ATLAS Trigger and Data Acquisition Upgrades for the High Luminosity LHC

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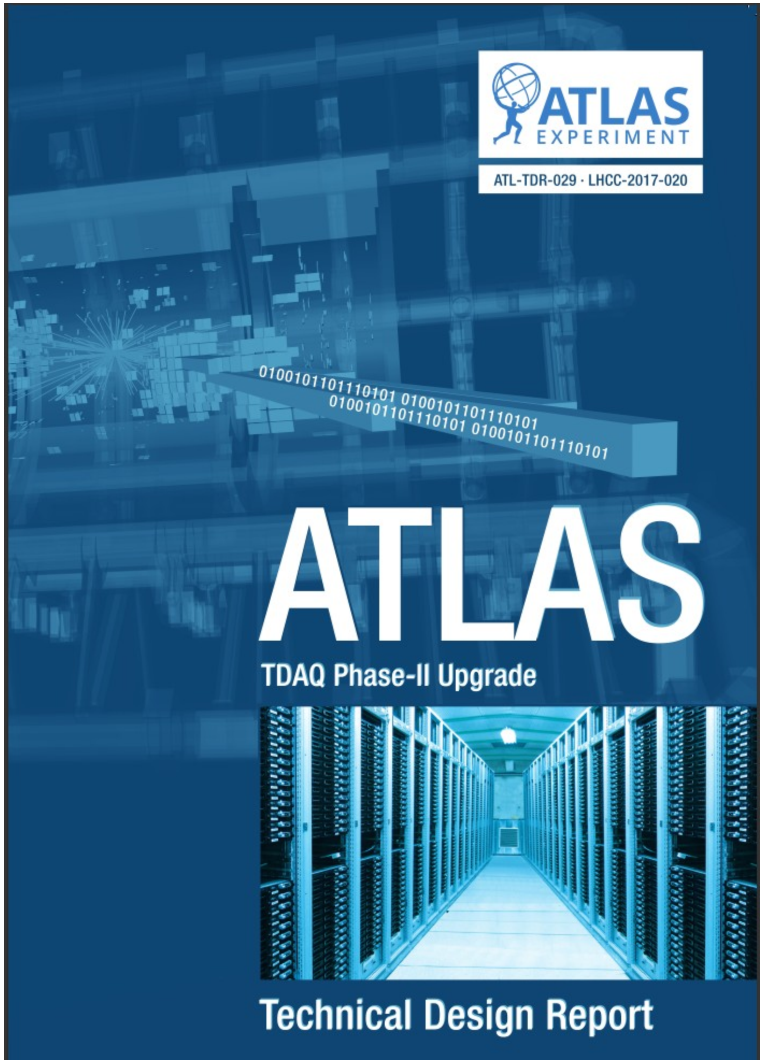
on behalf of
ATLAS Collaboration

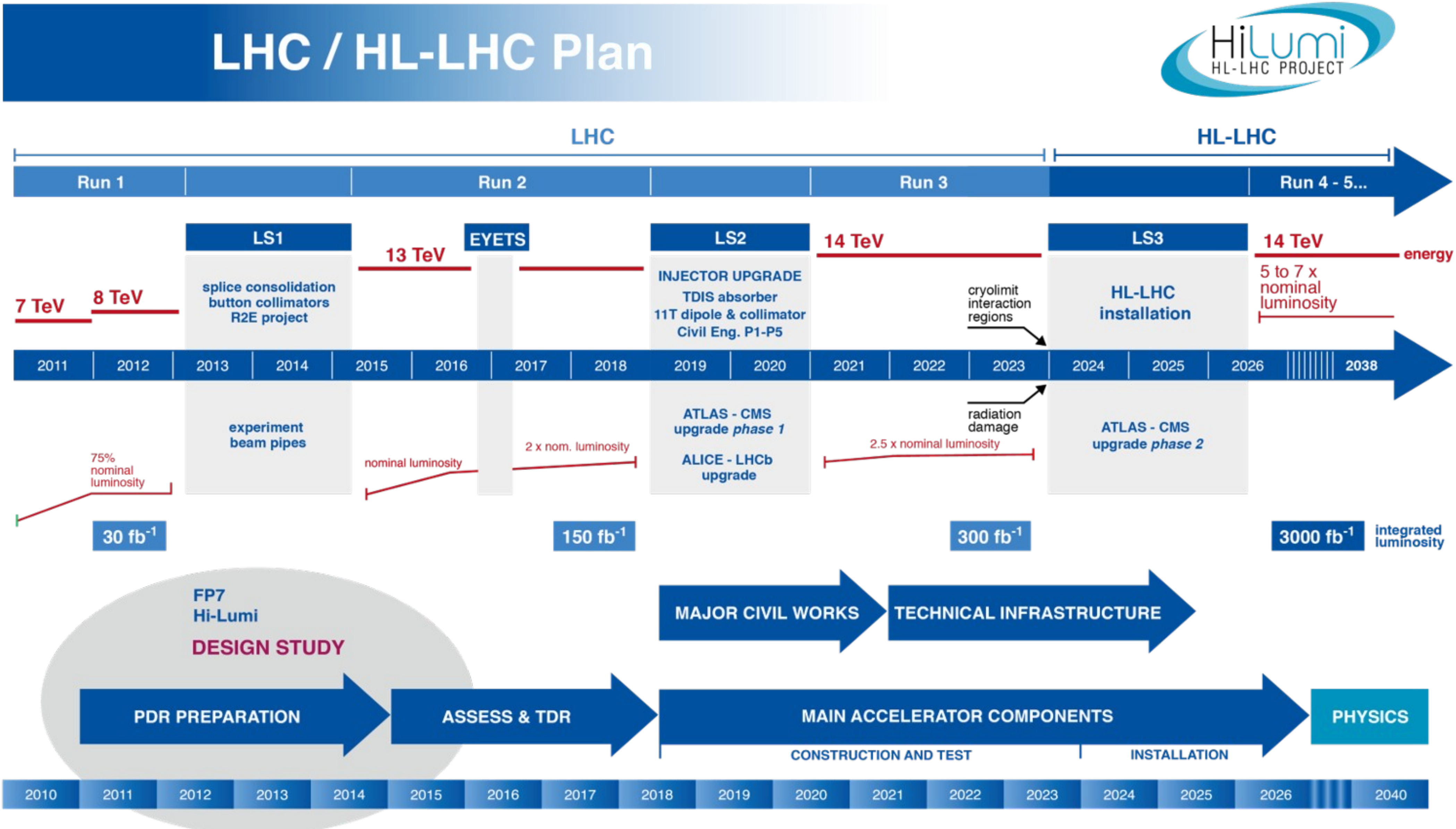
Outline

- HL-LHC Overview
- Physics Motivations & Challenges
- ATLAS Phase-II TDAQ Architecture
- TDAQ Sub-Systems
- Outlook



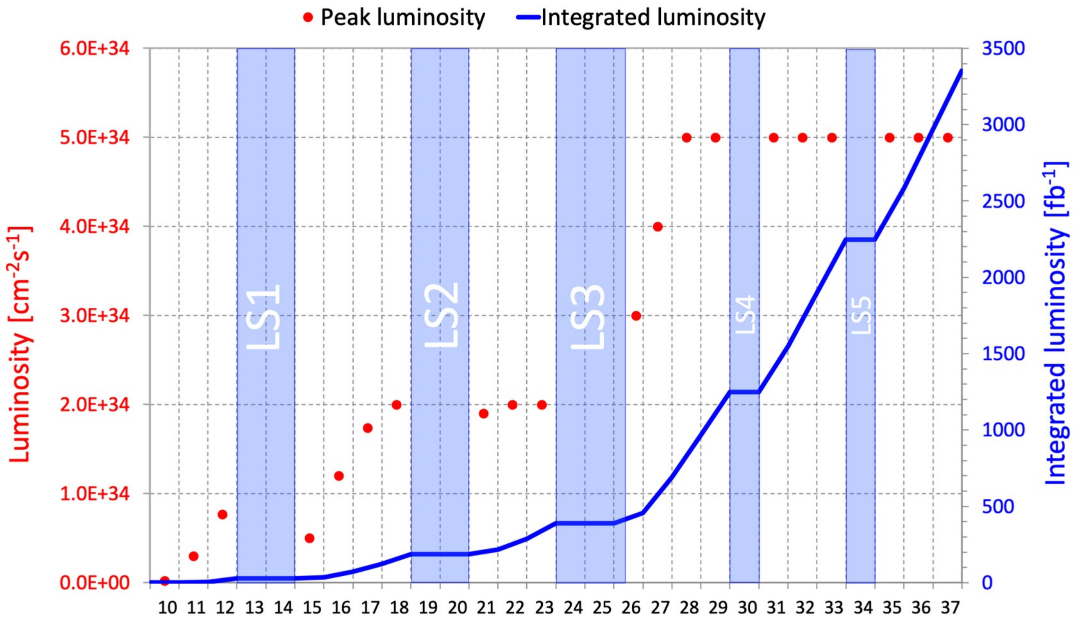
ATLAS Collaboration
Technical Design Report for the Phase-II Upgrade of the ATLAS TDAQ System
https://cds.cern.ch/record/2285584

