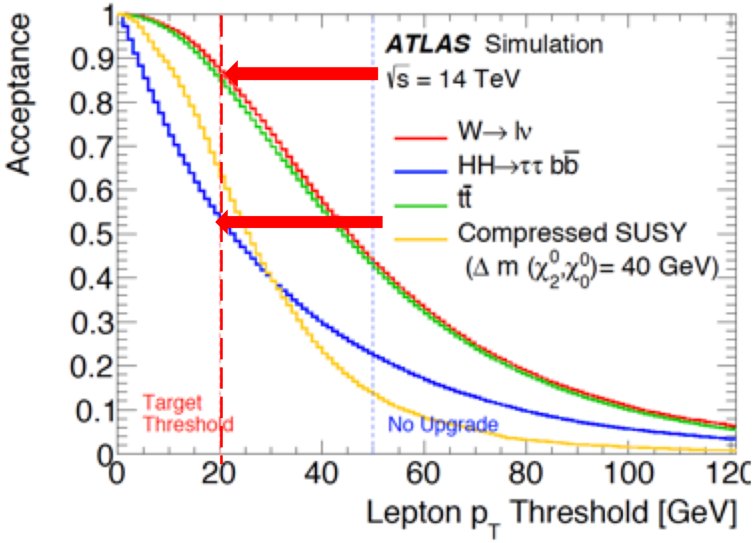
Upgrade of existing luminomiters and forward detectors to withstand HL-LHC conditions in progress:

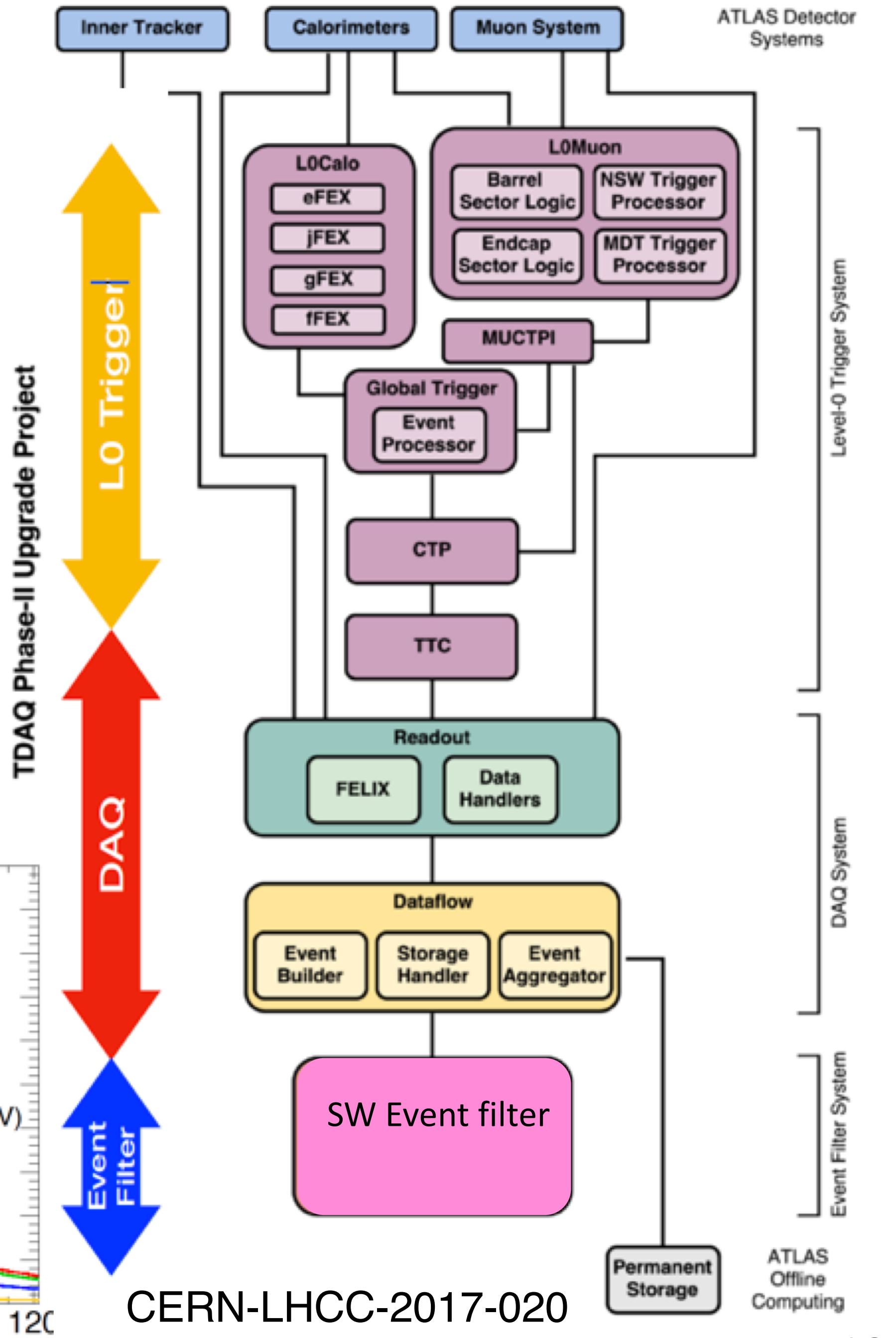
- Beam Condition Monitor (BCM)
- Luminosity Cherenkov Integrating Detector (LUCID3)
- Pixel luminosity rings (PLR)
- Zero Degree Calorimeter

