LIGHT CONE 2017

Frontiers in Light Front Hadron Physics : Theory & Experiment

18 - 22 September 2017 | University of Mumbai, India

LC 2017 belongs to a series of Light-Cone conferences, which started in 1991. Light-Cone conferences are held each year under the auspices of the International Light Cone Advisory Committee (ILCAC).

ATLAS EXPERIMENT

Future Plans of the ATLAS Collaboration for the HL-LHC

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on behalf of the ATLAS Collaboration

Light Cone 2017 (LC2017), University of Mumbai, 19 September

HUMBOLDT-UNIVERSITÄT ZU BERLIN

Bundesministerium für Bildung und Forschung

Introduction

CERN European Organization for Nuclear Research (Conseil Européen pour la Recherche Nucléaire)

- Established on 29 September 1954
- Host to 12,500 users (visiting scientists) (September 2016)
- Gradual global enlargement challenging but important for the future

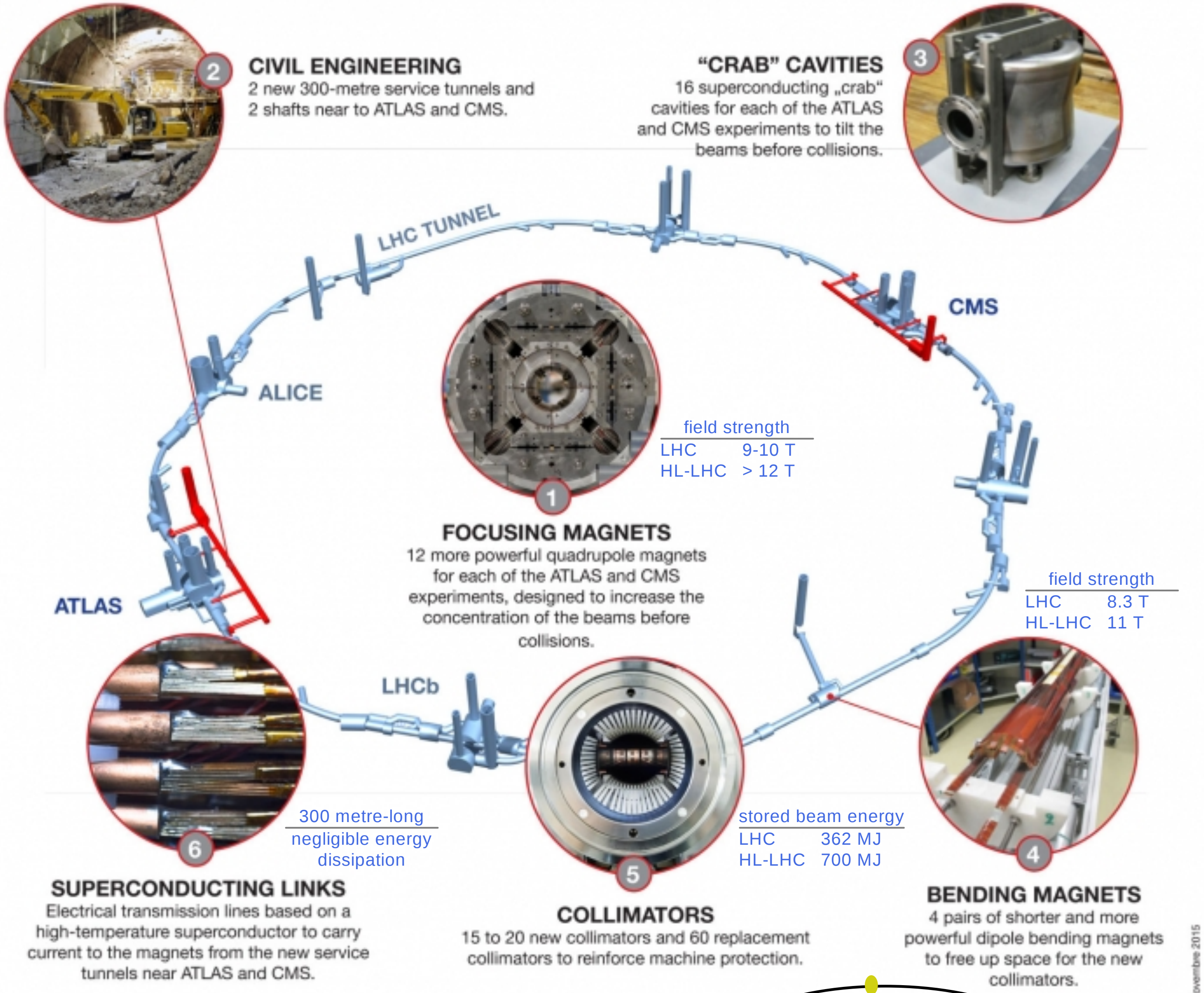
LHC The Large Hadron Collider

- Largest particle accelerator and most powerful machine to explore the new high-energy frontier
- Global user community of 7,000 scientists from all over 60 countries (cf. UN's 193)
- Started up on 10 September 2008 → ATLAS, CMS, ALICE, LHCb experiments ready
- High-Luminosity LHC (HL-LHC) project in construction phase since 1 November 2015
- 15 December 2017 Symposium → 25 Years of LHC Experimental Programme

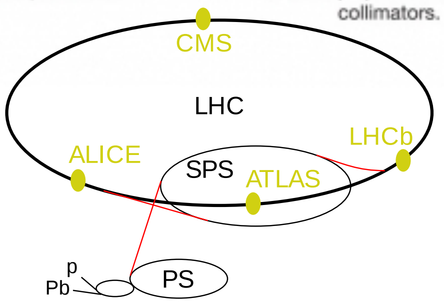
ATLAS A Toroidal LHC ApparatuS

- Detector is 46 metres long, 25 metres in diameter, and weighs about 7,000 tonnes
- Comprises > 3,000 physicists from about 182 institutions in 38 countries
- Letter of intent submitted to the LHC Experiments Committee on 1 October 1992
- On 4 July 2012 ATLAS and CMS announce observation of higgs of ~126 GeV mass

Machine Upgrades for HL-LHC



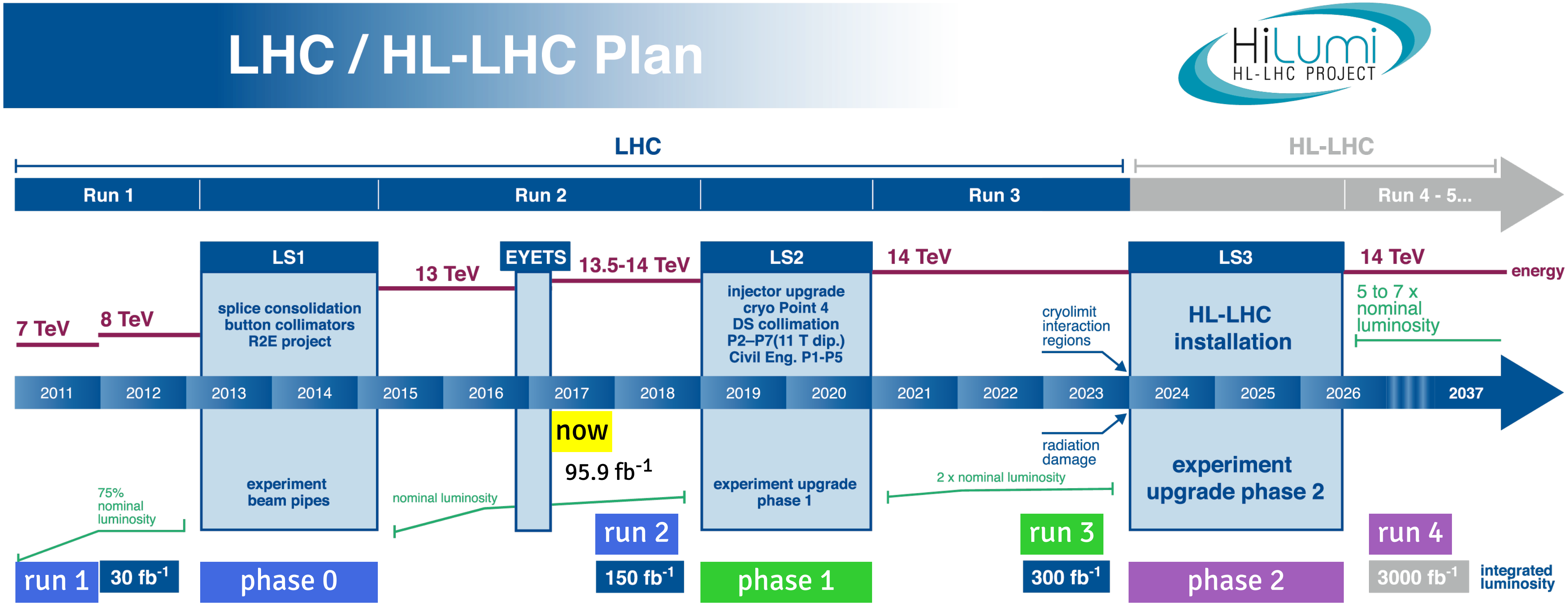
- In 2020 new Linac4 replacing Linac2 to increase beam brightness twice
- Improvements in accelerator chain (PS Booster, PS, SPS)



Innovative technologies

- Superconducting magnet materials: niobium-titanium (NbTi) up to 9-10 Tesla → niobium-tin (Nb_3Sn) reaching 12-13 Tesla → > double magnet aperture of dipoles and quadrupoles
- Crab cavities: rotation of the beam by providing a transverse deflection of the bunches → to increase luminosity at collision points and to reduce beam–beam parasitic effects
- New magnesium-diboride-based (MgB_2) superconducting cables from 20 to 100 kA → move power converters from the LHC tunnel to new service gallery
- > 1.2 km (~5%) of current ring to be replaced with new components

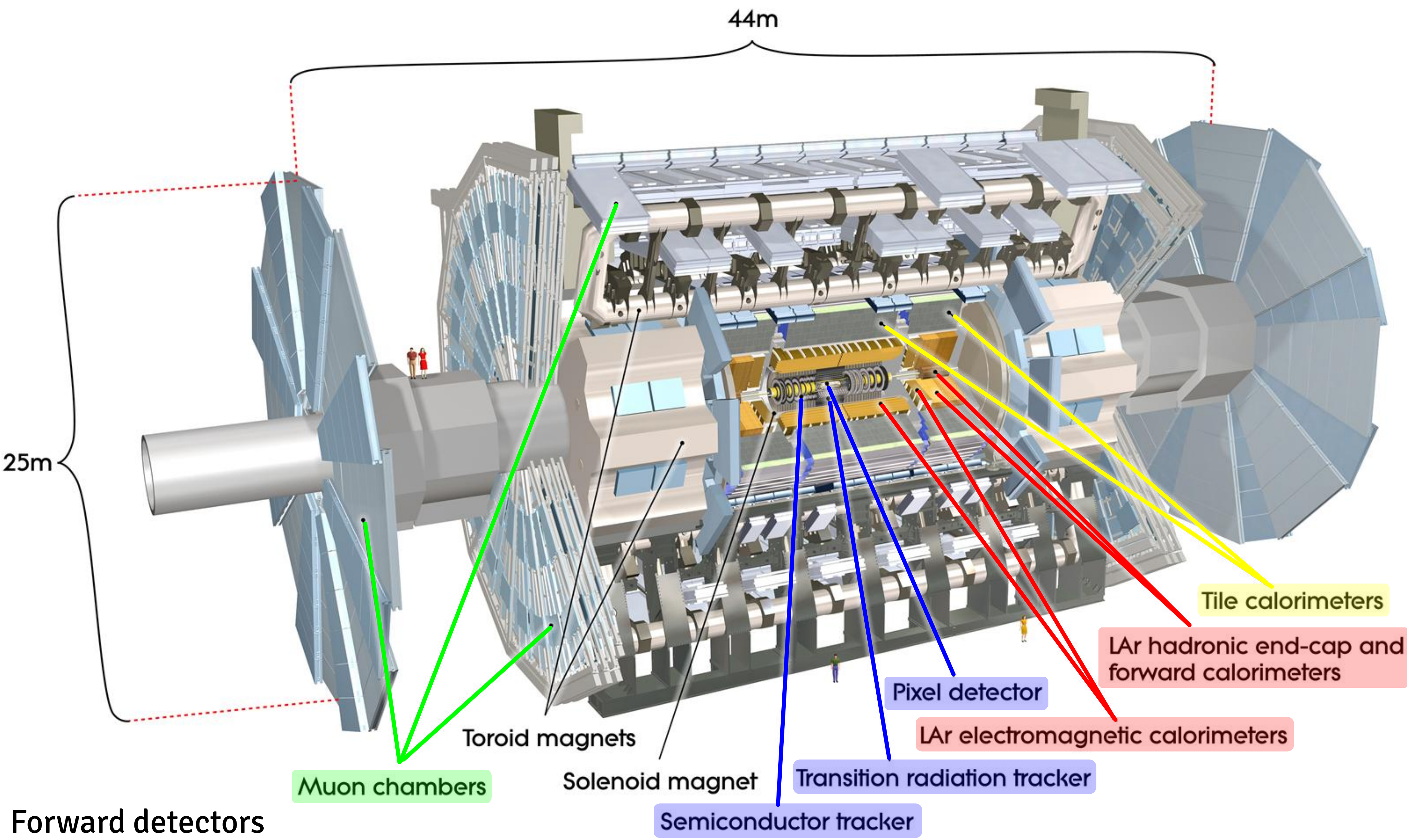
HL-LHC Baseline Parameters



Plan to extend the LHC physics programme to study higgs and enhance discovery potential → High-Luminosity LHC (HL-LHC)