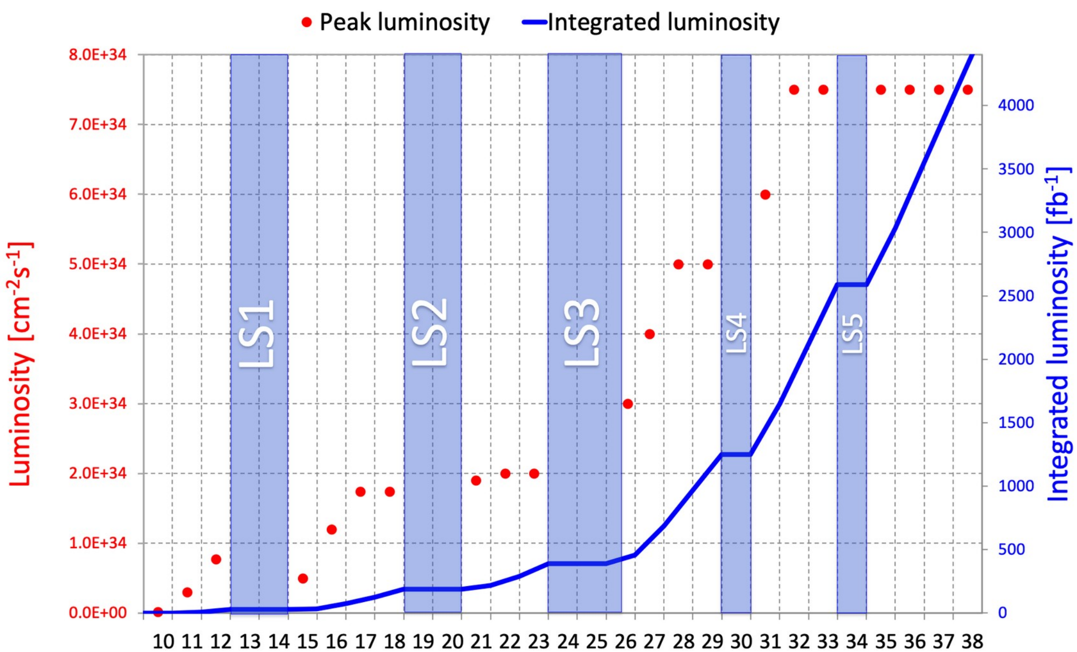
LHC Schedule



HL-LHC Operation Point

- HL-LHC programme aims at a total integrated luminosity of at least 3000 fb^{-1}
  - ten-fold increase wrt Run 1/2/3 aggregate
- Corresponding increase in peak instantaneous luminosity
  - $\mathscr{L}$~$5\cdot10^{34}$ $cm^{-2}s^{-1}$ (ultimate $7.5\cdot10^{34}$ $cm^{-2}s^{-1}$)
  - achieved mainly via pileup <μ>: 140 (ultimate 200)
- For reference Run 3 operation point:
  - $\mathscr{L}$~$2\cdot10^{34}$ $cm^{-2}s^{-1}$ - <μ>~50





https://lhc-commissioning.web.cern.ch/lhc-commissioning/schedule/HL-LHC-plots.htm

Physics Motivations

- The challenging and broad HL-LHC programme requires trigger thresholds comparable with the current ones, e.g.:
  - electroweak scale requires low p_T leptons
  - searches for new physics with low Δm
  - HH measurements requires low p_T jets /b-jets
- At fixed threshold, trigger rates scale with peak luminosity
  - worsened by pileup environment

→ Major increase in readout and recording rates

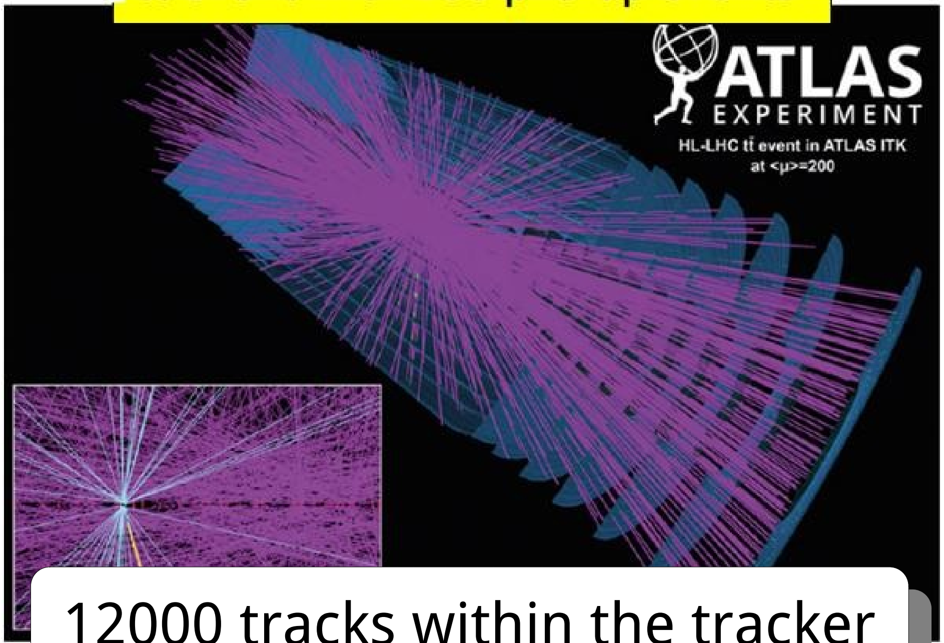
Trigger Selection offline threshold (GeV)	Run 1	Run 2	HL-LHC
Isolated single e	25	27	**22**
Isolated single μ	25	27	**20**
Di-γ	25, 25	25, 25	**25, 25**
Di-τ	40, 30	40, 30	**40, 30**
Four-jet w/ b-jets	45	45	**65**
H_T	700	700	**375**
MET	150	200	**200**

	Run 3	Phase II
Readout rate (MHz)	0.1	1 (4)
Recording rate (kHz)	1.5	10

ATLAS Phase-II Upgrade

- High-granularity to cope with pileup
  - both for readout and trigger
  - complete replacement of inner detector → ITk

Larger event size



- Higher readout rate needs overhaul of detector front-end electronics
  - occasion to increase first level-trigger latency
    - *currently limited by on-detector buffer depths*
  - adopt unified readout link technology
    - *GBT/Versatile*

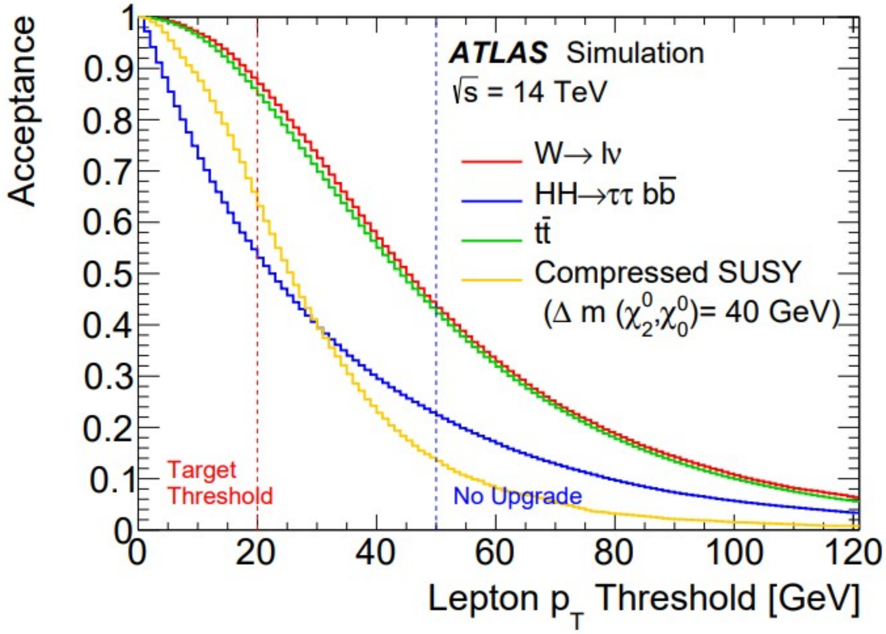
	Run 3	Phase II
First-level trigger latency (μs)	2.5	10
Event size (MB)	2.5	>5