Trigger and DAQ (TDAQ) upgrade

- TDAQ provides the required bandwidth and processing capacity to efficiently select events at HL-LHC
- L0Trigger Data from the detectors @ 40 MHz
- Maximum output rate of 1 MHz (was 100 kHz in Run2) and 10 μs latency (was 2.5 μs)
- Complete event-data transmitted through Readout & Dataflow into Event-Filter
- Event Filter performs event reconstruction & selection
- Final selected events (5 vs 2 MB today) then transferred to permanent storage @ **10 kHz** (1 kHz today)

FELIX Phase II test board



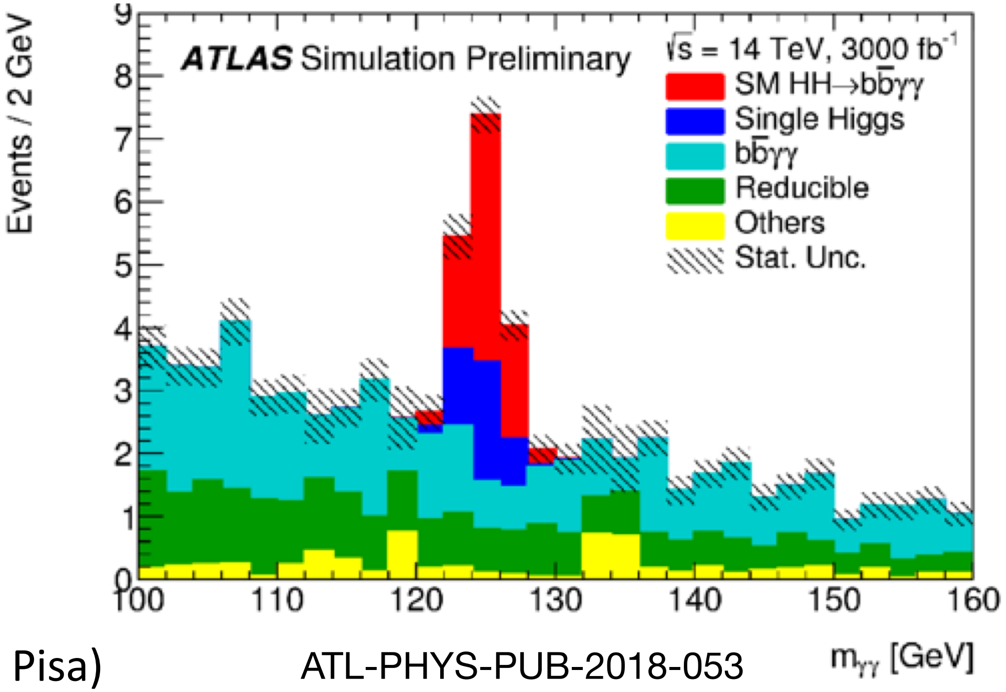


CERN-LHCC-2017-020
ATLAS-TDR-029

Conclusions

- The HL-LHC experimental conditions challenge the detector and electronics in many aspects, including high pile-up and high radiation doses exceeding current ATLAS detector capabilities
- Upgrades are underway to ensure high efficiency and high quality data taking, and exploit the full physics potential of HL-LHC
- Many projects entering pre-production or production phase
- Outstanding work of all teams despite pandemic difficulties (lock down of labs, reduced lab operation efficiency, delays in component delivery schedule)

- Wide range of physics possibilities: the large datasets that will be collected will allow
  - → precision measurements in the 125 GeV Higgs boson sector
  - → the exploration of extremely rare Standard Model processes
  - → the search for new phenomena Beyond the Standard Model



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