The ATLAS Trigger in Run-2

Design, Menu and Performance

Tamara Vázquez Schröder
(McGill University)
on behalf of the ATLAS Collaboration

EPS Conference on High Energy Physics
Venice, Italy, 6. July 2017

Outline

- Introduction
- ATLAS Trigger and DAQ System Overview
- ATLAS Trigger Menu & Online Performance
- ATLAS Trigger Rates, CPU Usage & Software Validation
- Highlights ATLAS Trigger Signature Performance
- Conclusions

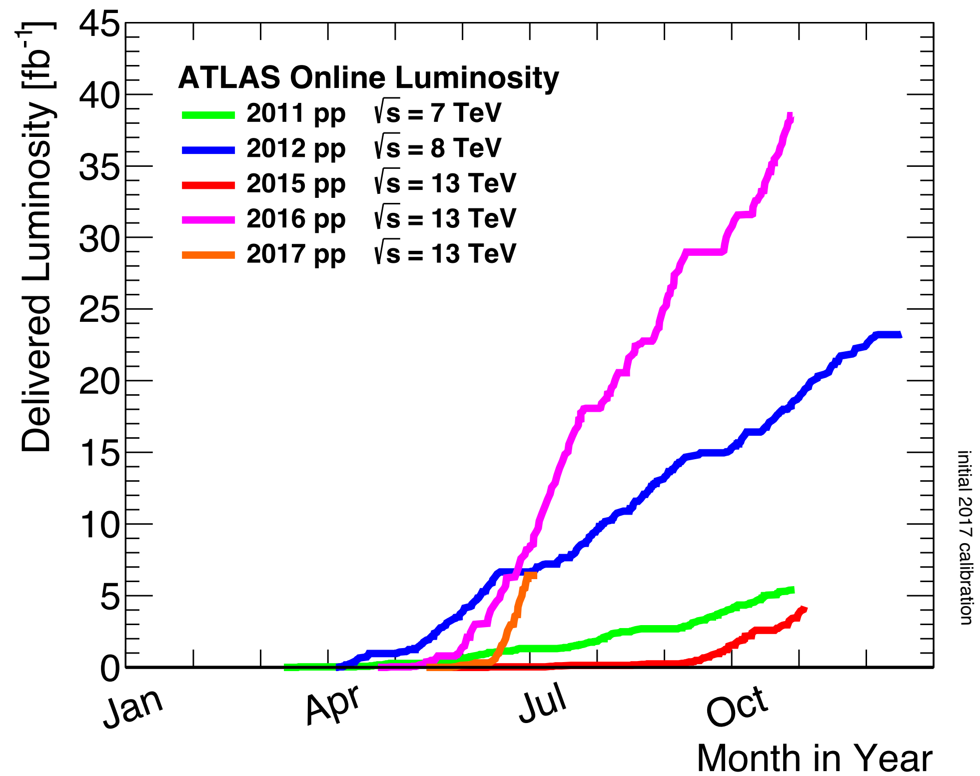
Introduction

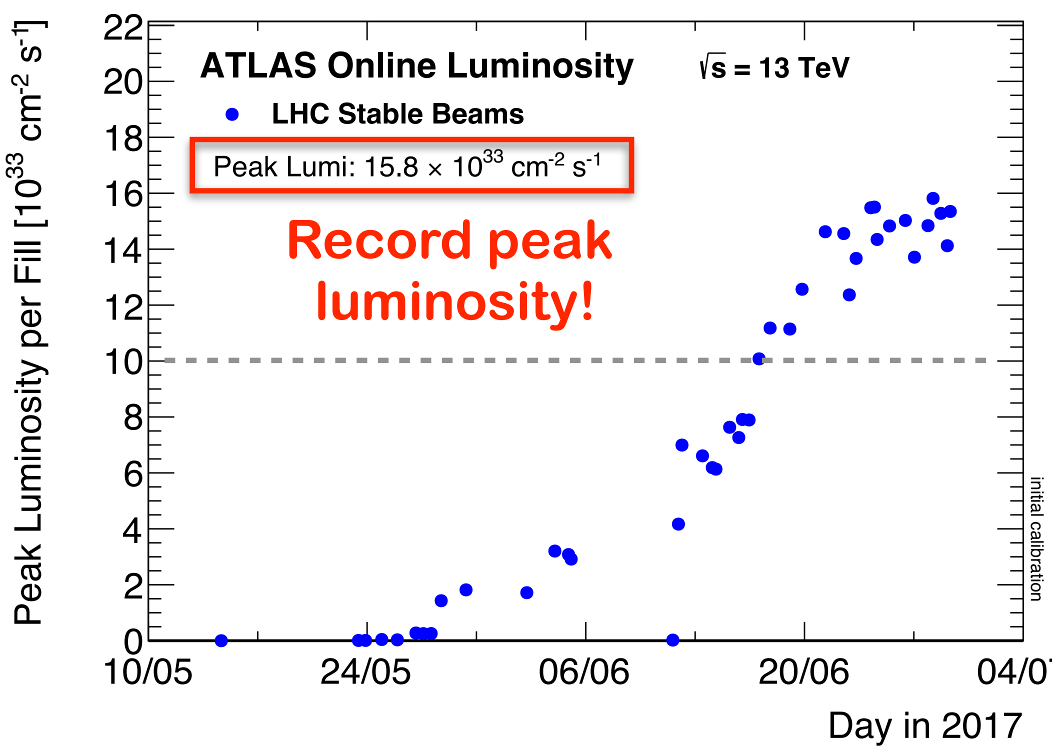
- Trigger system decides online whether or not to keep an event
  - Crucial **impact on quality** of data used in physics analysis!