- Aims to deliver > 10 times the original design integrated luminosity → 3000-4000 fb^{-1}
- Peak luminosity up to ~5–7.5×10^{34} $cm^{-2}s^{-1}$ (compared to nominal 1.0×10^{34} $cm^{-2}s^{-1}$)
- 140–200 proton–proton interactions per bunch crossing, i.e., every 25 ns (max. 40 MHz rate) → unprecedented pileup (μ) and event rates pose huge challenge to detector systems

ATLAS Detector

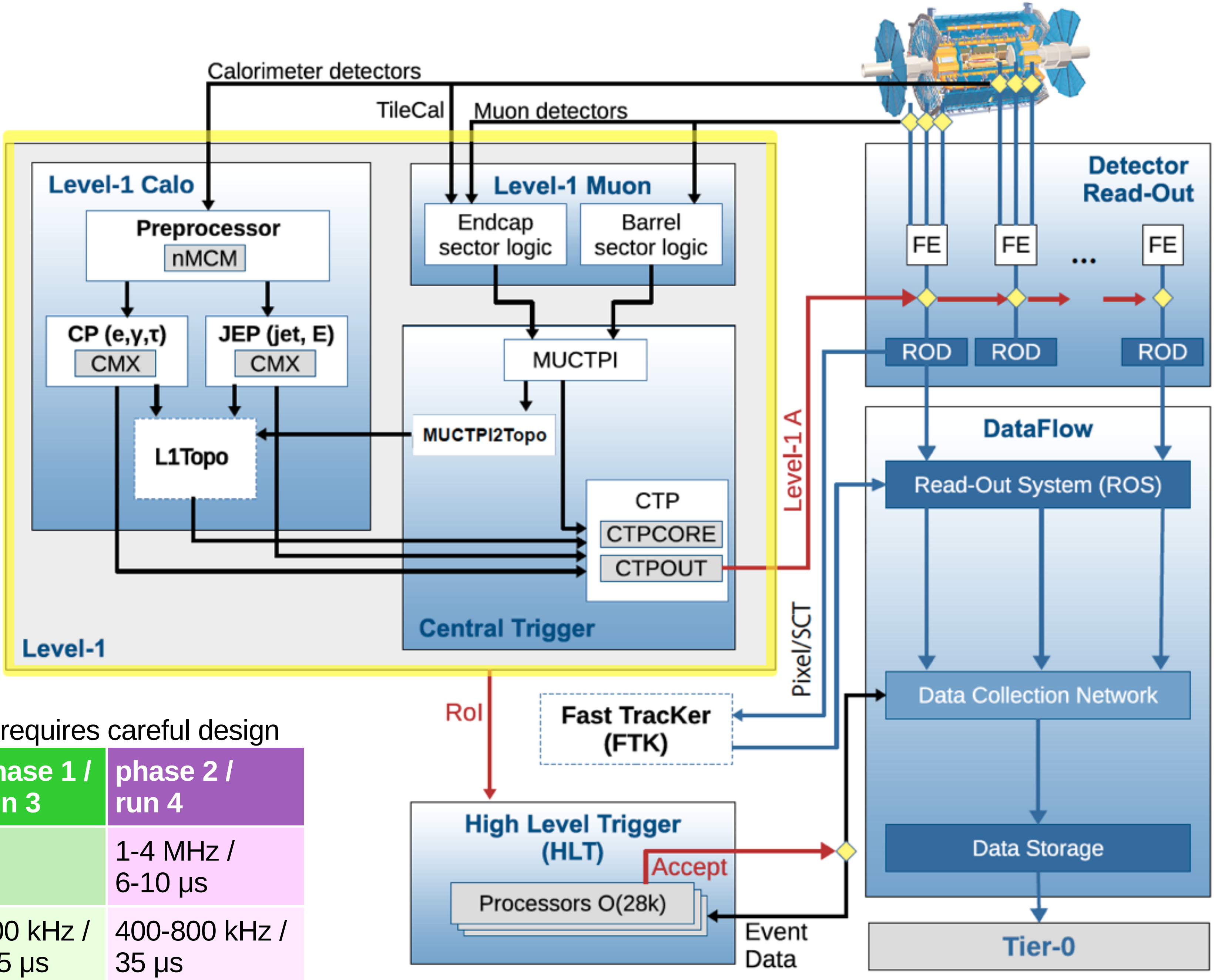


- Forward detectors
- Trigger and Data Acquisition

ATLAS Trigger and Data Acquisition (TDAQ)

Collecting data

- Custom hardware (ASIC, FPGA, SoC, PCB), COTS and commercial components (CPU, GPU, networking) to reduce up to 40 MHz collision rate to manageable levels at each stage of data processing and transport until the final recording step
- Optimal performance would ideally require coherent upgrades among detector systems and TDAQ



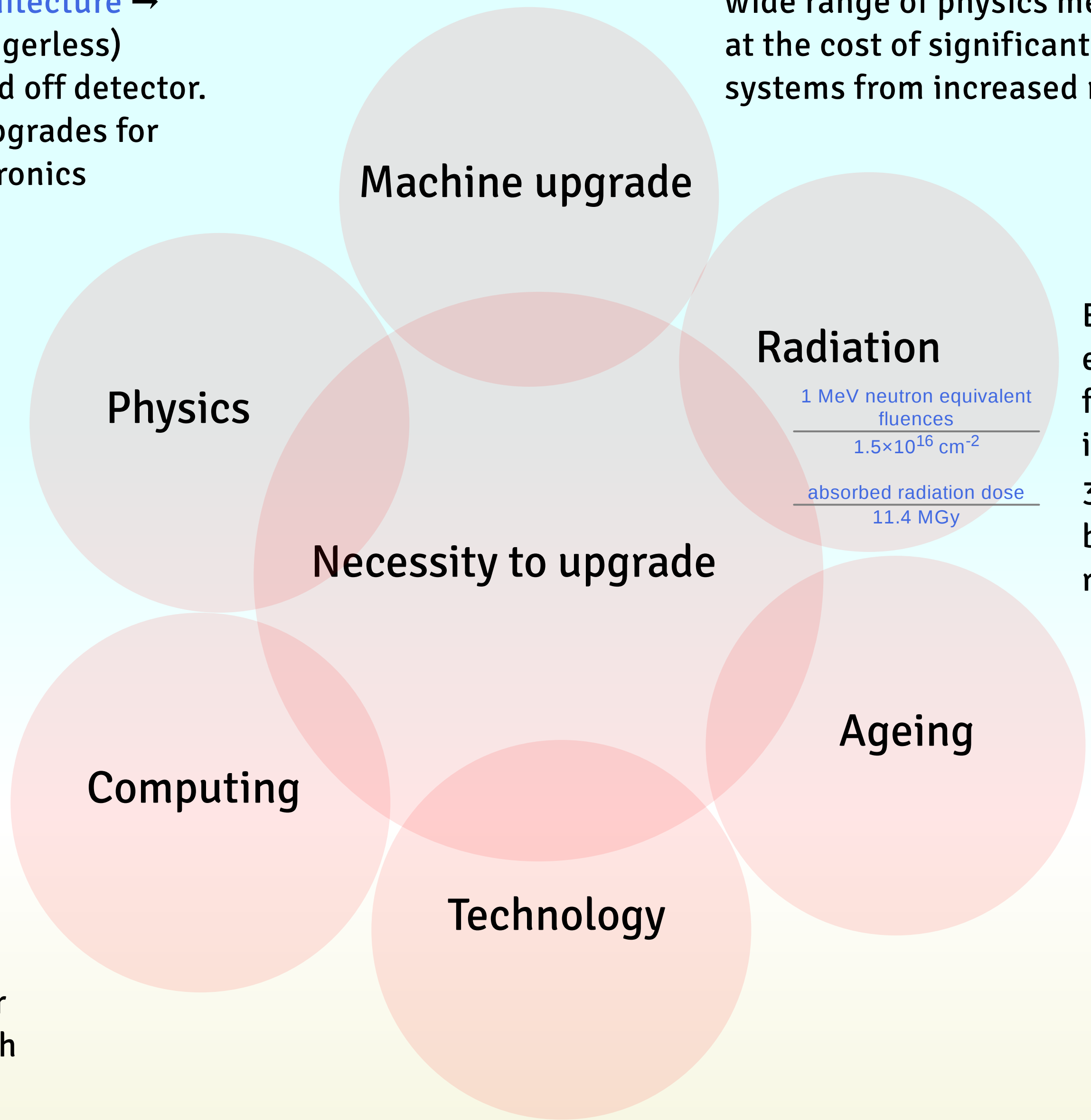
L0/L1 rate least flexible → requires careful design

rate / latency	phase 0 / run 2	phase 1 / run 3	phase 2 / run 4
L0	-	-	1-4 MHz / 6-10 μs
L1	100 kHz / 2.5 μs	100 kHz / 2.5 μs	400-800 kHz / 35 μs
HLT / O(ms)	1 kHz	1 kHz	10 kHz

Motivation for HL-LHC Upgrades

High trigger rates with longer latencies require revision of readout electronics architecture → evolving towards free-running (triggerless) scheme where all data are streamed off detector. This allows for unlimited further upgrades for trigger with new off-detector electronics

HL-LHC offers large luminosity needed to cover wide range of physics measurements and searches at the cost of significant challenges to detector systems from increased rates and occupancies



Keep detector performance for physics at least as good as in run 1 and run 2

Existing front-end electronics not qualified for operation at HL-LHC integrated luminosity of 3000 fb^{-1} and needs to be replaced due to radiation exposure

Keep acceptable trigger rate with low p_T thresholds and suppress pileup up to high $|\eta|$

Systems will be in operation > 20 years in harsh radiation environment. Mitigation strategies needed for inaccessible/irreplaceable detector components, e.g., adding new sensitive layers to maintain required performance

Benefit from high performance (digital) components such as larger and faster FPGAs, higher bandwidth transmission links, backplane, network and storage technologies, advanced computing