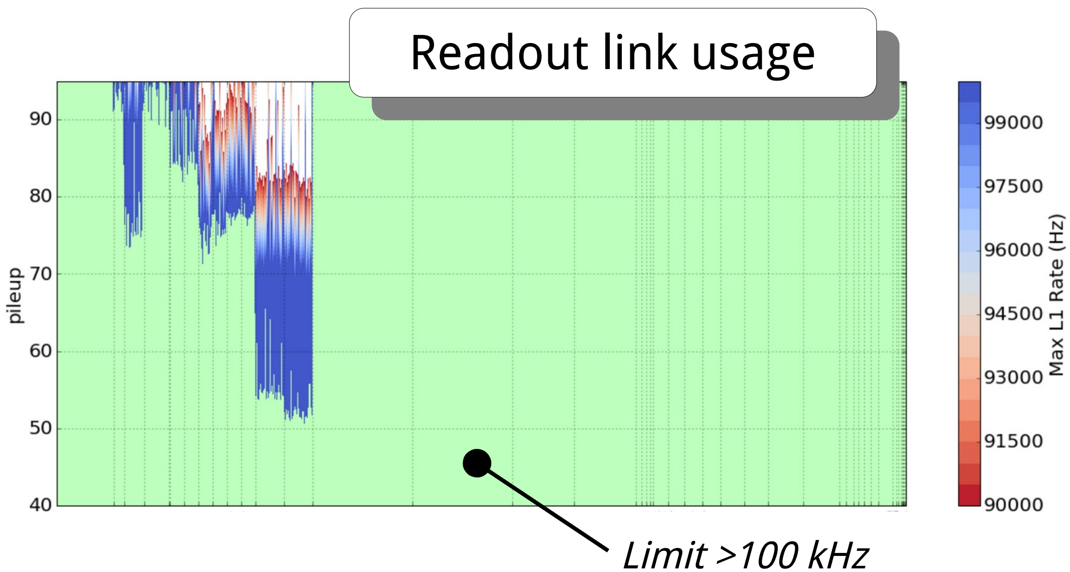
TDAQ Challenges and Design Criteria

- ATLAS TDAQ requires a major overhaul to cope with the Phase-II conditions and requirements

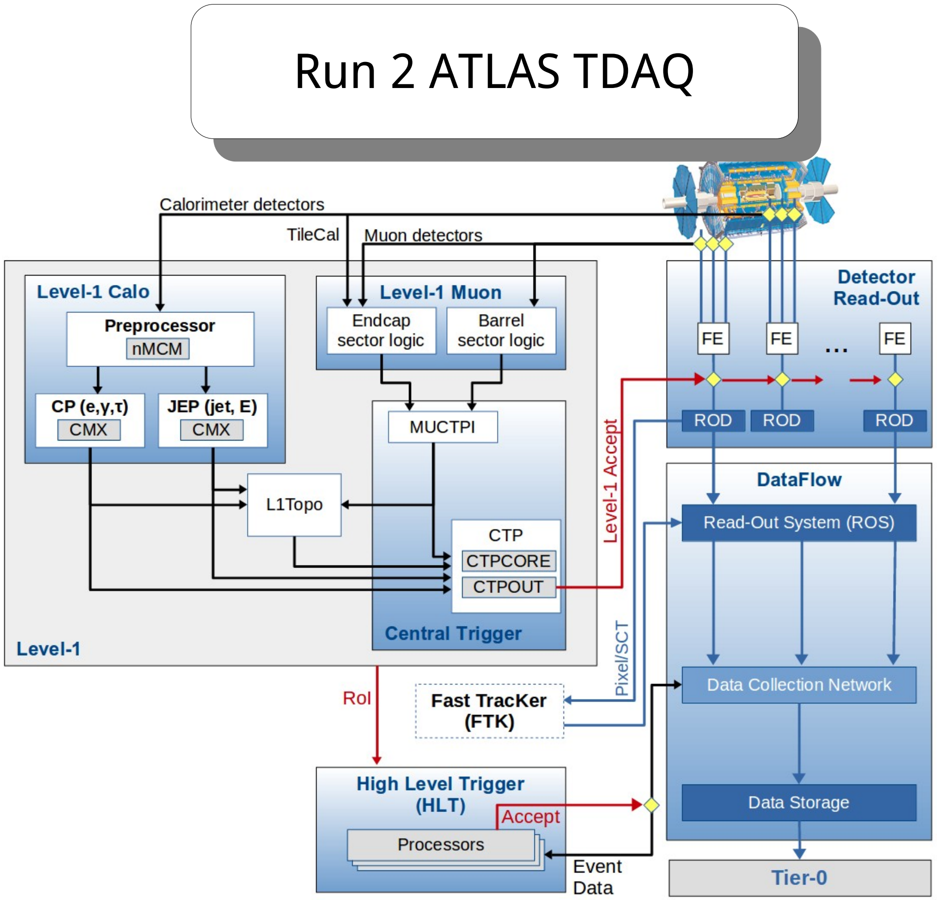
- Existing system limited in every aspect
  - trigger and timing distribution
  - capabilities of the first-level trigger
  - readout and dataflow bandwidth

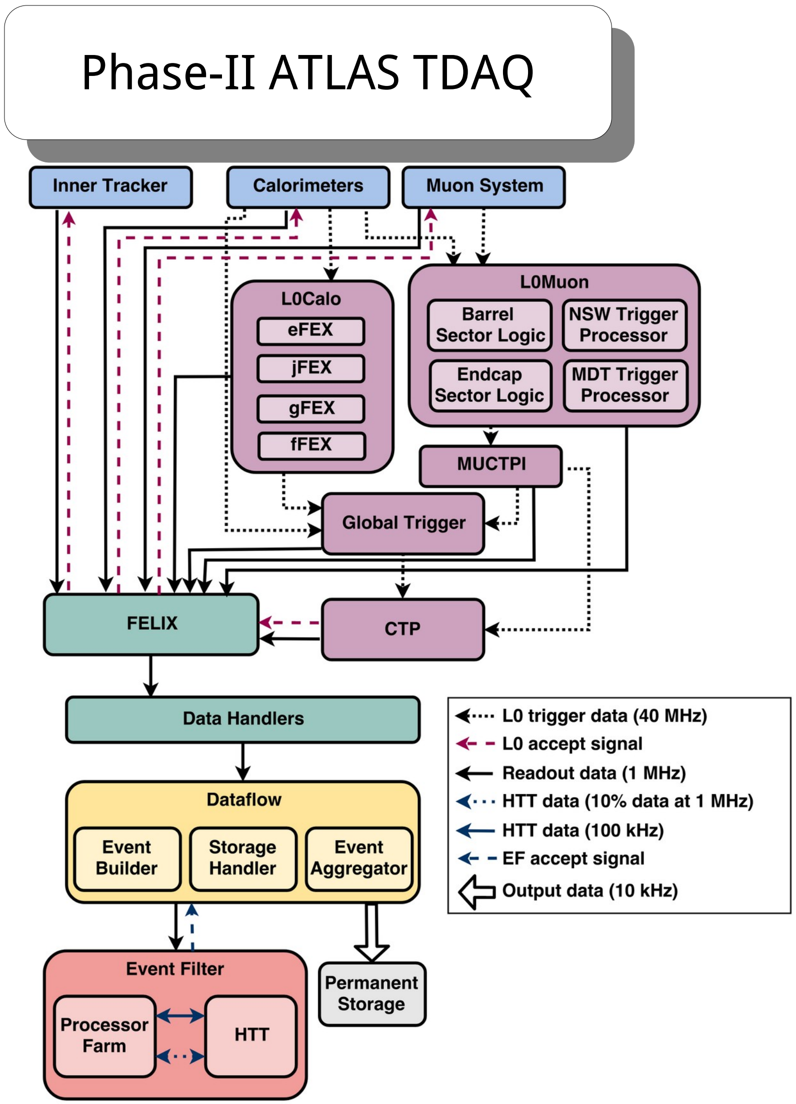
- Phase-II TDAQ design is not a revolution
  - scale implementation to Phase-II requirements
  - learn lessons from previous runs
  - take advantage of last 10+ years of technology evolution
  - apply solutions specific to the HL-LHC challenges