- Successful operation of ATLAS Trigger System during first part of Run-2 at the LHC
  - Thanks to **several upgrades and improvements since Run-1** to cope with:
    - **Increase of rate**
    - **Increase of number of interactions per bunch crossing / pileup**

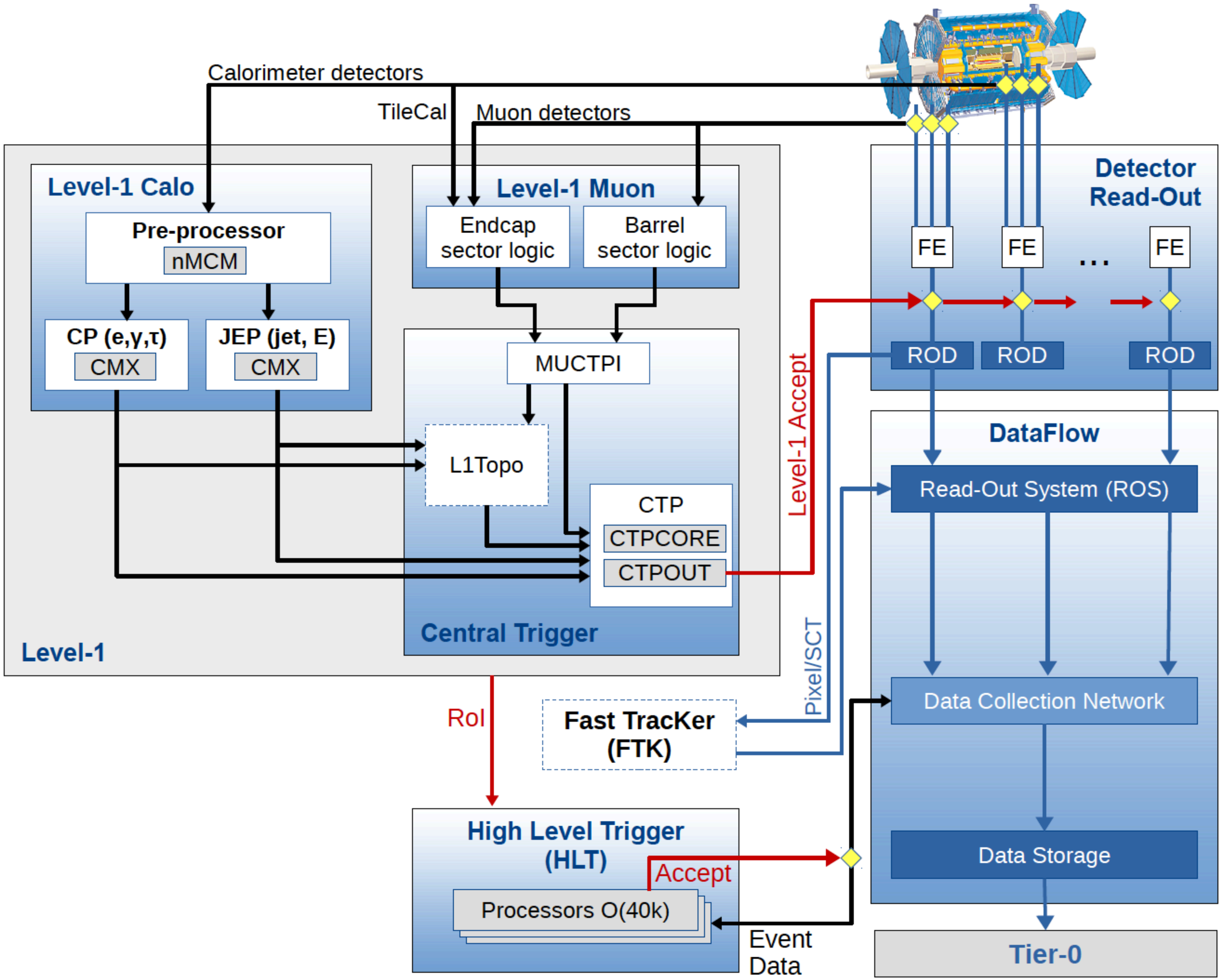
    due to:
    - **higher centre-of-mass energy collisions**
    - **higher instantaneous luminosity**