ATLAS Systems for Data Taking

ATLAS Experiment

Tracking

Inner Detector

- **Pixel**: Pixel
- **SCT**: Semiconductor Tracker
- **TRT**: Transition Radiation Tracker
- **ITk**: Inner Tracker

silicon sensors

pixel
strip

Calorimetry

Calorimeters

- **LAr**: Liquid Argon Calirimeter
- **Tile**: Tile Calorimeter

sampling calorimeters

lead/copper /thungsten (passive)
+
liquid argon (active)

scintillator tiles

Muon

Muon Detectors

- **CSC**: Cathode Strip Chambers
- **RPC (Barrel)**: Resistive Plate Chamers
- **TGC (Endcap)**: Thin-Gap Chambers; New Small Wheel (NSW)
- **MDT**: Monitored Drift Tubes

gas chambers (various types)

precision tracking

triggering

Forward

Forward Detectors

- **AFP**: ATLAS Forward Protons
- **ALFA**: Absolute Luminosity For ATLAS

Forward Physics Programme

elastic scattering
single diffraction
double diffraction
double Pomeron (photon) exchange

total proton-proton cross section
luminosity measurement

ALFA

aim to finish data taking in run 2
no plans for phase 1

AFP

possible refurbishment in phase 1
possible refurbishment of ALFA!
decision to be based on run 2 results

TDAQ

Trigger and Data Acquisition

- **L1Calo**: Level 1 Calorimeter Trigger; Level 1 Topological Processor (L1Topo)
- **RPC Trigger**: Barrel Trigger
- **TGC Trigger**: Endcap Trigger
- **FTK**: Fast Tracker
- **CTP**: Central Trigger Processor
- **DAQ/HLT**: High Level Trigger

Detector Upgrades

system	phase 0 / run 2	phase 1 / run 3	phase 2 / run 4
Pixel	Insertible B-Layer (IBL, 4th barrel pixel layer), new pixel services, new evaporative cooling plant, CO2 cooling plant for IBL, new tracking detector at 220m (AFP)		replaced by ITk Pixel
SCT			replaced by ITk Strip
TRT			de-commissioned
LAr	change all power supplies	new L1 trigger electronics	new readout electronics (including trigger), inputs used by L0Calo, 40 MHz streaming, High Granularity Timing Detector (HGTD, option)
Tile	low voltage power supply replacement		readout electronics (40 MHz streaming), improved drawer mechanics, new high voltage power supplies
RPC detector	gas leaks repair	BMG (small-diameter MDT, sMDT) in acceptance gaps, BIS78 chambers (sectors 7 and 8, sMDT + thin-gap RPCs) at the boundary between barrel and endcaps	new chambers in inner barrel (BI) region
TGC detector		New Small Wheel (sTGC + MicroMegas)	new frontend electronics, forward muon tagger (using MicroMegas, option)
MDT detector			replace front-end electronics on all chambers

TDAQ Upgrades

system	phase 0 / run 2	phase 1 / run 3	phase 2 / run 4
L1Calo / Global Event	new L1Topo integrated in L1 trigger decision, improved processing: optimised FIR filters, dynamic pileup pedestal correction per BCID, EM isolation	new L1Topo, new fibre optics system, new feature extractors (FEX) to make use of better detector granularity, more efficient algorithms	becomes L0Calo: improved FEX firmware, L1Topo replaced by Global Event Processor (Global)
RPC trigger	additional chambers in key positions: new feet chambers (sectors 12 and 14)	copper cables to MUCTPI replaced with optical fibres → new FPGA-based sector logic to MUCTPI interface boards (SL2MUCTPI), data rate up to 6.4 Gbps	additional improved trigger logic in FPGA to send seed to MDT trigger processors, detector data streaming at 40 MHz, power system replacement
TGC trigger	additional better trigger capability for muons using Tile (Tile-Muon Coincidence), improved data taking efficiency (Burst Stopper)	NSW integration in trigger	new trigger algorithm seeding MDT processors, detector data streaming at 40 MHz, power system replacement
MDT trigger			MDT information added to muon trigger (TGC/RPC in RoIs) (no standalone trigger), power system replacement
FTK	add trigger level tracking between L1 and HLT, partial system (fewer processing units) used in trigger decisions	full FTK installation, assistance with tracking very useful in high pileup conditions	FTK++ an upgraded version of FTK using more common hardware components
L1Track			perform tracking in custom hardware either at L0/L1 (L1Track) or L0 (EFTrack) only in regions of interest (RoIs), complementary to FTK++ to confirm L0 decision
CTP	improved capacity and capability, increase Level 1 (L1) accept rate 75 → 100 kHz	new CTP firmware, Trigger, Timing and Control (TTC) module replacement, new Muon-CTP Interface (MUCTPI)	new electronics and firmware
HLT	removal of internal division between Level 2 (L2) and Event Filter (EF) → High Level Trigger (HLT), increased number of cores per commodity CPU, HLT acceptance rate (400 → 1000 Hz), offline algorithms wrapped	multi-threading, multiple events in parallel, seamless integration of offline algorithms	major revision, more offline-like algorithms, more thread-safety, parallelism, optimisation
Readout	custom hardware and firmware, S-Link and G-Link transmission protocol	FELIX for some systems (NSW, BIS78, L1Calo) replacing previous readout hardware with software processors, functions as router (h) between frontend links (GBT) and commercial multi-gigabit network technology, transmits data to desired destination node (ROD, DCS, etc)	FELIX standard for all systems

Upgrade Preparation

Lepton Photon 2011, Mumbai

higgs discovery

LHC nominal peak luminosity > 1.0×10^{34} cm^{-2}s^{-1}, pileup μ=40

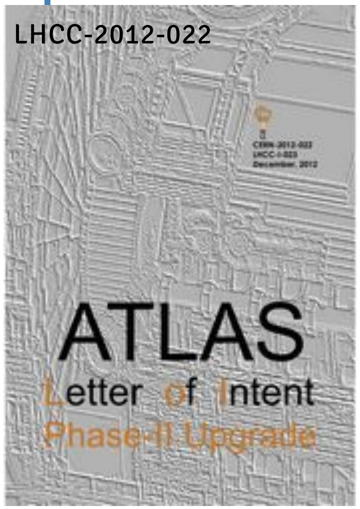
$2\text{-}3\times10^{34}$ cm^{-2}s^{-1}, μ=60-80

$5\text{-}7.5\times10^{34}$ cm^{-2}s^{-1}, μ=140-200

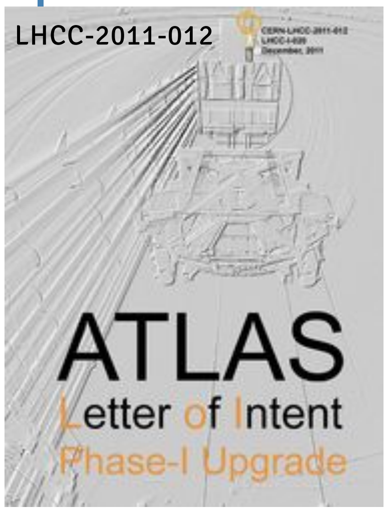
2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | ... | 2037

now

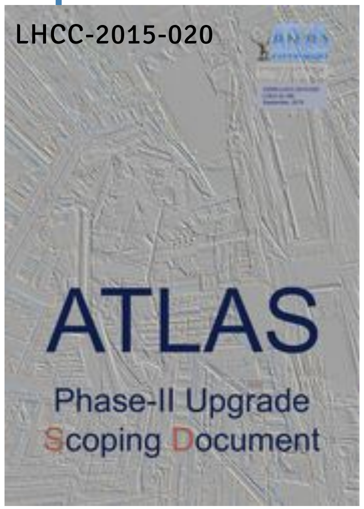
LHCC-2012-022



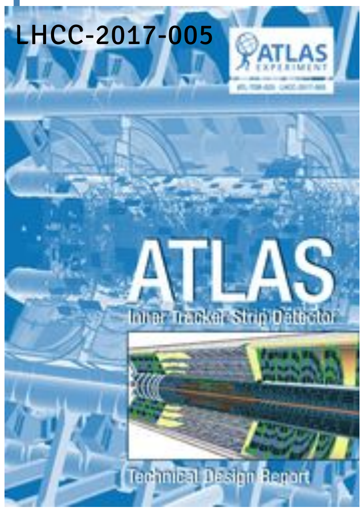
LHCC-2011-012



LHCC-2015-020



LHCC-2017-005



phase 1 TDRs

CERN-LHCC-2010-013
CERN-LHCC-2013-006
CERN-LHCC-2013-007
CERN-LHCC-2013-017
CERN-LHCC-2013-018
CERN-LHCC-2015-009

Enormous progress made in 2016 at finalising upgrade architectures - in parallel to data taking and stable beam operations

Muon TDR 2017.Q2

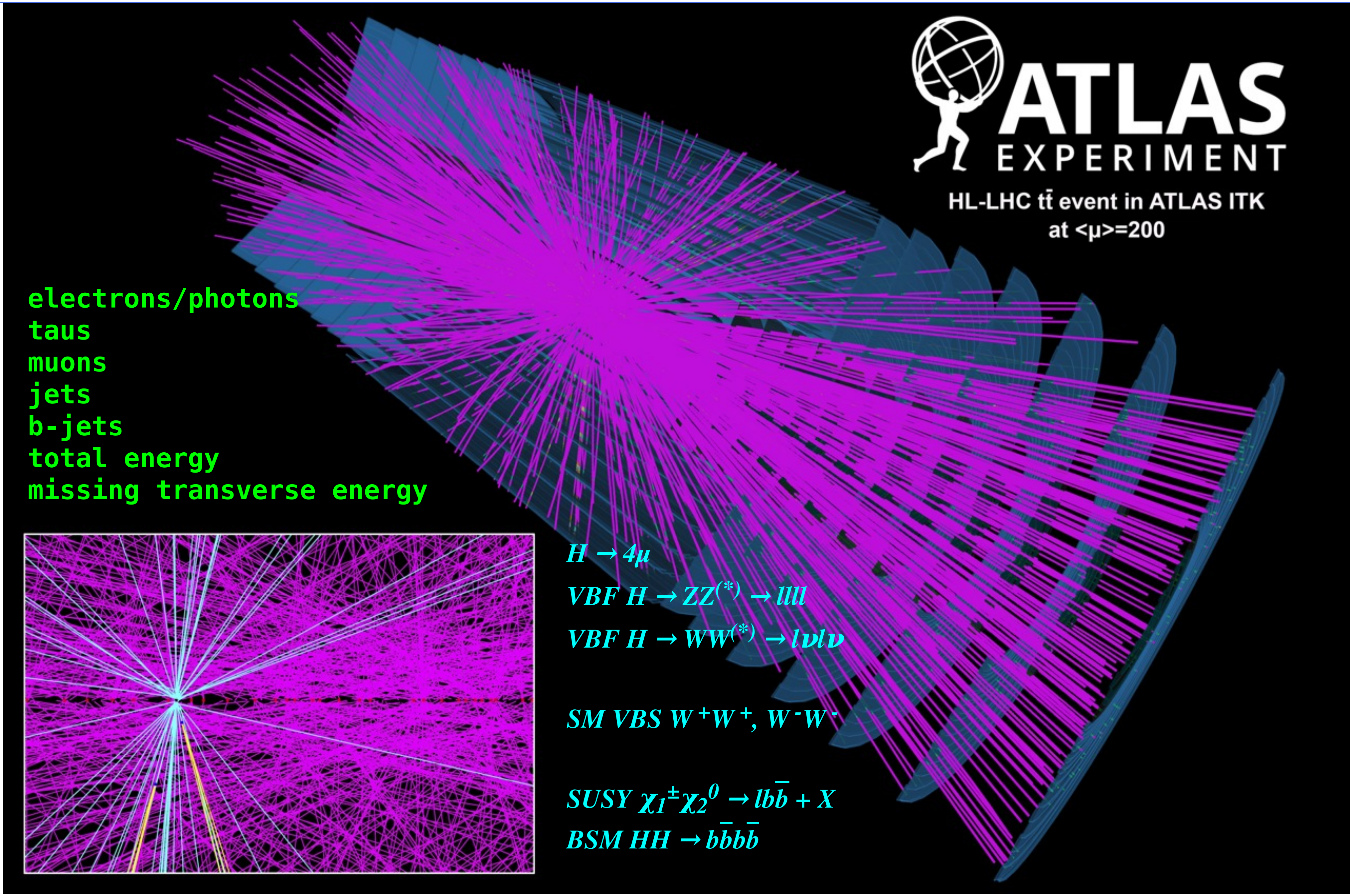
LAr TDR 2017.Q3

Tile TDR 2017.Q3

Itk Pixel TDR 2017.Q4

TDAQ TDR 2017.Q4

Meeting the HL-LHC Challenge



electrons/photons
taus
muons
jets
b-jets
total energy
missing transverse energy

$H \rightarrow 4\mu$

VBF $H \rightarrow ZZ^{(*)} \rightarrow llll$

VBF $H \rightarrow WW^{(*)} \rightarrow l\nu l\nu$

SM VBS W^+W^+, W^-W^-

SUSY $\chi_1^{\pm}\chi_2^0 \rightarrow lb\bar{b} + X$

BSM $HH \rightarrow b\bar{b}b\bar{b}$

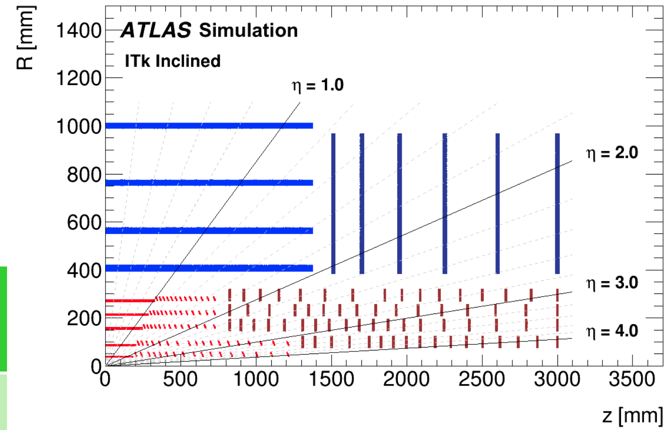
Inner Tracker (ITk)