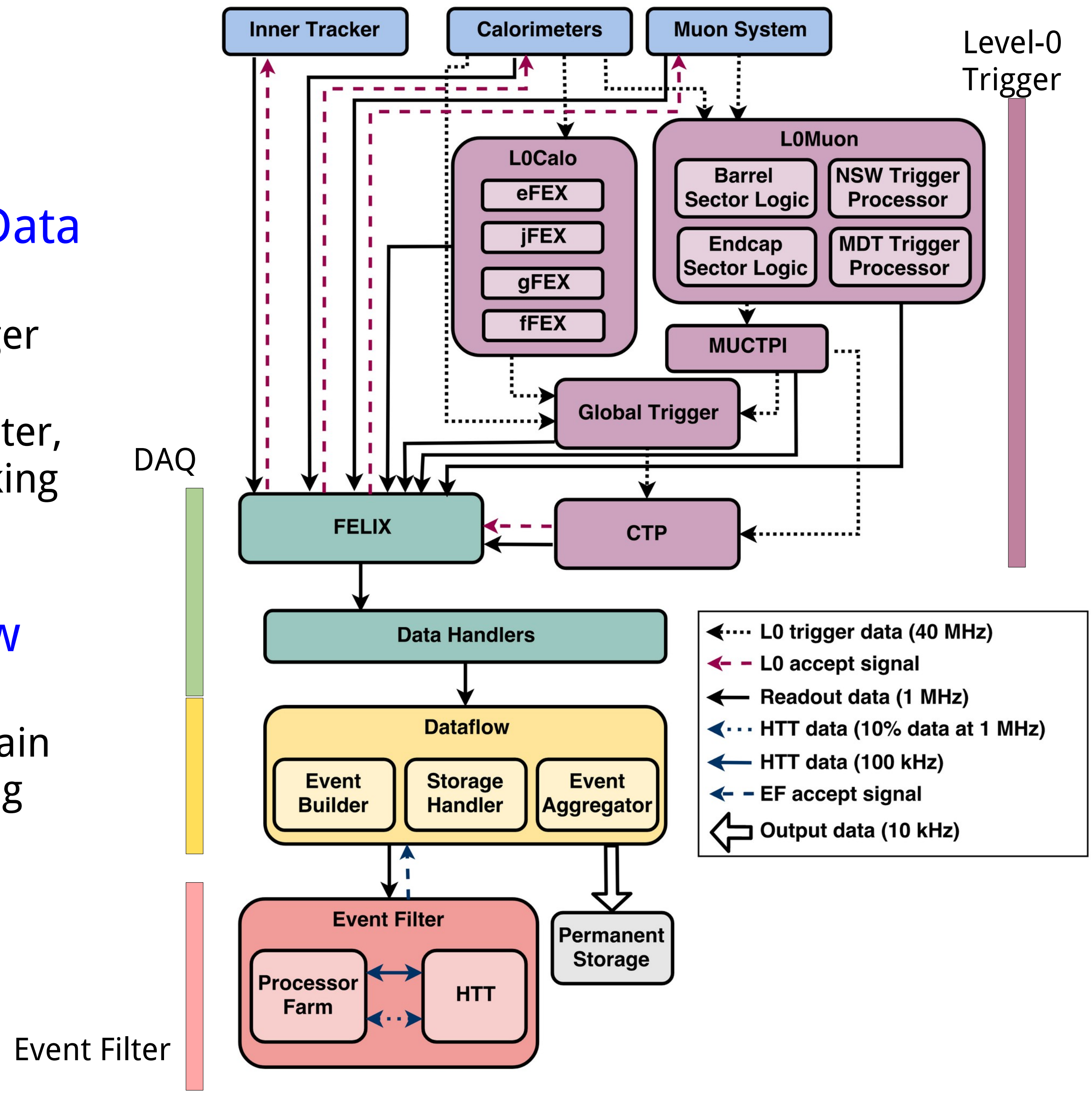
Phase-II TDAQ Architecture





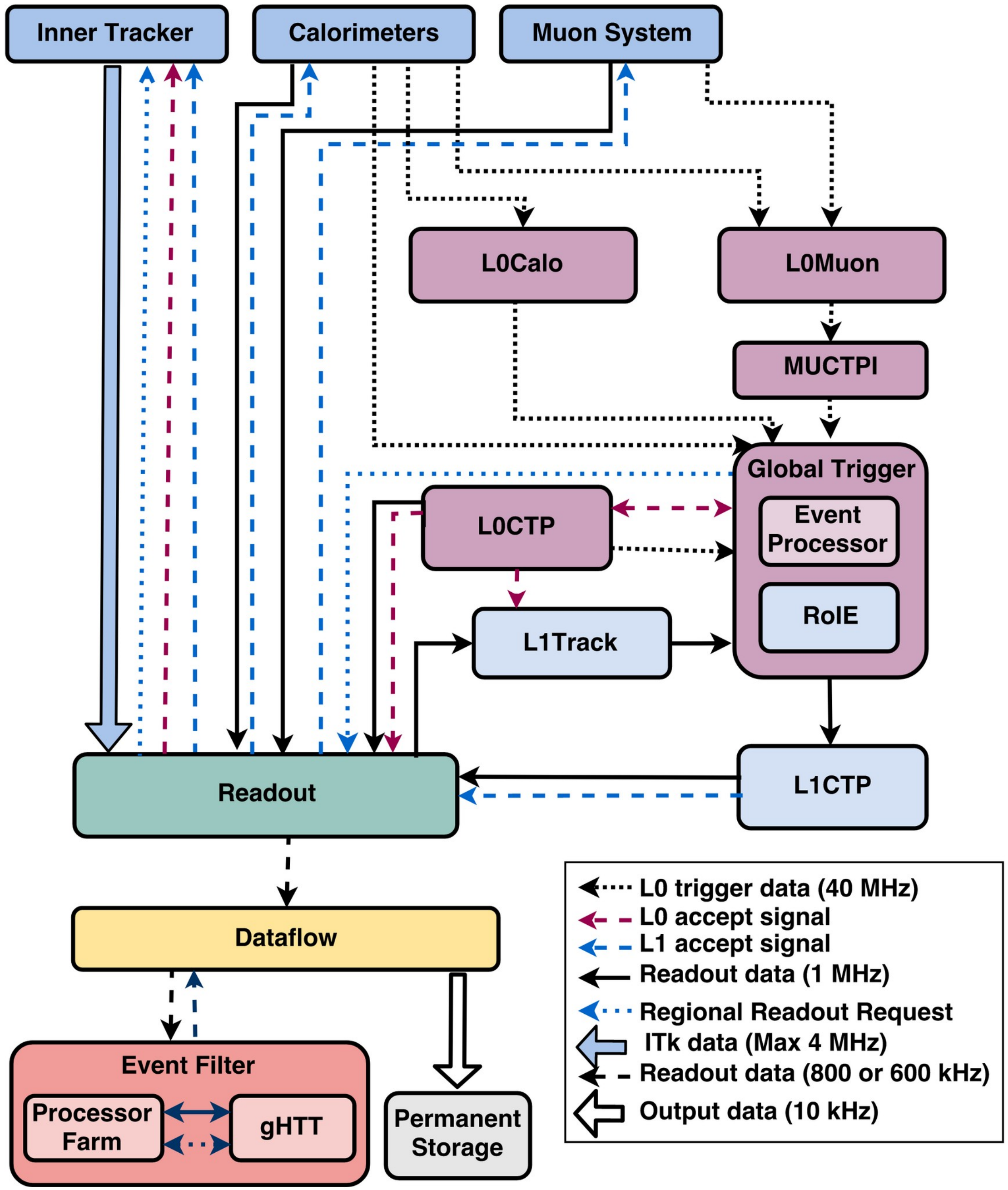
Phase-II TDAQ Architecture

- Two-Level Trigger and Data Acquisition System
  - hardware-based L0 trigger system
  - software-based Event Filter, aided by dedicated tracking accelerator
- Storage-based data-flow infrastructure
  - decouple real-time domain from software processing
  - enable advanced data processing strategies