- Intensive preparation for second part of Run-2 (2017/2018)





ATLAS Trigger and DAQ System



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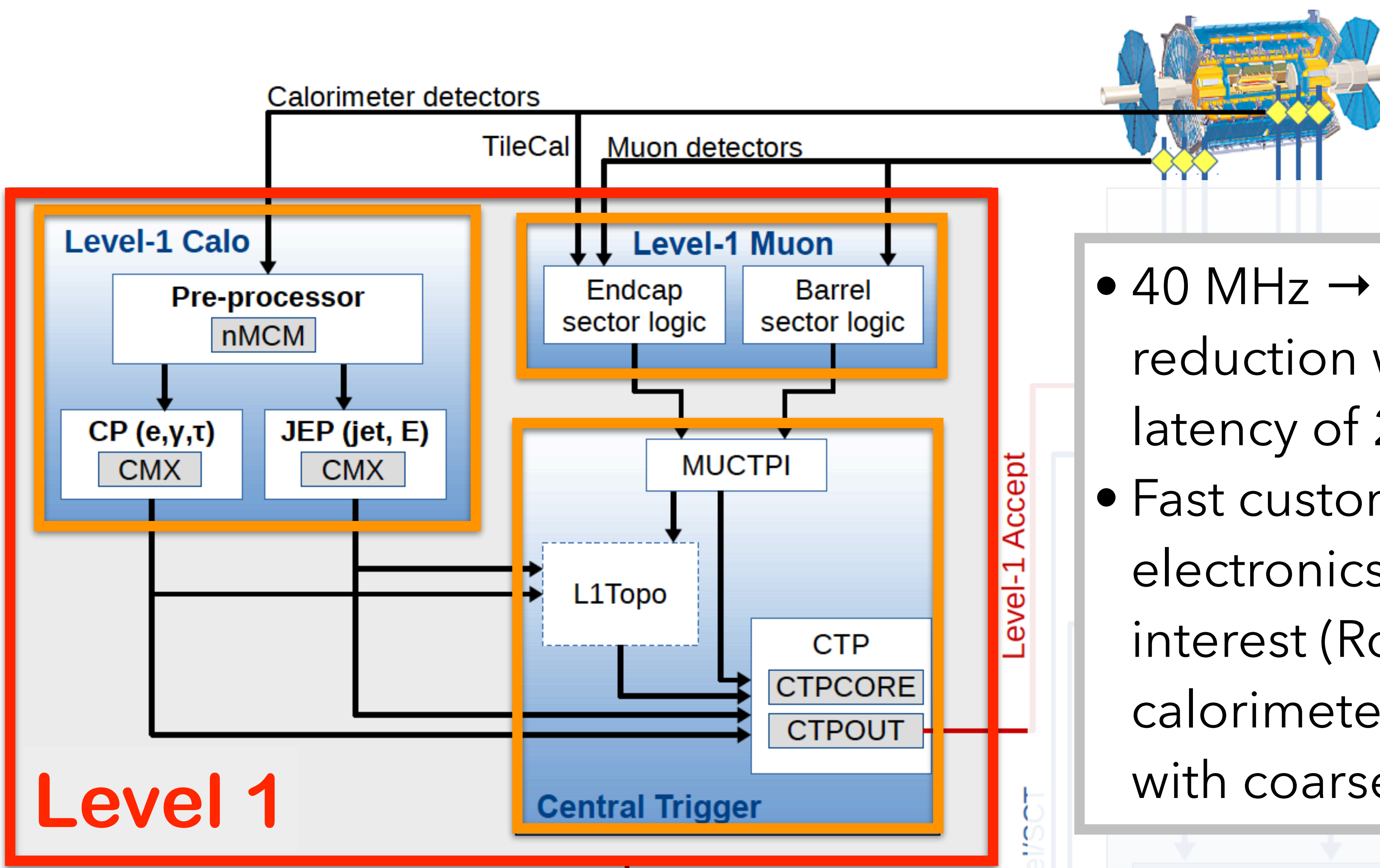
ATLAS Trigger: **Level 1 Trigger (L1)**