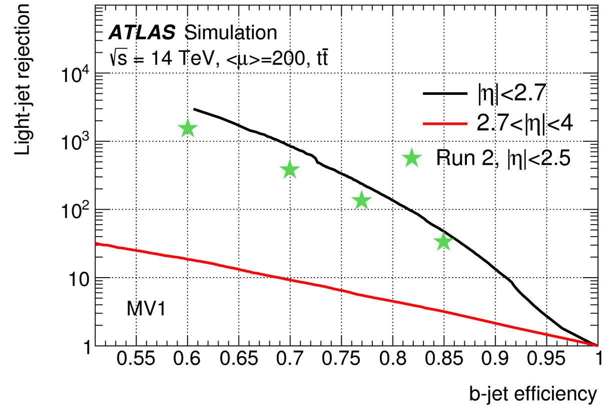
Complete replacement of inner detector inevitable after ~10 years of operation due to accumulated radiation dose

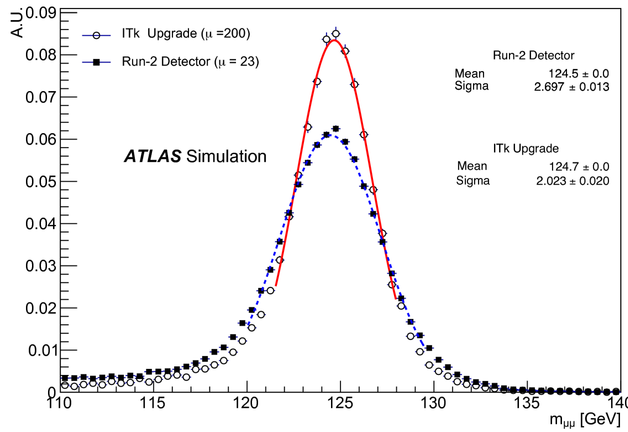
- A crucial component of the ATLAS detector with wide range of capabilities and potential at high luminosities
  - Reconstruction of charged-particle trajectories, heavy-flavour tagging, identification of *e*, γ, μ, τ
  - Primary and secondary vertex identification, full reconstruction of exclusive decay modes, tracking of interactions and γ-conversions, pileup vertex and pileup jet rejection
  - Improving jet energy measurement, determining isolation criteria, measurement of missing transverse energy (E_T^{miss})
  - Towards extended role of tracking information in triggering

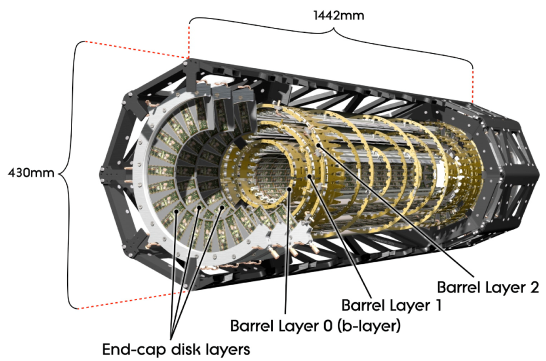
# channels [million]	Pixels	Strips
Current	80	6
Upgrade	> 400	~ 60

- Extends coverage to η = ±4.0 (currently η = ±2.7), novel layout design (tilted sensors, optimised rings), strip occupancy < 1%
- ITk material budget > 30% lower thus improving efficiency and reducing multiple scattering effects









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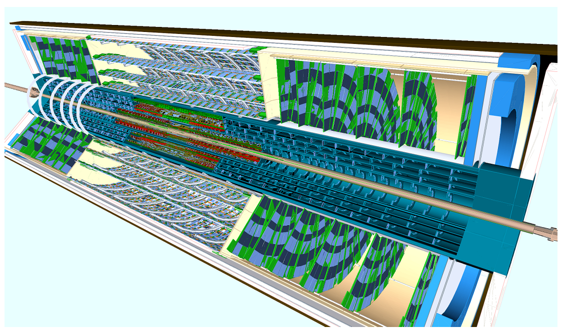


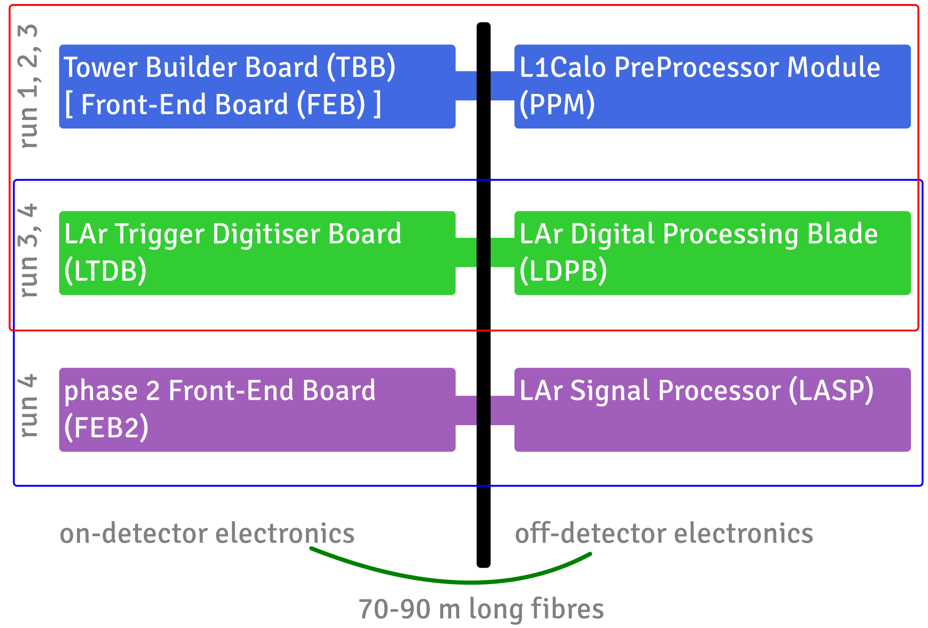
LAr Calorimeter

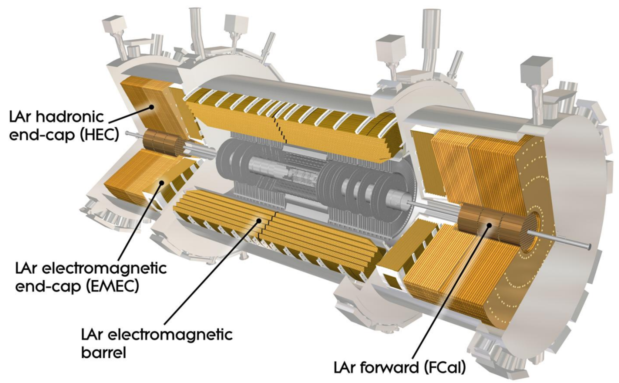
Major effort to design, build and install new trigger electronics during phase 1

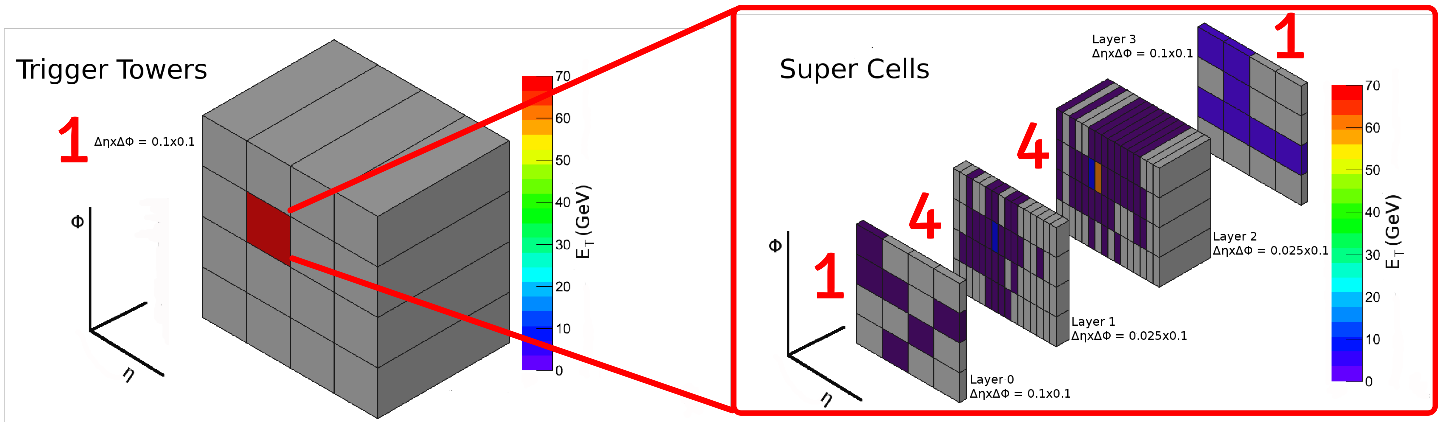
- Resulting in 10-fold increase in granularity → higher resolution as well as longitudinal shower information sent from the calorimeter to the L1 trigger processors (182468 cells / 7168 trigger towers = 25, currently)
  - Improving trigger energy resolution and efficiency for selecting events with *e*, γ, τ, jets and E_T^{miss}
  - Enhancing discrimination against background and fake clusters at high pileup
- 10 digitised pulses (Super Cells) in place of an analog signal sum per Trigger Tower received in L1Calo
- Staggered deployment with old and new systems overlapping in time to allow for detailed verification