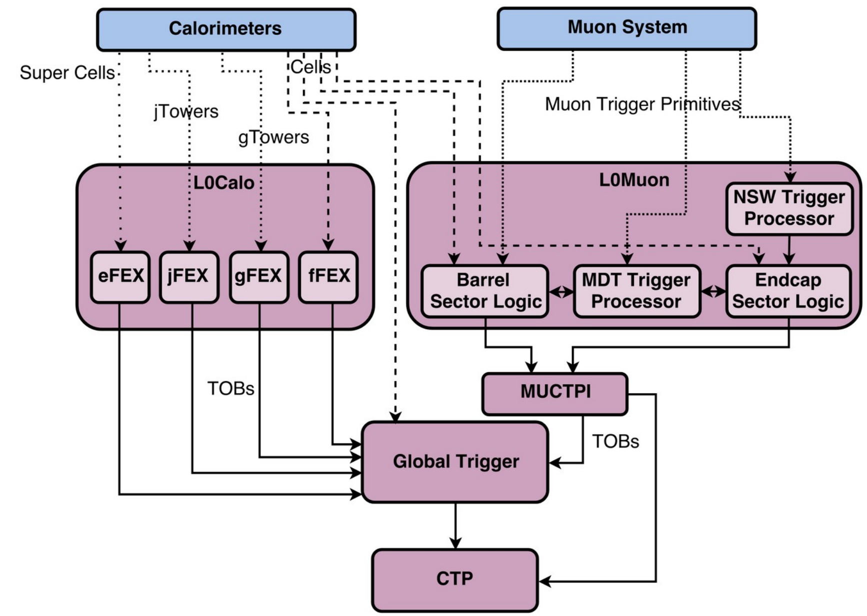
Phase-II TDAQ Evolution Architecture

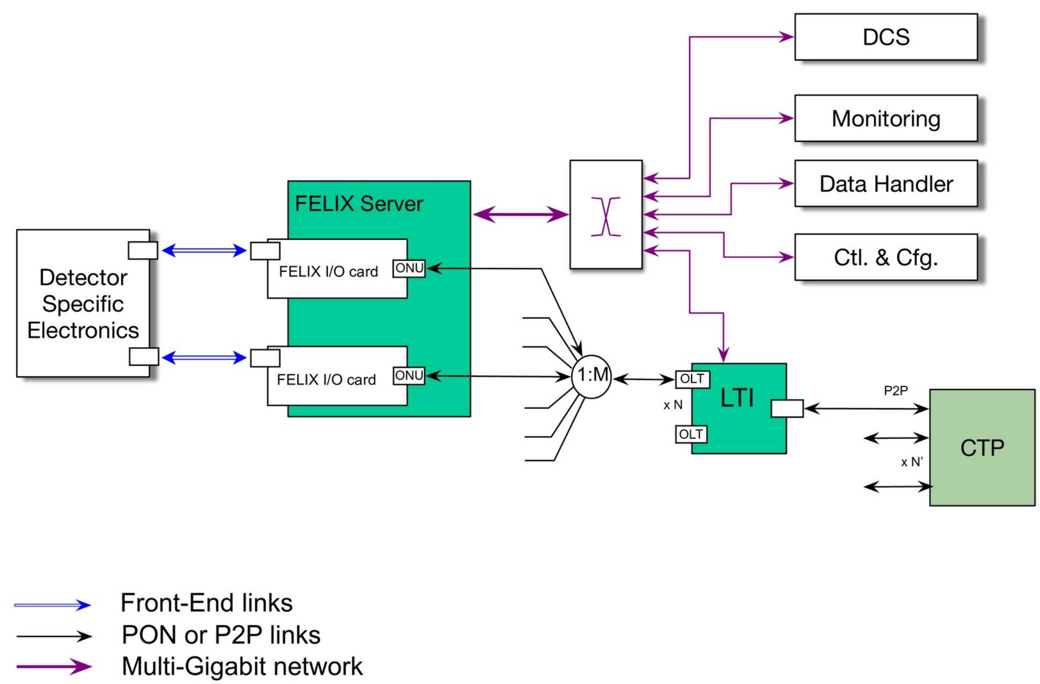
- Evolution path to a two-level hardware trigger included in the design
  - L0 – 4 MHz
  - L1 – 1 MHz
  - Event Filter – 10 kHz
- Possible transition from baseline to evolution driven by physics requirements
  - hadronic trigger rates
  - occupancy of inner layers of ITk
- Avoid the baseline TDAQ implementation restricting the trigger menu at the ultimate HL-LHC operating conditions
- Level-1 Trigger combines L0 objects with track information from a dedicated subsystem to discriminate against pileup in the calorimeter



Level-0 Trigger & TTC

- Operates at 40 MHz applying selection criteria based on
  - calorimeter activity
  - muon detection
  - topological information
- Central Trigger Processor includes
  - interface to the LHC timing
  - prescaling and preventive deadtime functionalities
- Completely new trigger & timing distribution system
  - options based on passive optical splitters and point-to-point links

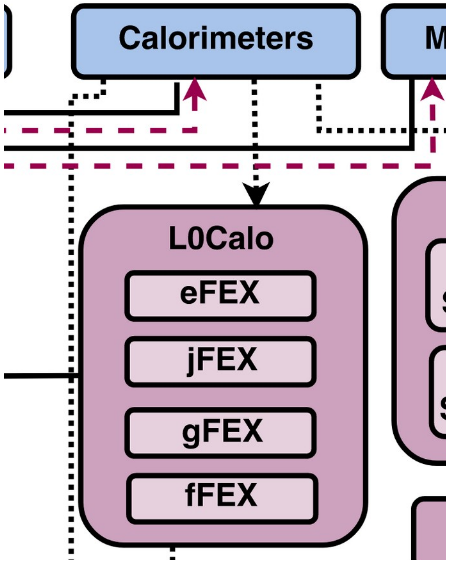




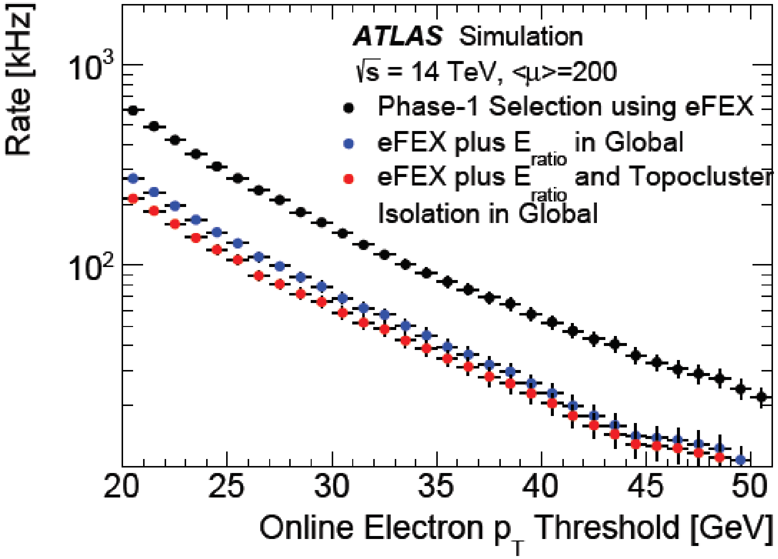
Level-0 Calo

- Largely inherited from the ongoing Phase-I upgrade

- Exploits reduced-granularity data from EM and hadronic calorimeters. Dedicated collections of boards implement:
  - electron and photon identification (eFEX)
  - single jet identification (jFEX)
  - large-R triggers and global quantities (gFEX)
  - forward electromagnetic jets identification (fFEX)