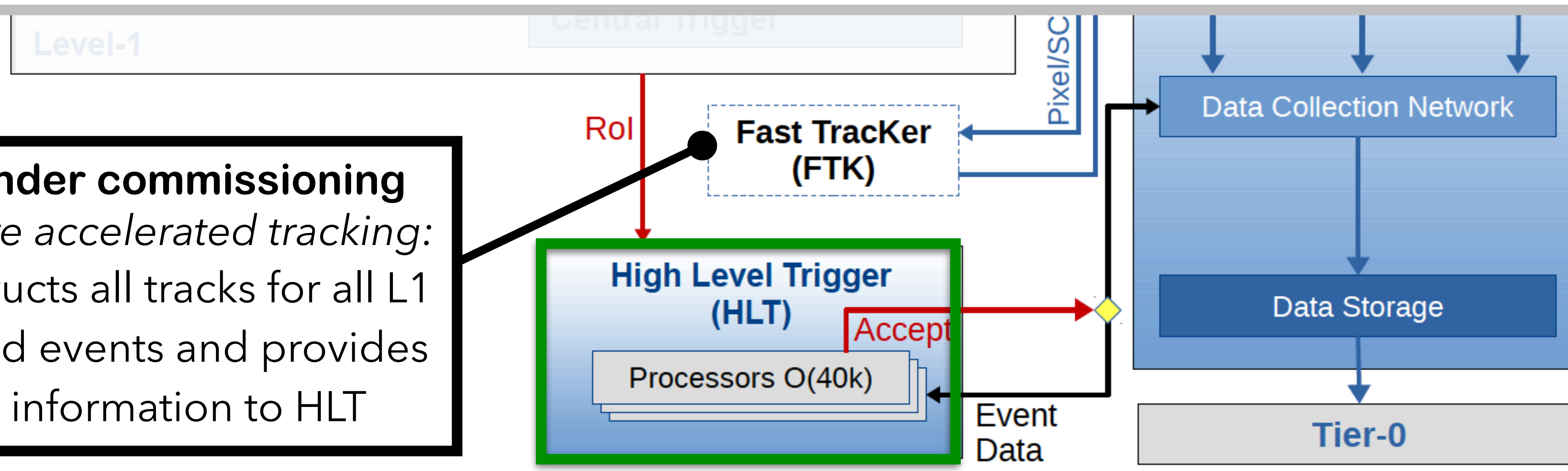
- 40 MHz → 100 kHz rate reduction with a fixed latency of 2.5 μs
- Fast custom-made electronics find regions of interest (RoIs) using calorimeter and muon data with coarse information

- Upgraded L1 Calo, L1 Muon and CTP (Central Trigger Processor)
  - **L1 Calo**: new Multi-Chip Module (nMCM) allows more flexible signal processing, more thresholds
  - **L1 Muon**: coincidences with inner detector, additional chambers in the feet of the barrel region and from Tile extended barrel region
  - **CTP**: more resources, support multi-partition running
- **L1Topo**
  - Allows for topological selections between L1 trigger objects (e.g. ΔR) to keep L1 thresholds low

ATLAS Trigger: **High Level Trigger (HLT)**

- Single farm (merged L2-EF) for better resource sharing and overall simplification
- Fast offline-like algorithms running mostly in L1 RoIs
- Average 350 ms latency
- Full upgrade of readout and data storage systems
- ~1 kHz of physics (full event building) output rate achieved
- Partial event building used for Trigger Level Analysis, detector monitoring and calibrations
- Once HLT is passed, the event is accepted and written into data streams
- Then offline software is run at Tier-0 to reconstruct the objects

FTK under commissioning
Hardware accelerated tracking: reconstructs all tracks for all L1 accepted events and provides track information to HLT