Upgrade of all fontend and backend electronics during phase 2

- To comply with new trigger architecture and radiation tolerance requirements



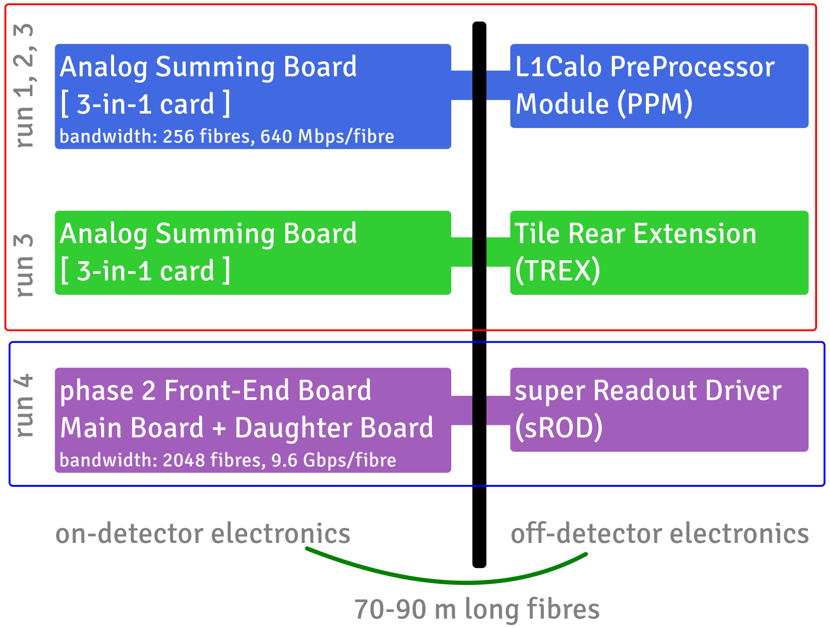


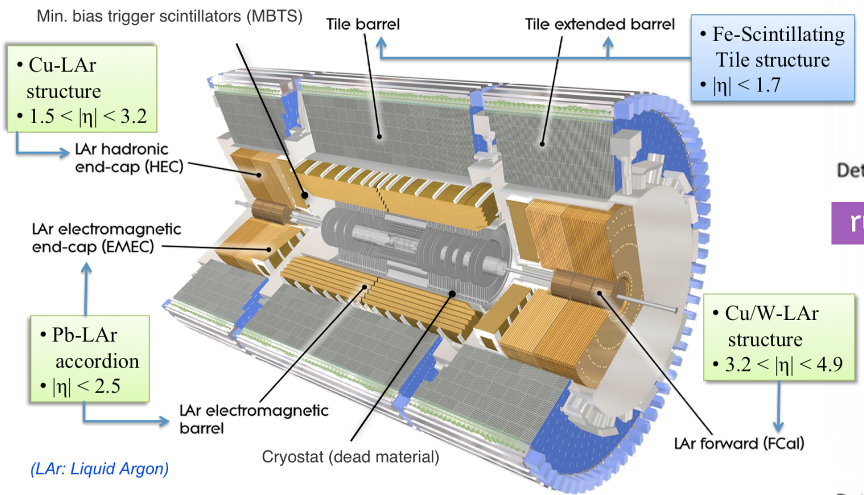


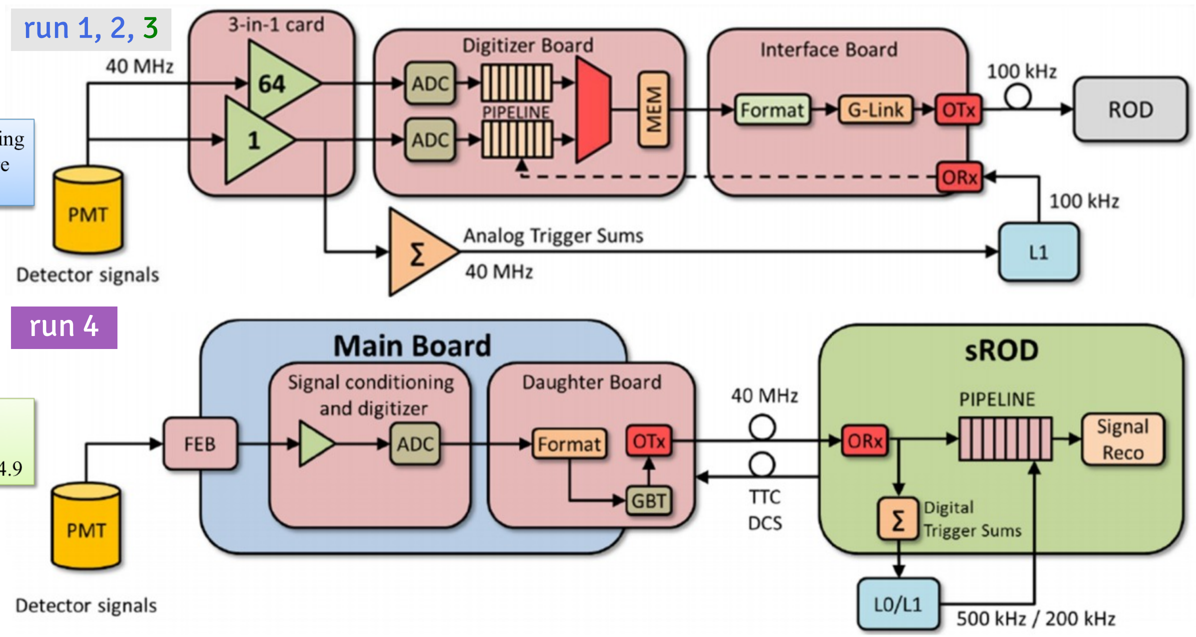
Tile Calorimeter

Upgrade is outcome of large research and development effort over many years

- Focusing on new frontend electronics design
  - Required to achieve fully digital calorimeter trigger system with higher granularity and precision
  - Conform to phase 2 trigger rate and latency
  - Digitise all data at 40 MHz and send off detector
- New high voltage regulation system movement outside detector radiation environment
- New more modular and easier to maitain design to hold frontend electronics



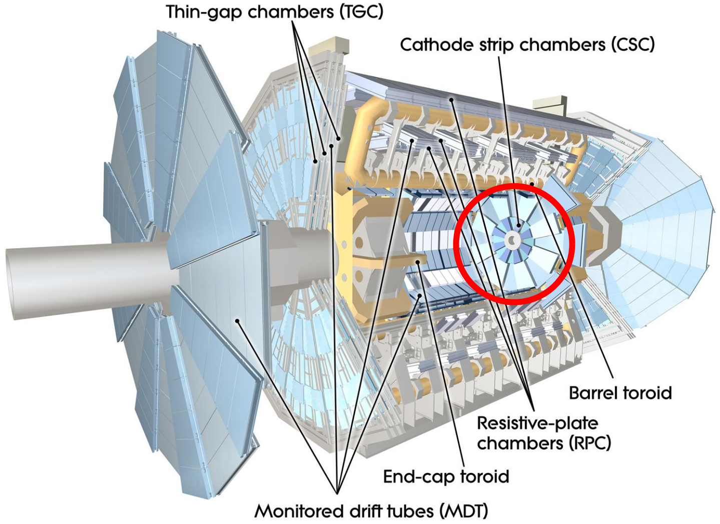


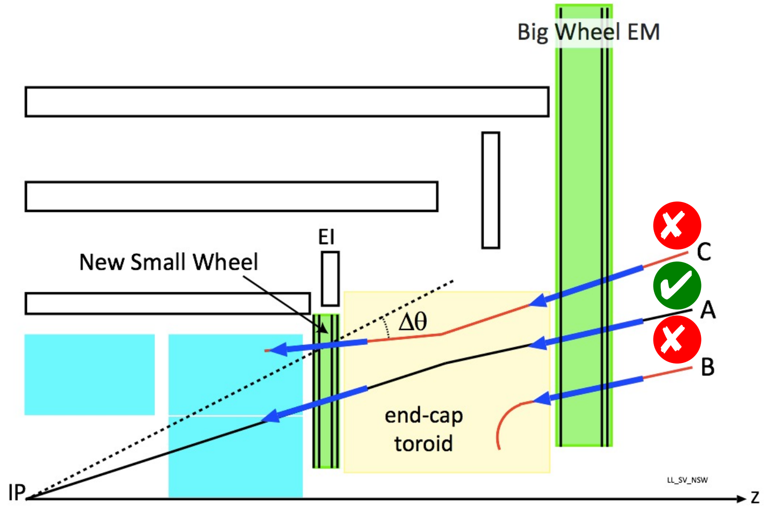


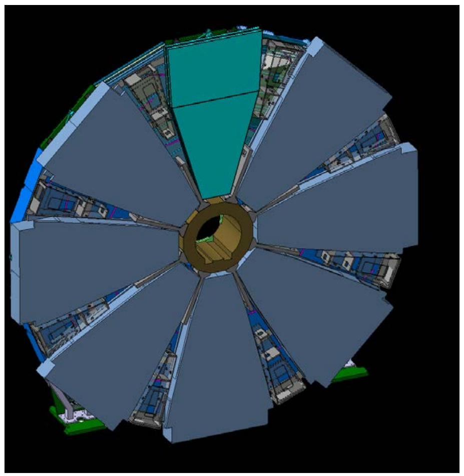
New Small Wheel (NSW)

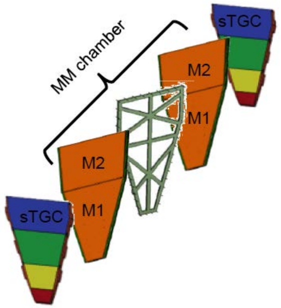
First station of muon end-cap system (Small Wheel) will need to be replaced in phase 1

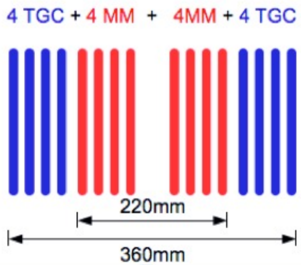
- Located in high background radiation region, 1.3 < |η| < 2.7 → ~90% of muon triggers in endcaps are fake due to cavern background (low energy photons and neutrons) and pileup
- Aim at providing both high L1 trigger efficiency and precision reconstruction of muon tracks
- Therefore combining two technologies: small-strip Thin Gap Chambers (sTGC) for fast triggering and Micromegas detector (MM) for precision tracking (as well as trigger with TGC)
  - sTGC: < 1 mrad angular resolution, MM: < 1 μm spatial resolution
- Design compatible with latency/readout rate to phase 2 trigger









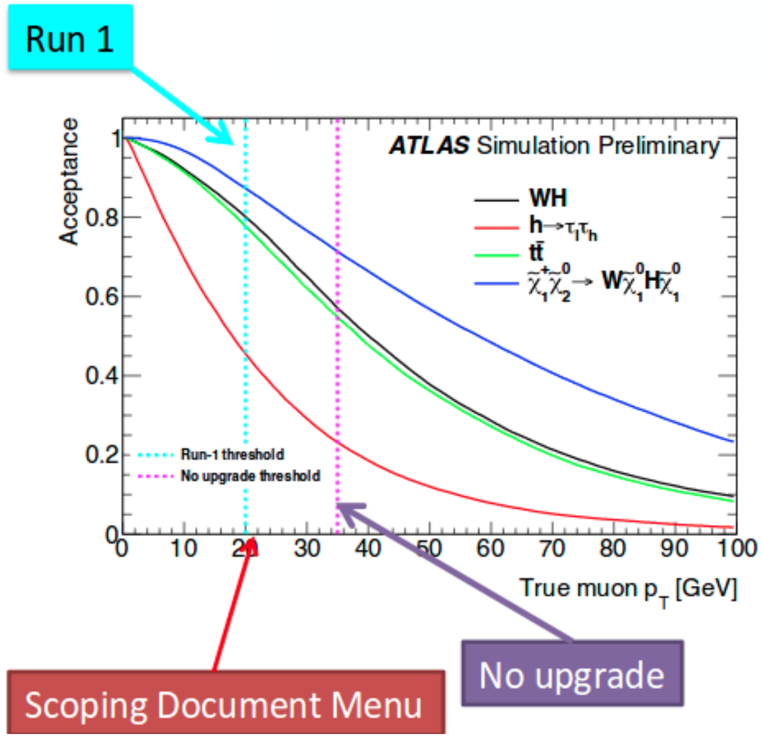


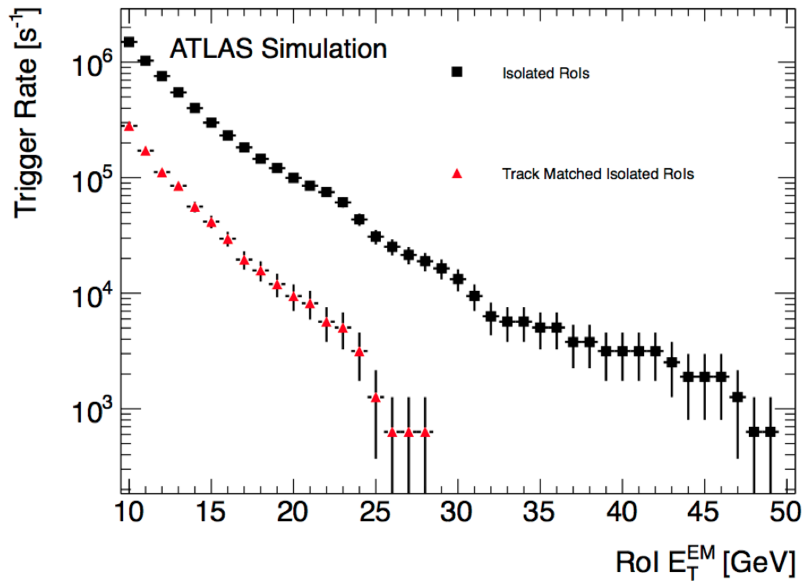
L1MU threshold (GeV)	Level-1 rate (kHz)
$p_T > 20$	60 ± 11
$p_T > 40$	29 ± 5
$p_T > 20$ barrel only	7 ± 1
$p_T > 20$ with NSW	22 ± 3