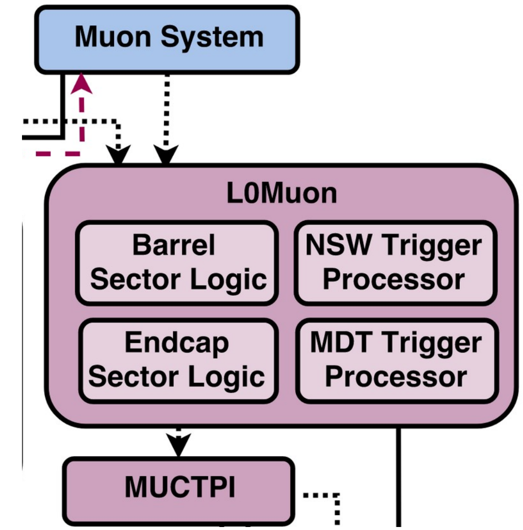


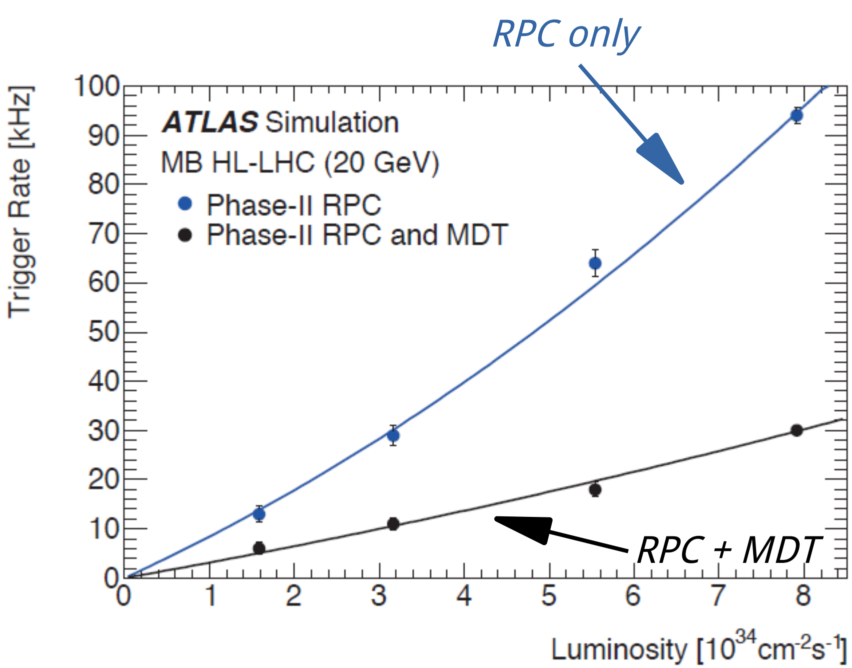
Subsystem	Trigger Object	Approximate Granularity	Coverage $\|\eta\|$
eFEX	$e/\gamma, \tau$	Super Cells (10 in 0.1×0.1)	< 2.5
jFEX	τ, jet, E_T^{miss}	0.1×0.1	< 2.5
jFEX	τ, jet, E_T^{miss}	0.2×0.2	$2.5 - 3.2$
jFEX	τ, jet, E_T^{miss}	0.4×0.4	$3.2 - 4.9$
gFEX	Large-R jet, E_T^{miss}	0.2×0.2	< 4.9
fFEX	e/γ	Full detector EMEC, HEC, FCal	$2.5 - 4.9$
fFEX	jet	Full detector FCal	$3.2 - 4.9$



Level-0 Muon

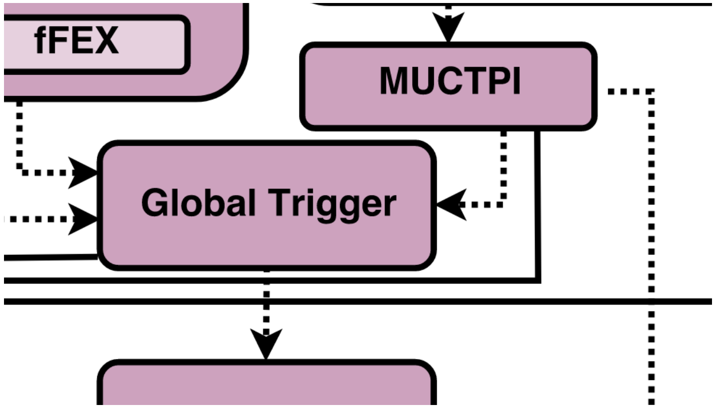
- Muon identification based on muon spectrometer and hadronic calorimeter
  - data processing moved mainly to off-detector electronics
- Major improvements
  - increased acceptance thanks to extended detector coverage (RPC chambers)
  - better momentum resolution by including precision drift chambers (MDT) information
- Selectivity of current Level-1 muon trigger limited by spatial resolution of trigger detectors (RPC, TGC)
  - thanks to MDT → p_T resolution close to offline reconstruction
  - significant reduction in trigger rate