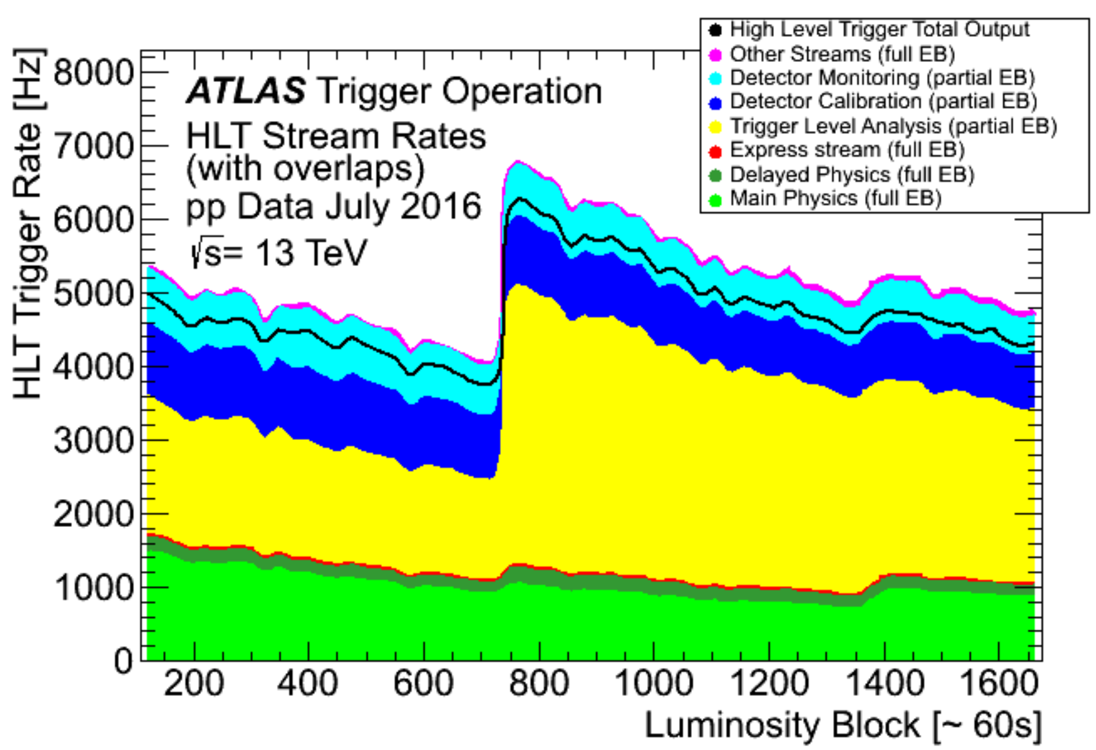
High Level Trigger

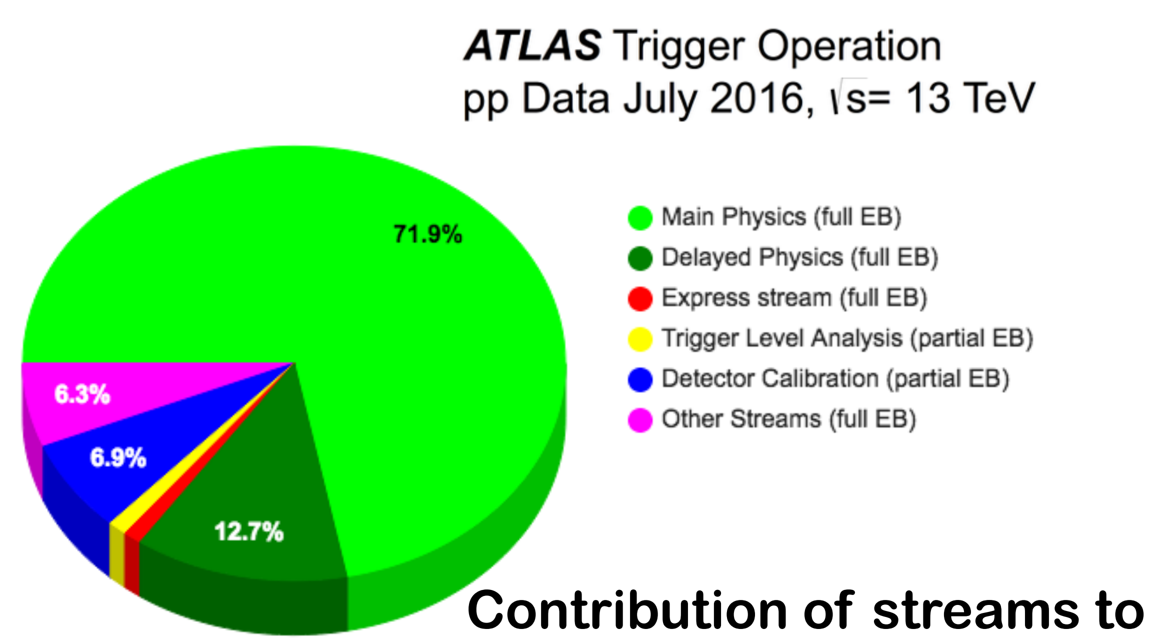
ATLAS Trigger Menu: **strategy**

- The **trigger menu** comprises the list of L1→HLT trigger chains with prescale factors
  - reflects the physics goals of the collaboration
    - high acceptance for BSM searches & Higgs/SM precision measurements
  - takes into account available data taking resources (L1, HLT and Tier-0)
- Trigger menu strategy based on:
  - **primary triggers**: for physics measurements, typically un-prescaled
  - **support triggers:** for efficiency and performance measurements, monitoring
  - **alternative triggers:** running alternative online reconstruction algorithms
  - **backup triggers:** tighter selections in case rate of primary trigger too high
  - **calibration triggers:** run at high rate but store only part of the event

Partial Event Building (EB)

Full EB





Contribution of streams to total output bandwidth

ATLAS Trigger Menu: **content**

[ATL-DAQ-PUB-2017-001]

For illustration:

Trigger	Typical offline selection	Trigger Selection Level-1 (GeV)	Trigger Selection HLT (GeV)	Level-1 Peak Rate (kHz) $L = 1.2\times10^{34}$ cm^{-2}s^{-1}	HLT Peak Rate (Hz) $L = 1.2\times10^{34}$ cm^{-2}s^{-1}
Single leptons	Single isolated μ, $p_T > 27$ GeV	20	26 (i)	13	133
	Single isolated tight e, $p_T > 27$ GeV	22 (i)	26 (i)	20	133
	Single μ, $p_T > 52$ GeV	20	50	13	48
	Single e, $p_T > 61$ GeV	22 (i)	60	20	13
	Single τ, $p_T > 170$ GeV	60	160	5	15
Two leptons	Two μ's, each $p_T > 15$ GeV	2×10	2×14	1.5	21
	Two μ's, $p_T > 23, 9$ GeV	20	22, 8	13	30
	Two loose e's, each $p_T > 18$ GeV	2×15	2×17	8	7
	One e & one μ, $p_T > 8, 25$ GeV	20 (μ)	7, 24	13	2
	One loose e & one μ, $p_T > 18, 15$ GeV	15, 10	17, 14	1.5	2.6
	Two τ's, $p_T > 40, 30$ GeV	20 (i), 12 (i) (+jets)	35, 25	6	35
	One τ & one isolated μ, $p_T > 30, 15$ GeV	12 (i), 10 (+jets)	25, 14 (i)	1.5	7
	One τ & one isolated e, $p_T > 30, 18$ GeV	12 (i), 15 (i) (+jets)	25, 17 (i)	3	9
Three leptons	Three loose e's, $p_T > 18, 11, 11$ GeV	$15, 2\times8$	$17, 2\times10$	15	< 0.1
	Three μ's, each $p_T > 7$ GeV	3×6	3×6	0.1	3
	Three μ's, $p_T > 21, 2\times5$ GeV	20	$20, 2\times4$	13	4
	Two μ's & one loose e, $p_T > 2\times11, 13$ GeV	2×10 (μ's)	2×10, 12	1.5	0.2
	Two loose e's & one μ, $p_T > 2\times13, 11$ GeV	2×8, 10	2×12, 10	1.1	0.1
One photon	One loose γ, $p_T > 145$ GeV	22 (i)	140	20	30
Two photons	Two loose γ's, $p_T > 40, 30$ GeV	2×15	35, 25	8	40
	Two tight γ's, $p_T > 27, 27$ GeV	2×15	2×22	8	16
Single jet	Jet ($R = 0.4$), $p_T > 420$ GeV	100	380	3	38
	Jet ($R = 1.0$), $p_T > 460$ GeV	100	420	3	35
E_T^{miss}	$E_T^{miss} > 200$ GeV	50	110	6	230
Multi-jets	Four jets, each $p_T > 110$ GeV	3×50	4×100	0.4	18
	Five jets, each $p_T > 80$ GeV	4×15	5×70	3.5	14
	Six jets, each $p_T > 70$ GeV	4×15	6×60	3.5	5
	Six jets, each $p_T > 55$ GeV, $\|\eta\| < 2.4$	4×15	6×45	3.5	18
b–jets	One b ($\epsilon = 60\%$), $p_T > 235$ GeV	100	225	3	24
	Two b's ($\epsilon = 60\%$), $p_T > 160, 60$ GeV	100	150, 50	3	20
	One b ($\epsilon = 70\%$) & three jets, each $p_T > 85$ GeV	4×15	4×75	3.5	19
	Two b ($\epsilon = 60\%$) & one jet, $p_T > 65, 65, 110$ GeV	2×20, 75	2×55, 100	2.7	25
	Two b ($\epsilon = 60\%$) & two jets, each $p_T > 45$ GeV	4×15	4×35	3.5	56
b–physics	Two μ's, $p_T > 6, 6$ GeV plus dedicated b-physics selections	6, 6	6, 6	4.7	20
Total	**(including more triggers than listed here)**			85	1500

HLT rate expensive trigger

- Menu designed for different peak luminosities
- In 2016 reached 1.4×10^{34} cm^{-2}s^{-1} luminosity
  - above LHC design luminosity!
- In 2017, baseline menu designed for 2×10^{34} cm^{-2}s^{-1} luminosity
- Primary triggers kept stable within a menu
- Flexibility to adjust to changing conditions during LHC ramp-up

Over 3000 trigger chains running online and covering a large spectra of physics objects and processes!