Motivation for Trigger/DAQ Upgrade

Trigger (menu) balances between physics requirements and available DAQ/computing resources

- Goal is to maintain physics sensitivity at current level → keep trigger performance close to or better than run 1 and 2
- Trigger strategy
  - Retain single lepton (electron and muon) triggers with low thresholds, $p_T > 20$ GeV
  - Efficiently trigger on di-photons, di-leptons and hadronic di-taus with thresholds close to run 1
  - For hadronic final states from jets use single jet, multijet, H_T and E_T^{miss} to get close to run 1 performance
  - Increased understanding of hh analyses, other important physics measurements, and/or the discovery of new physics may strengthen the physics case for L0 rates beyond 1 MHz



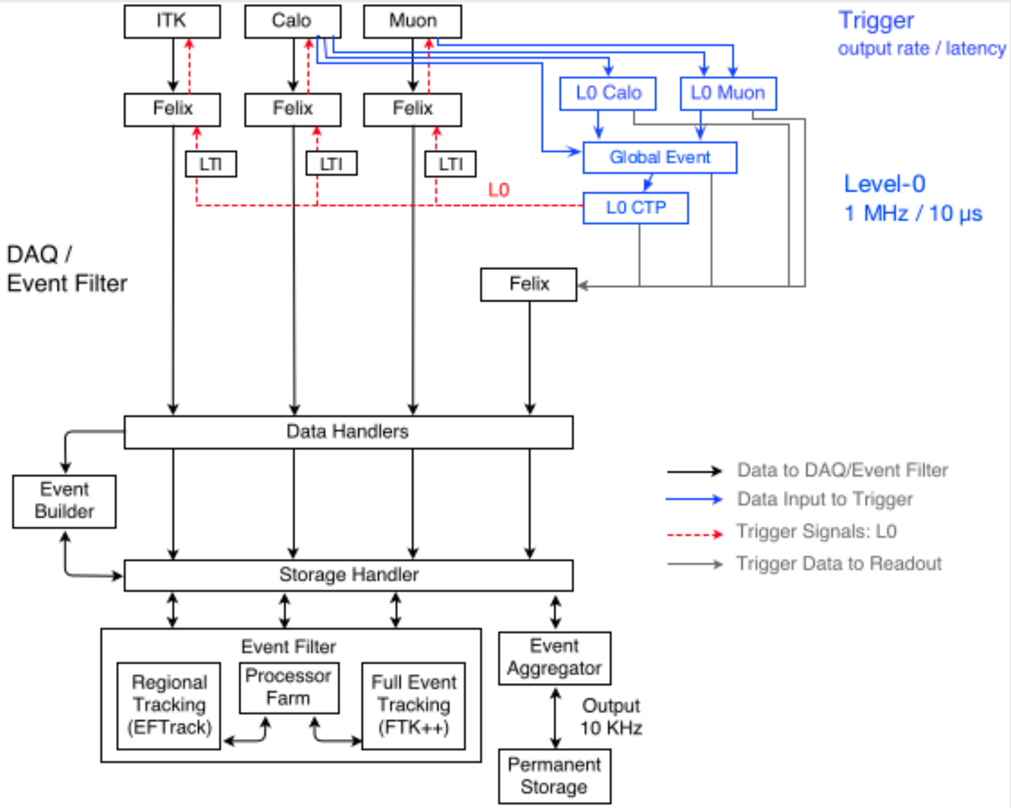


- Increasing pileup/occupancy necessitates hardware tracking integration into TDAQ

TDAQ Options for HL-LHC

Baseline single Level 0 (L0) trigger architecture

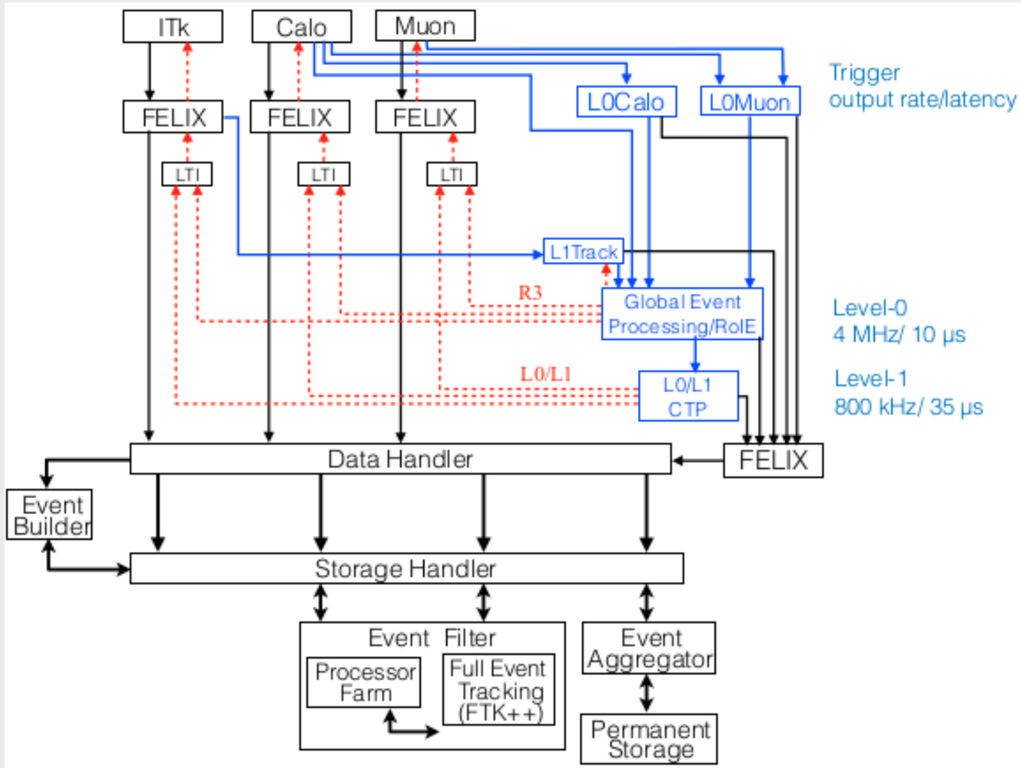
- Hardware triggers based on calorimeter and muon information
- MDT precision measurement available at L0
- Global Event processor refines *e*, γ, τ, jet and E_T^{miss} objects, improves rejection by combining fine granularity (cell) calorimeter information



Capable of evolving into a dual L0/L1 trigger system

- Supports L0 rates up to 4 MHz for unchanged latency of 10 μs (low latency scenario)
- Hardware tracking (L1Track) to become even more important for pileup suppression

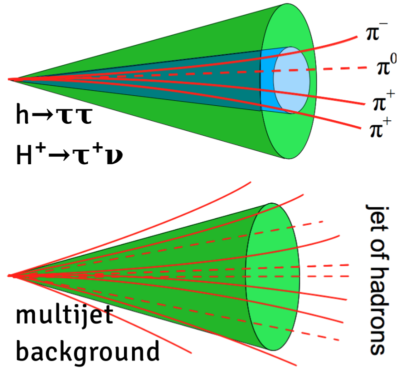
* Some systems in the original run 1 design had built-in flexibility that allowed for their upgrade in phase 0 (run 2)

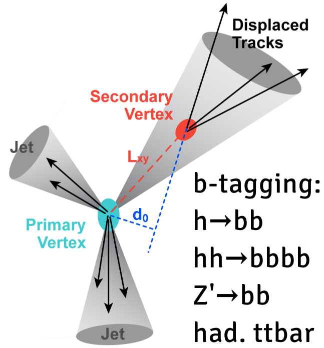


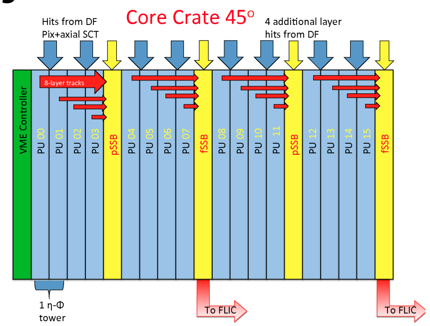
Fast Tracker (FTK)

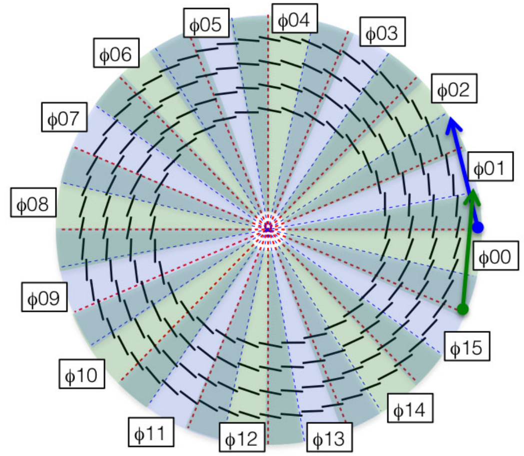
First attempt in ATLAS to add track information as seed to high level trigger decision, large hit occupancies and required high speed challenging

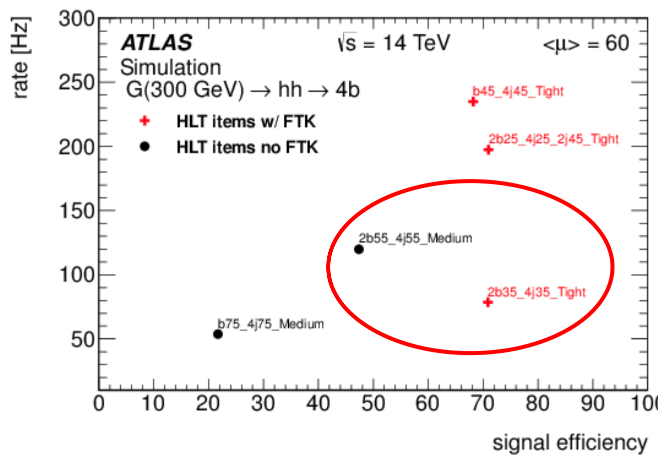
- Very useful in high pileup conditions
  - Hadronic τ reconstruction (and multijet background rejection)
  - Finding displaced tracks and secondary vertices for b-tagging
- Fast hardware tracking preprocessor → runs on every L1 accept (100 kHz) to provide HLT with full-scan offline-quality tracks
  - p_T > 1 GeV, latency O(100 μs)
  - 64 independent η-φ regions processed simultaneously
  - 8192 associative memory (AM) chips, > 2000 FGPAs
  - Combined VME + ATCA boards
- Partial FTK system with fewer processing units (for limited detector coverage) being commissioned during run 2
- Simulations show significant performance gains, e.g., b-jet algorithms can run with looser HLT jet p_T thresholds (55 → 35 GeV)