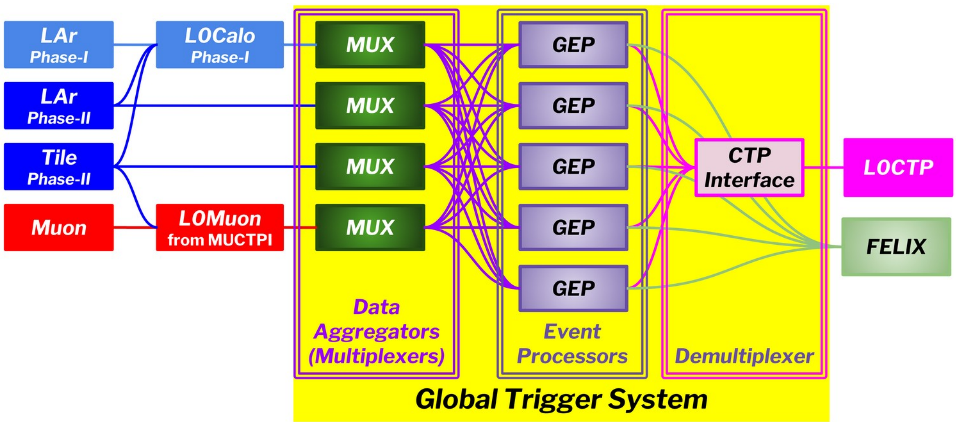




Level-0 Global

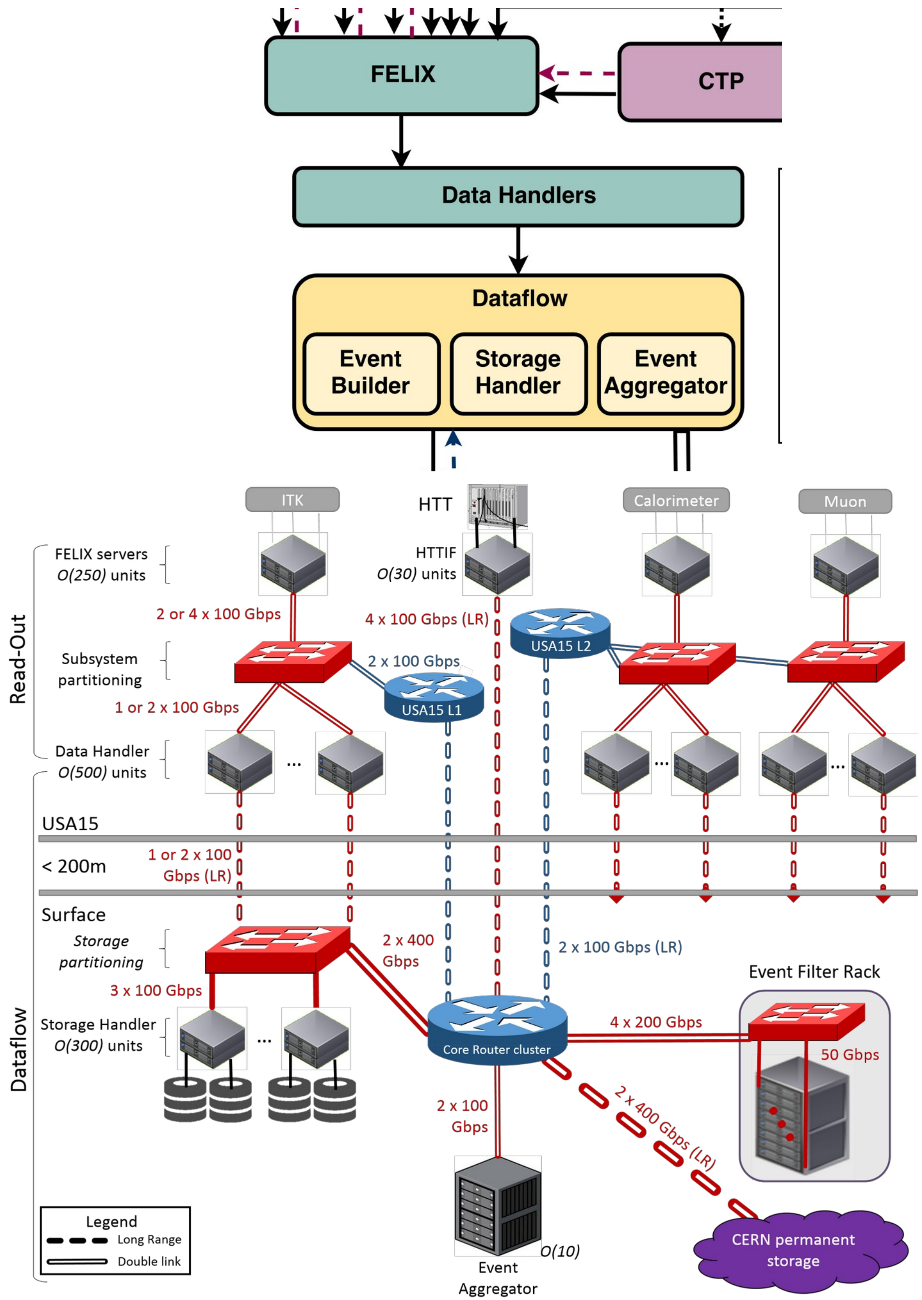
- Complements Level-0 Calo with additional high-granularity energy data and muon information
- Aims to bring Event Filter-like algorithms to the hardware trigger level
  - e.g. topological clusters and “anti-k_T” algorithm
  - overall event view enables topological selections
- Time-based multiplexing/de-multiplexing design
  - multiple processing boards operating in parallel on different events
  - input and output systems provide data aggregation and serialisation functionalities





DAQ: data transport and management

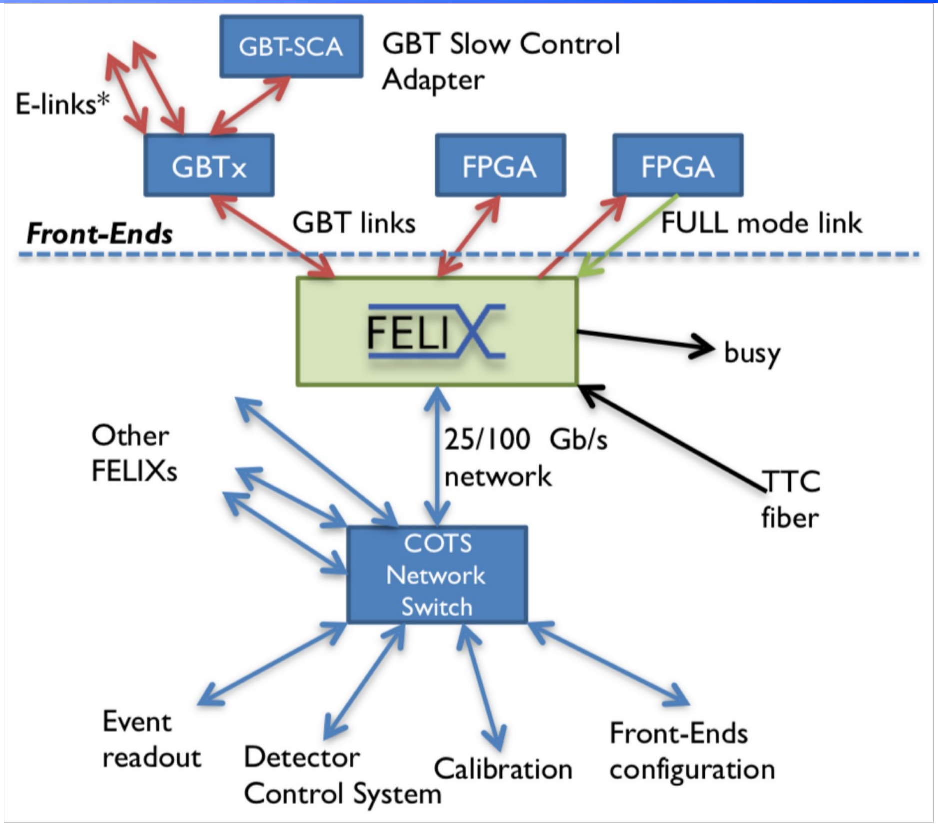
- DAQ infrastructure responsible for
  - interfacing the detector readout links to a commercial network domain
  - buffering the data and serving them to the Event Filter processors
  - discarding rejected events and formatting selected data for offline transfer
- Largely implemented with commodity off the shelf hardware
- Backbone is a multi-layered sliced network
  - baseline design based on Ethernet, do not exclude HPC technologies
- Investigating the use of commodity software
  - filesystem and cluster management



DAQ: Detector Interface

- Detector interfacing relies on a concept being deployed for Run 3
  - extended to the whole ATLAS
- Front-end Link Exchange (FELIX) acts a heterogeneous router
  - translates between network and serial links
  - distributes timing and trigger signals
  - as detector-agnostic as possible
    - *still provision for detector specific firmware*
- Implementation based on commercial servers equipped with custom FPGA-based PCIe interfaces
  - plan for 48 10Gbps links per card
  - ~550 cards serving almost 20000 links
- Detector-specific data processing deferred to dedicated servers
  - "Data Handlers"

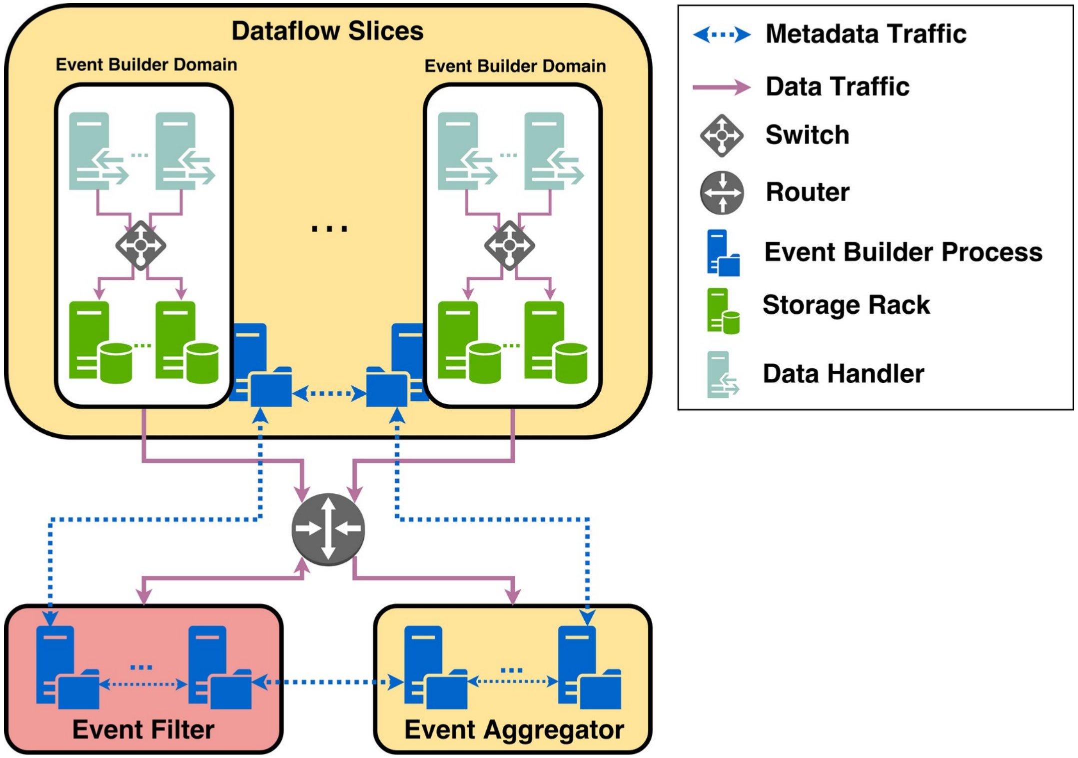
"FELIX: commissioning the new detector interface for the ATLAS trigger and readout system"
N.Ilic, October 3rd