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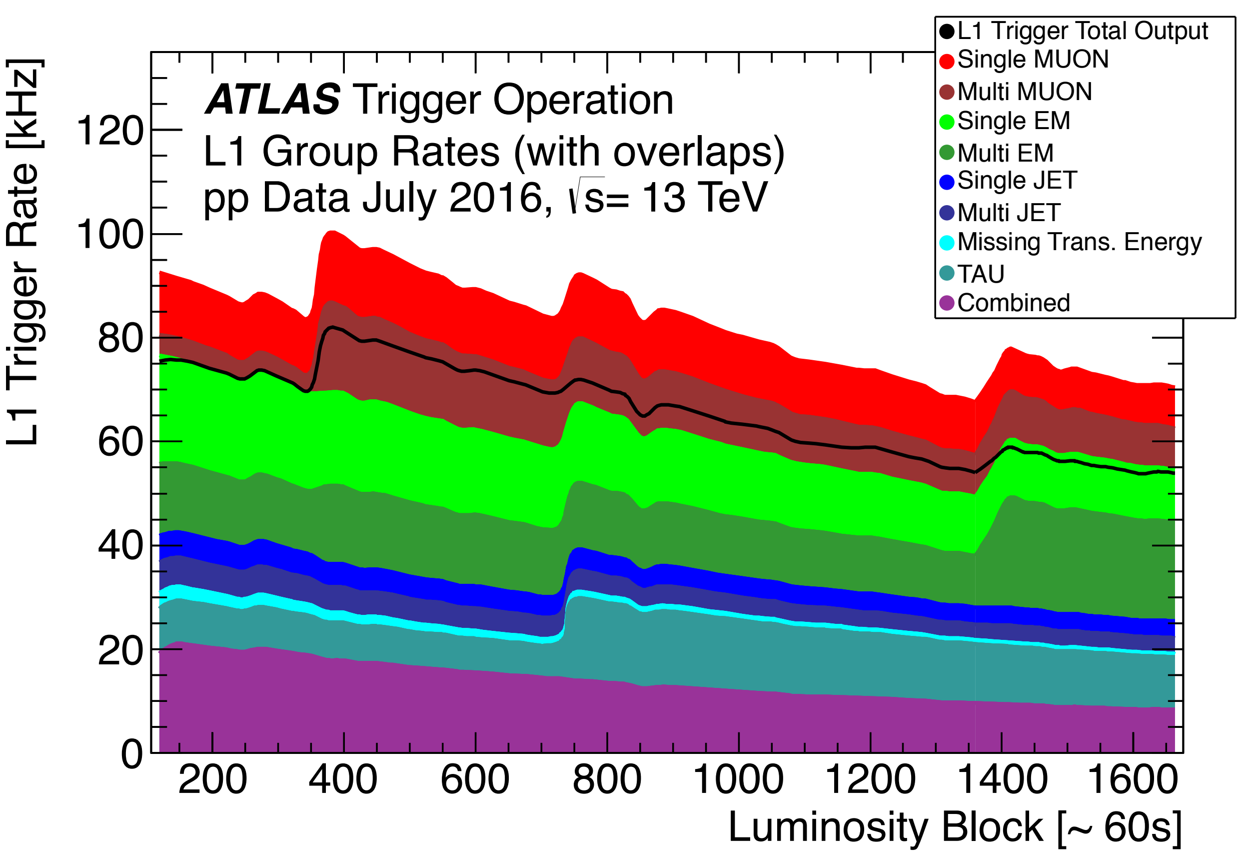
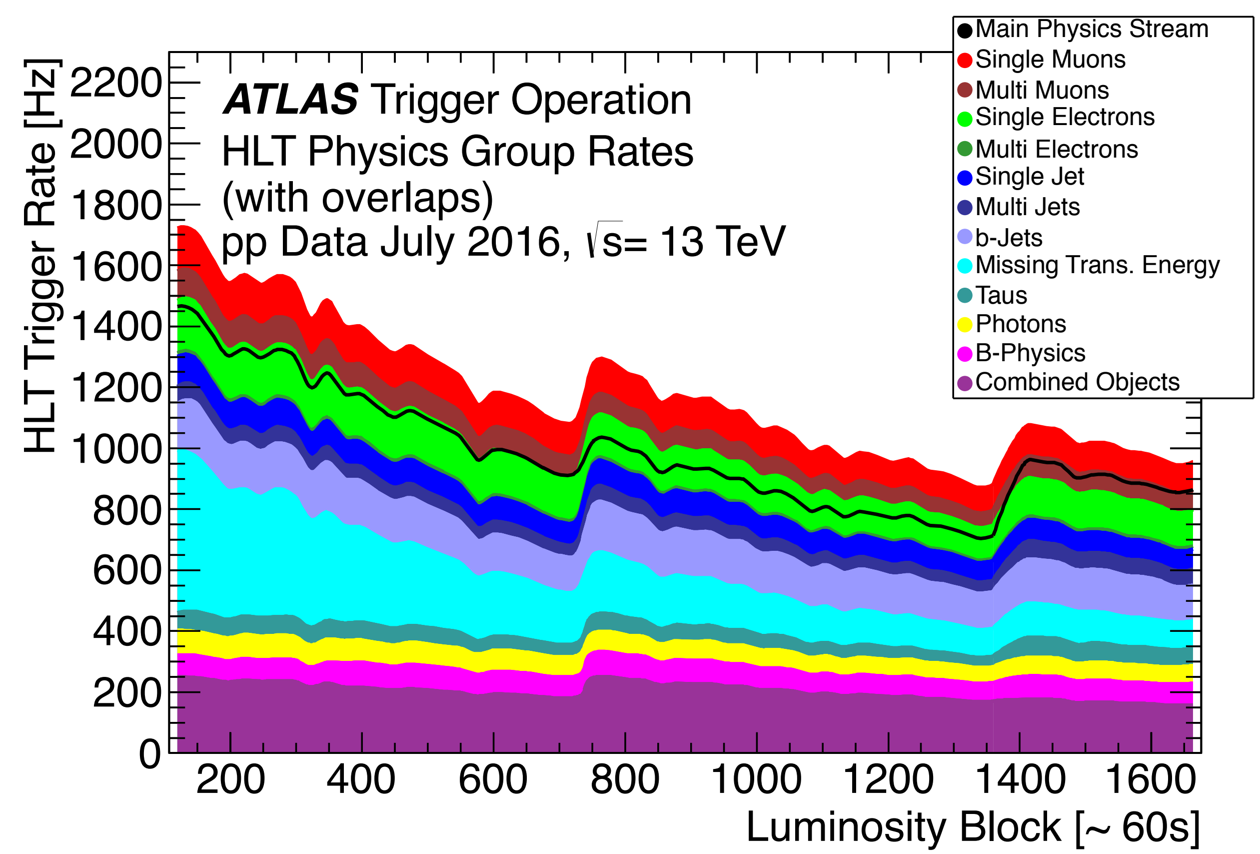
ATLAS Trigger Menu: **online**