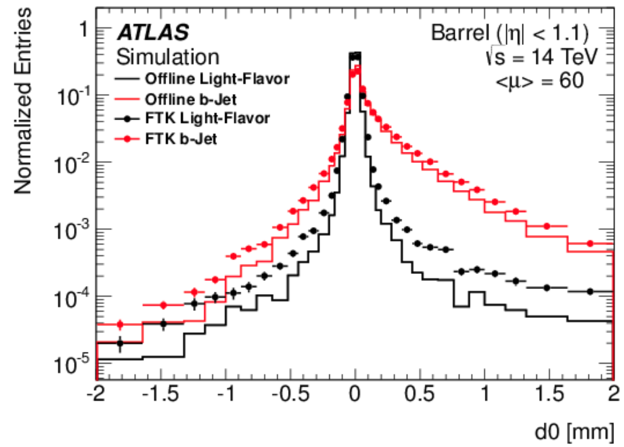








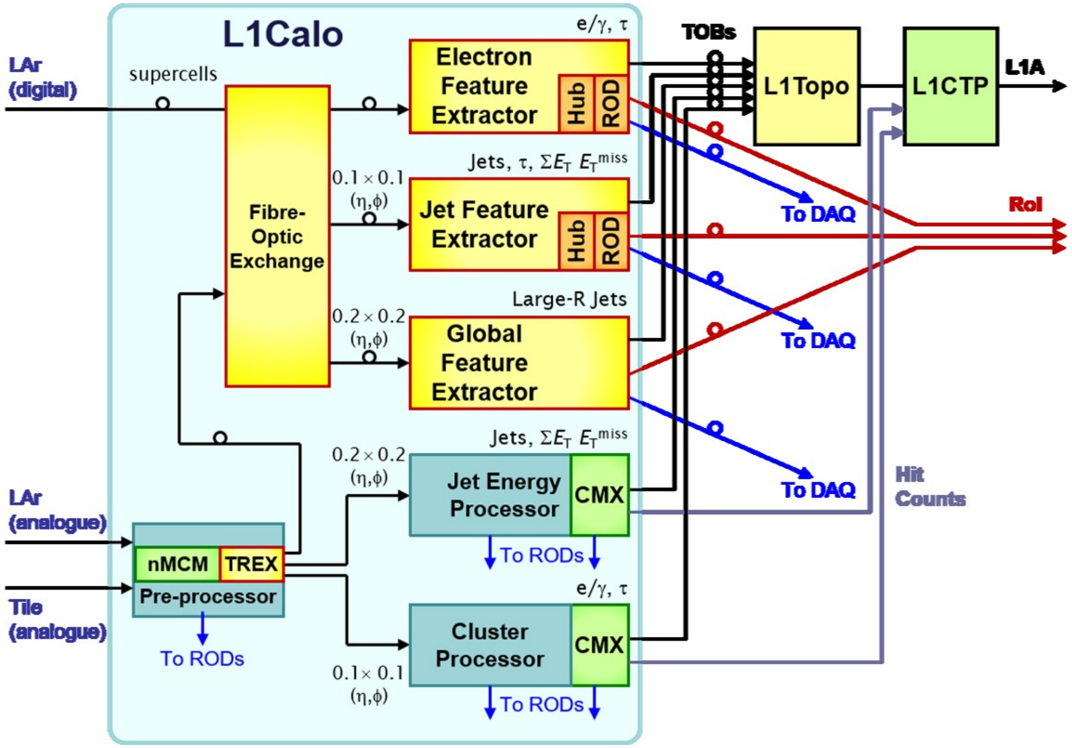


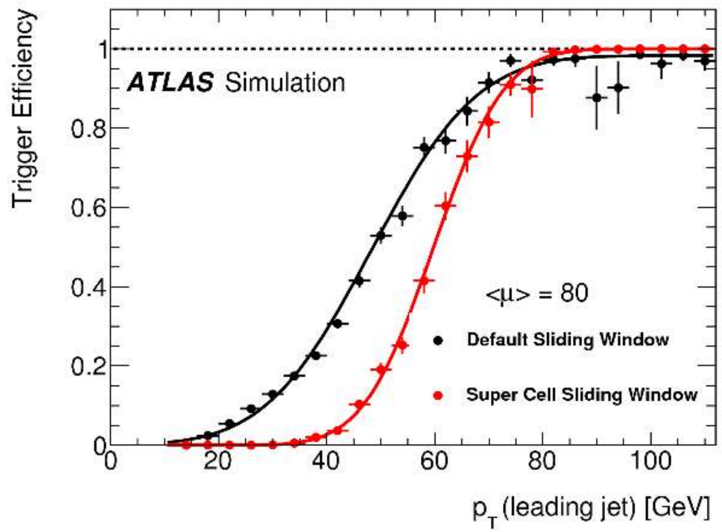


Calorimeter Trigger Upgrade

New hardware system components installed in phase 1 with possibility for further revision in phase 2

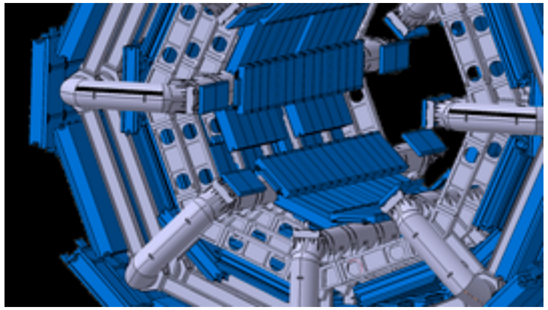
- Improved object-finding relies on firmware algorithms implemented in new feature extractor (FEX) processors
- eFEX for *e*, γ and τ candidates
  - E_T (R_η, R_{had}, f_3, etc algorithms), hadronic veto, electromagnetic isolation
  - 24 ATCA modules covering $|\eta| < 2.5$
- jFEX for jets (large τ), ΣE_T, E_T^{miss}
  - Gaussian weighting, jets-without-jets algorithms
  - 7 ATCA modules covering $|\eta| < 4.9$
- gFEX (global) for large-radius jets
  - Jet-level pileup subtraction, global event observables: E_T^{miss}, jets-without-jets, centrality
  - 1 ATCA module to process full calorimeter data
- L1Topo improves selection based on event topology, using calorimeter and muon data





Muon Trigger Upgrade

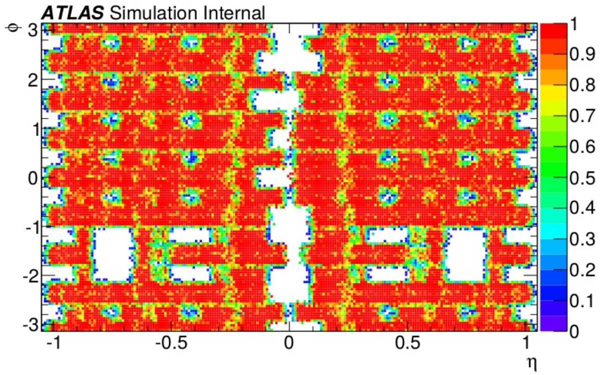
Muon chambers cannot be replaced but significant enhancements required to sustain operations during HL-LHC



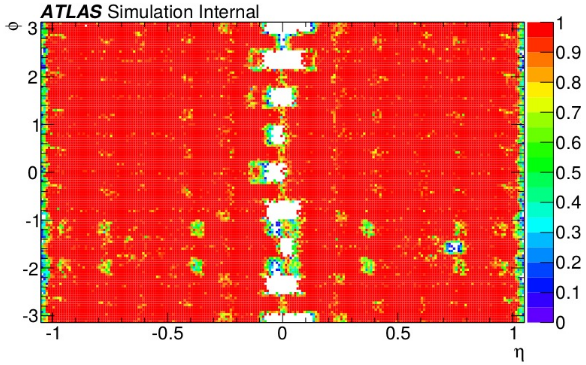
Barrel Inner Small region BIS78
RPC+sMDT

- Data from RPC, TGC, and NSW detectors used in phase 1 system to be complemented with new BI RPC, Tile calorimeter and MDT information
  - Increased trigger efficiency and reduce fake rate
  - New MDT trigger sharpens turn-on curve thus improving background rejection
- New on-detector boards for full digital data streaming off-detector at 40 MHz
- New off-detector boards implement trigger algorithm for seeding MDT trigger processor
- New MDT trigger processor boards to match MDT hits with RCP/TGC seed
- Power system of RPC, TGC, and MDT will to be replaced due to component obsolescence, aging, and radiation damage

- To endure harsh conditions RPC gains to be lowered
  - Decreases muon trigger efficiency
  - Adding to already low geometrical acceptance of ~70%
  - Will add new inner barrel RPC (BI) station to recover 3-out-4 layer coincidence
  - Increases efficiency from ~70% to ~90%



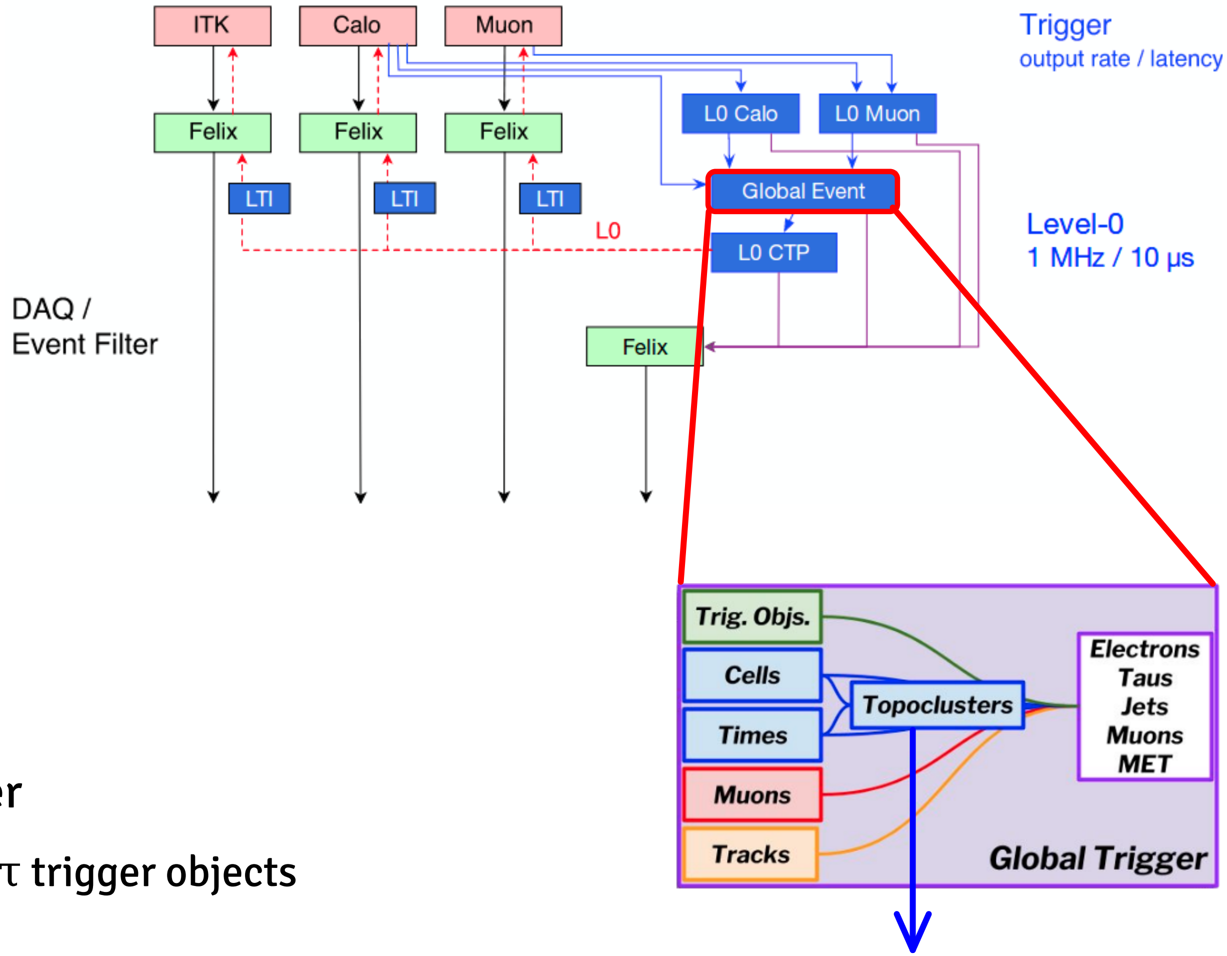
RPC trigger coverage in run-1 (78%)