Phase-I FELIX Interface Card

DAQ: Storage & Data management

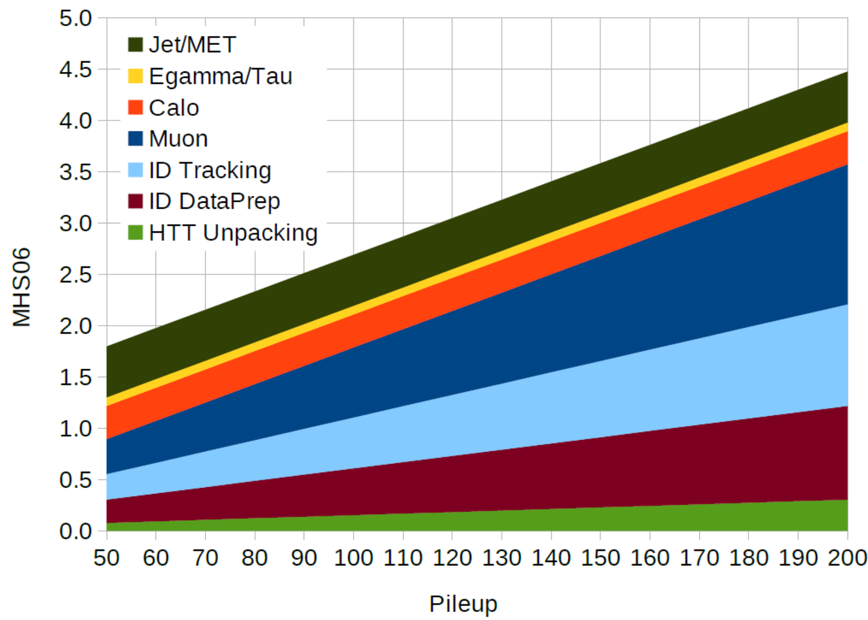
- Extend the DAQ buffering capabilities using a large storage infrastructure
  - decouple real-time domain (Level-0) and software domain (Event Filter)
  - enable delayed processing or fail-over scenarios
- Event building could be either logical or physical
- Event Filter computer farm may be operated similarly to a batch system
  - quasi-real-time data stream required for online physics and detector monitoring



Component Connection		Traffic
Detector Front-ends to FELIX		5.2 TB/s
FELIX to Data Handlers		5.2 TB/s
Data Handlers to Event Builder/Storage Handler		5.2TB/s
Storage Handler to Event Filter		2.6 TB/s
Event Filter to HTTIF	Event Filter to rHTT	175 GB/s
	Event Filter to gHTT	560 GB/s
Event Filter to Event Aggregator and Permanent Storage		60 GB/s

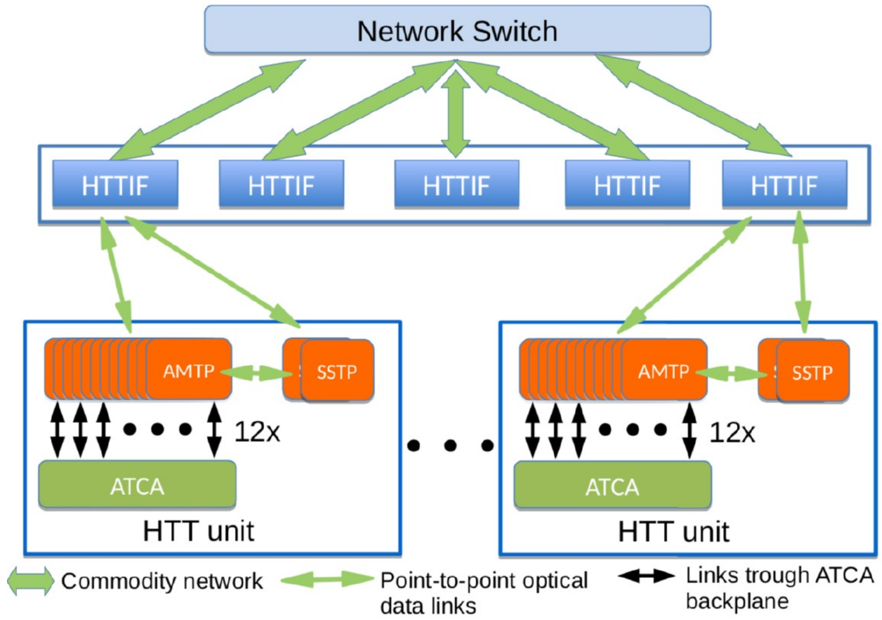
Event Filter

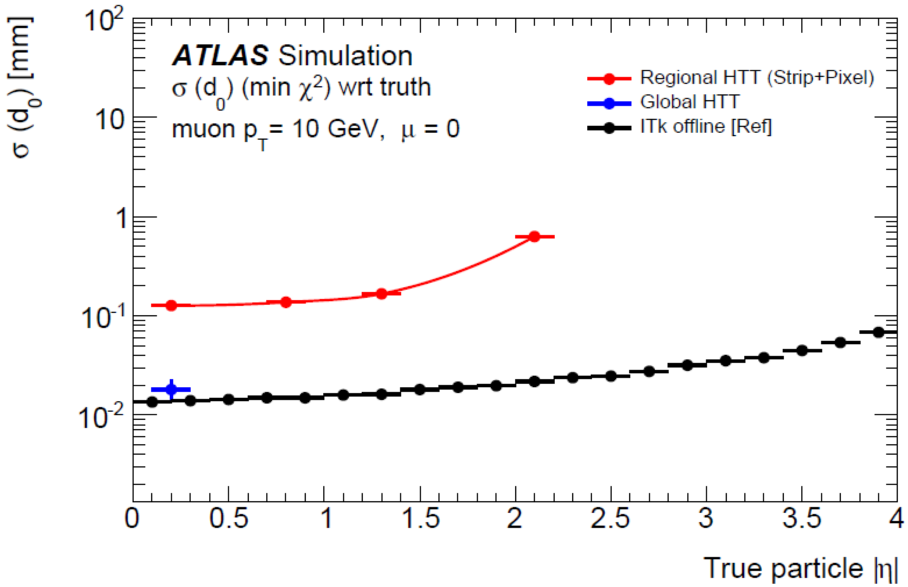
- Similar to Run 3 → large computer farm
  - aided by a dedicated tracking system
  - performs the last level of selection from 1 MHz to 10 kHz
- In high pileup environment tracking is key to recover algorithms performance and maintain low thresholds
  - separation of electrons and background jets
  - calculation of global event quantities like E_T^{miss}
  - jet energy resolution
- Baseline implementation is based on CPUs
  - assume 3000 dual-socket servers will suffice on the time-scale of Phase-II
  - in parallel investigations of accelerators (GPGPU & FPGA) and associated dedicated algorithms



Hardware Track Trigger

- Based on current ITk tracking software → 10 times larger computer farm would be required
    - ongoing software optimisations potential to significantly reduce this estimate
- HTT (Hardware Track Trigger) massively parallel performing tracking via Associative Memories (AM ASICs)
    - driven by the Event Filter requests
    - the low latency feature enable a transition into a Level-1 tracking system in the evolved scenario
- Two tracking capabilities
    - rHTT: regional tracking with 8 ITk layers and p_T>2 GeV → support rate reduction to 400 kHz
    - gHTT: global tracking with full ITk data and p_T>1 GeV→ support rate reduction to 10 kHz
- In parallel to HTT development, alternative tracking strategies being assessed
    - using commodity hardware platform: software on CPU, accelerators (GPU, FPGA)





Outlook

Phase-II ATLAS TDAQ Upgrade documented in the Technical Design Report

Major re-implementation of the Trigger & Data Acquisition System
- apply lessons and experience from Run 1/2/3
- take advantage of the technology evolution
- coping with the HL-LHC conditions requires a major scale-up
- specific solutions to specific challenges
  - Global Trigger
  - Hardware Track Trigger
  - Evolution mechanism

Bonus