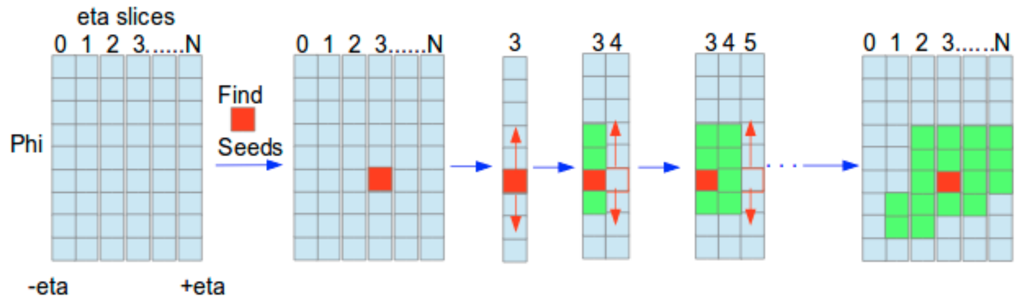
RPC trigger coverage in run-4 (96%)

Global Event Trigger

Maximises physics potential by concentrating full event data in a single event processor using time multiplexing



- Replacement for the phase 1 topolgical processor, explores event topology
- Provides additional capability, capacity, and flexibility in the ~4 μs time available
  - Besides calorimeter and muon trigger objects, receives full calorimeter cell information
- Possibility to add tracking information later
  - ITk strip information further refines *e*, γ and τ trigger objects
- Implements anti-k_T algorithm in FPGA based on three-dimensional topological clustering (topoclustering) of individual calorimeter cell signals
  - Improves τ, jets, object-based E_T^{miss}, isolation for *e*, μ, τ, forward (|η| > 2.4) *e*, γ identification

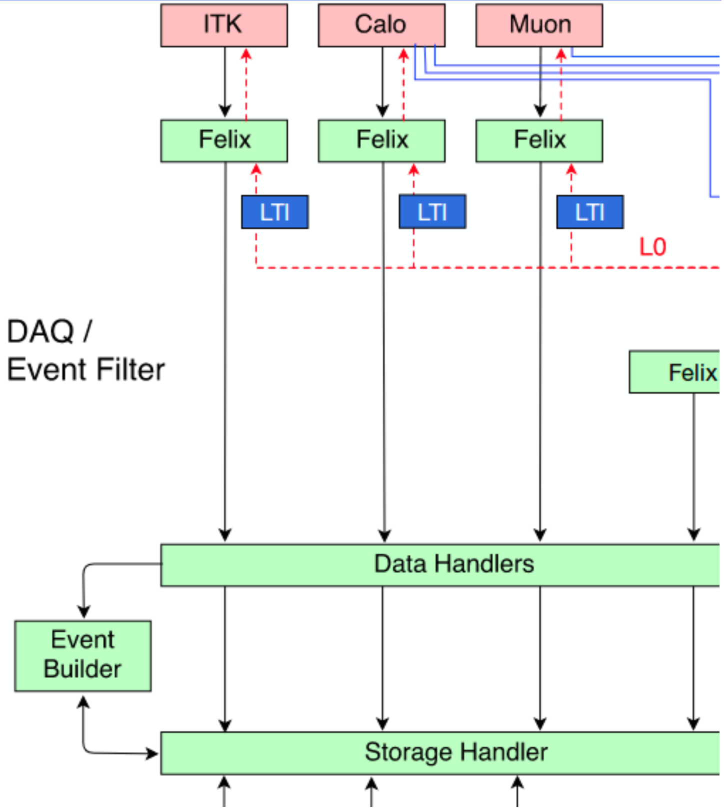


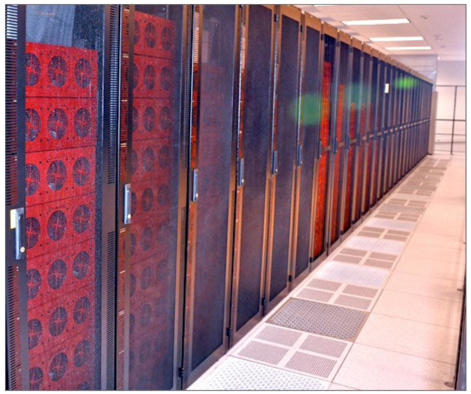
Topocluster firmware is non-iterative and fits within latency budget

Data Acquisition Upgrade

Trends from custom to commodity hardware, and from hardware to software

- Front End LInk eXchange (FELIX) → PCIe card with Xilinx FPGA
  - Uses homogeneous interface between fontend/trigger electronics and commodity multi-gigabit networks to transport detector data
  - Scalable architecture, detector independent
  - 2 modes of operation: 4.8 Gbps (GBT), 9.6 Gbps (full)
  - Hardware, firmware and software available to frontend developers
  - Initial use in phase 1, extended to full detector in phase 2
- Data Handler
  - Implement detector-specific data processing/monitoring (in software readout drivers), software toolkit and commodity computers replace custom hardware and firmware
- Event Builder
  - Assembles partial data fragments into coherent structured events for offline transmission. "Physical" or "logical" event building depending on storage performance/implementation, data compression driven by resources
- Storage Handler
  - Decouples data movement and data processing → allow for heterogeneous farm (hardware accelerator/tracking), perform event filtering between LHC fills
  - Requires storage volume of the order of 50 PB to accommodate data bandwidth of a few TB/s



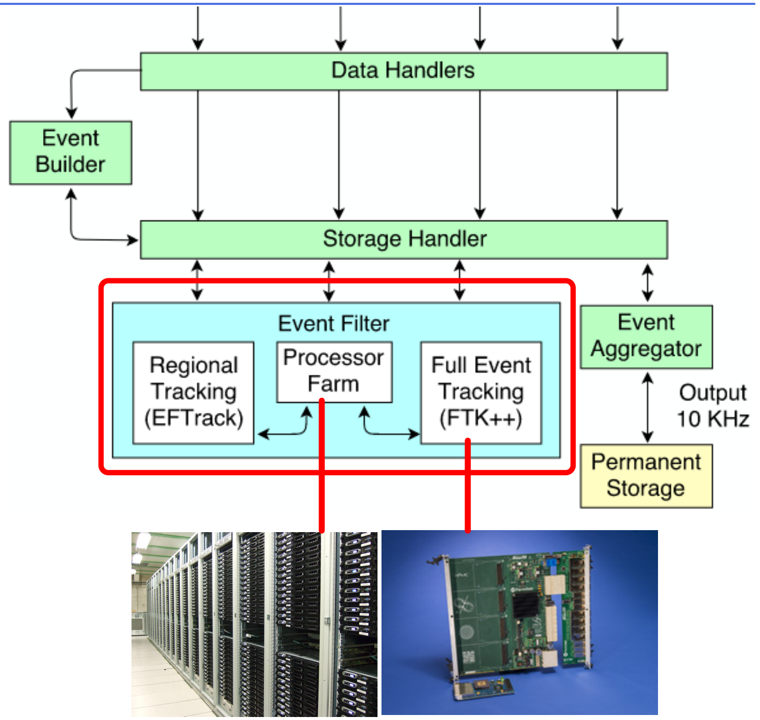


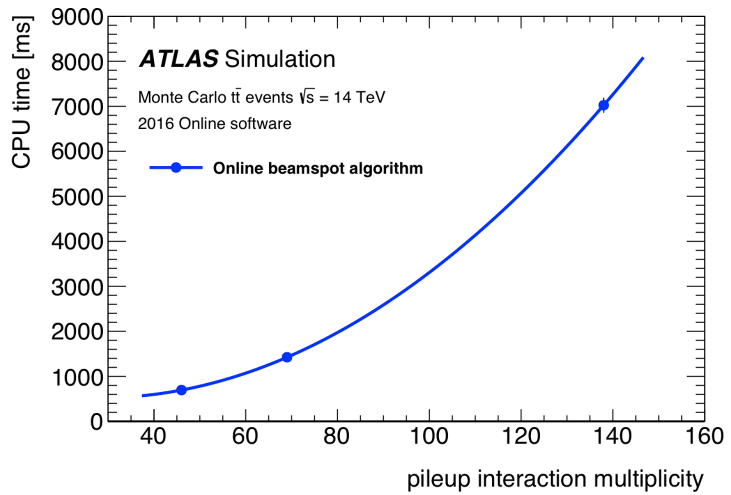
Example storage: from www.backblaze.com

Event Filter Upgrade

Event Filter (EF) combines commodity processor farm and hardware tracking

- Reduces 1(4) MHz input rate from hardware trigger to 10 kHz output rate to permanent storage
  - First rejection to ~400 MHz achieved by hardware tracking
  - Followed by high level trigger (HLT) fast trigger-specific (or offline-type) software reconstruction algorithms
- Current approach does not scale with pileup: linear/factorial increase of digitisation/reconstruction time, more memory
- Need new advanced algorithms, capable of higher rejection with same physics efficiency → software/hardware hybrid solution
  - Software for seeded precision tracking in regions of interest (RoIs)
  - Hardware for unseeded tracking → FTK++ (associative memory chips, $p_T > 1$ GeV) for pileup suppression, b-tagging, E_T^{miss}, jet calibration
- Main processing power delivered by CPUs but other advanced architectures being evaluated
  - Software algorithms, parallelisation, multi-threading
  - Hardware accelerators, e.g. GPUs, FPGAs integrated into Xeon CPU
- Data structures suitable for CPUs/GPUs would reduce processing overheads





Summary

ATLAS is getting ready for the HL-LHC era

- HL-LHC physics and luminosity requirements exceed present detector capabilities
- High occupancy and particles flux due to large number of events per bunch crossing (pileup)
- Resulting in increased trigger and data rates (including background and fakes)
- Significant detector upgrades
- Replacements and refurbishments, extended detector $|\eta|$ coverage and geometrical acceptance
- New readout electronics for all legacy systems to stream full data off-detector at 40 MHz collision rate
- Higher granularity data made available at trigger level
- Complete transition from S/G-Link to new GBT detector readout links (developed at CERN)
- Large overhaul of trigger and data acquisition architecture
- Trend in Trigger from trigger-specific to offline-type algorithms
- Trend in DAQ from custom to commodity hardware, and from hardware to software
- More event building, recording, storage capacity; hardware acceleration, parallelism
- Event filter interface with hardware tracking becomes more and more important at higher pileup
- ATLAS plans staged series of upgrades (phase 1 and phase 2)
- Take advantage of new technologies and ideas
- Design for flexibility and capacity to allow for discovery of new physics and precision measurements

Backup

Questions and Discussion

Stanley Brodsky raised the question and made the following comment after the talk

- What is the ATLAS η coverage for muons and can it measure very forward muons?
- ATLAS's most important measurement may be the higgs hadroproduction at large Feynman x
- To carry out such a study however, ATLAS would need to augment the forward detectors with muon detection capabilities
- A list of articles related to forward higgs production

  - *Diffractive Higgs Production from Intrinsic Heavy Flavors in the Proton, Stanley J. Brodsky, Boris Kopeliovich, Ivan Schmidt, Jacques Soffer, 2016*
    http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-11784.pdf
  - *Higgs Hadroproduction at Large Feynman x, Stanley J. Brodsky, Alfred S. Goldhaber, Boris Z. Kopeliovich, Ivan Schmidt, 2008*
    https://arxiv.org/abs/0707.4658
  - *Review Article Diffractive Bremsstrahlung in Hadronic Collisions, Roman Pasechnik, Boris Kopeliovich, Irina Potashnikova, 2015*
    https://www.hindawi.com/journals/ahep/2015/701467/ref/
  - *Novel QCD Phenomena at the LHC: The Ridge, Digluon-Initiated Subprocesses, Direct Reactions, Non-Universal Antishadowing, and Forward Higgs Production, Stanley J. Brodsky, 2014*
    https://arxiv.org/abs/1410.0404
  - *Novel Heavy Quark Phenomena in QCD, Stanley J. Brodsky, 2013*
    https://pos.sissa.it/205/013/pdf

This is in line with the message from the CERN Director of Research and Computing who

- ... encourages the community to think of using LHC in different ways to extract the maximum amount of knowledge within the LHC physics programme
- ... emphasizes the potential of LHC as an extremely flexible physics tool