- Menu deployed with different prescale sets depending on luminosity
  - as luminosity decreases throughout the fill, the bandwidth usage is optimised by increasing the rate of supporting triggers
- Event size ~ 1.6 MB (uncompressed) for <μ> = 24.9 in 2016

Physics trigger group rates in a fill taken in July 2016 with a peak luminosity of $L = 1.02 \times 10^{34} cm^{-2}s^{-1}$ and <μ>= 24.2.



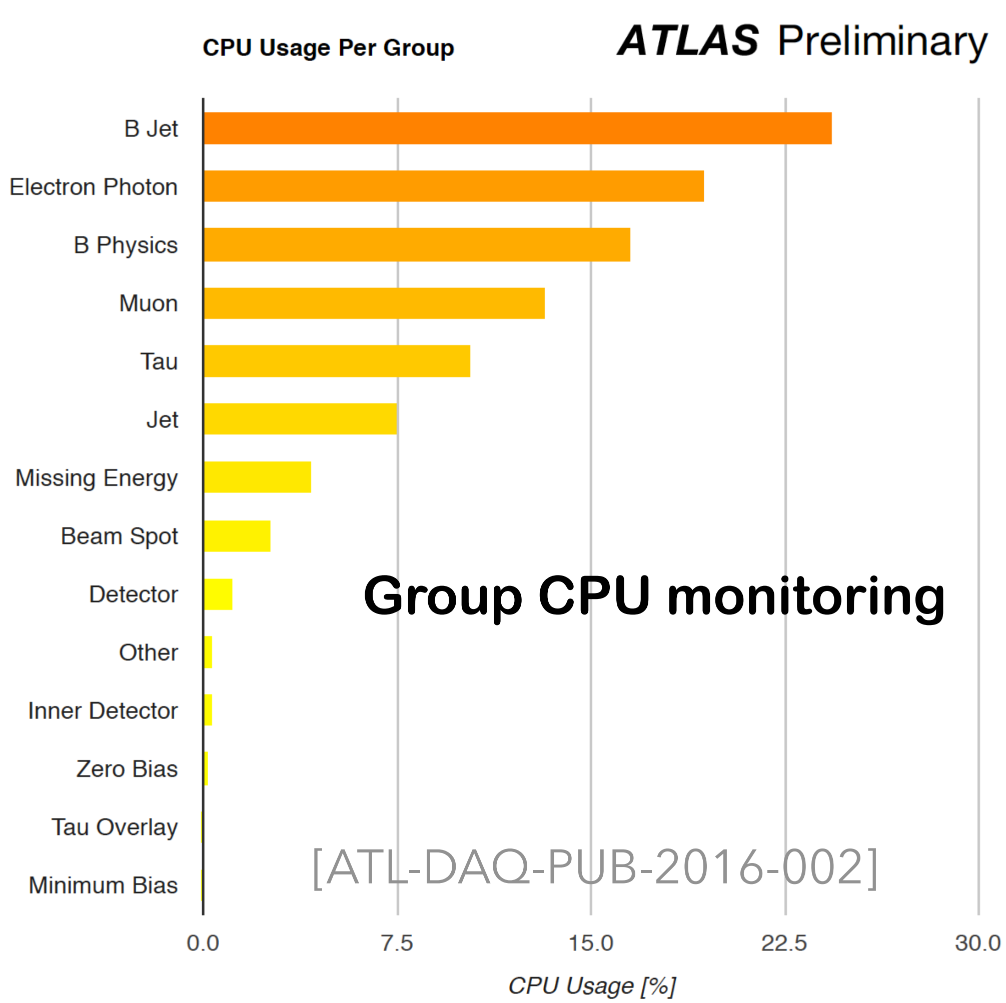


ATLAS Trigger **Monitoring Performance Online**

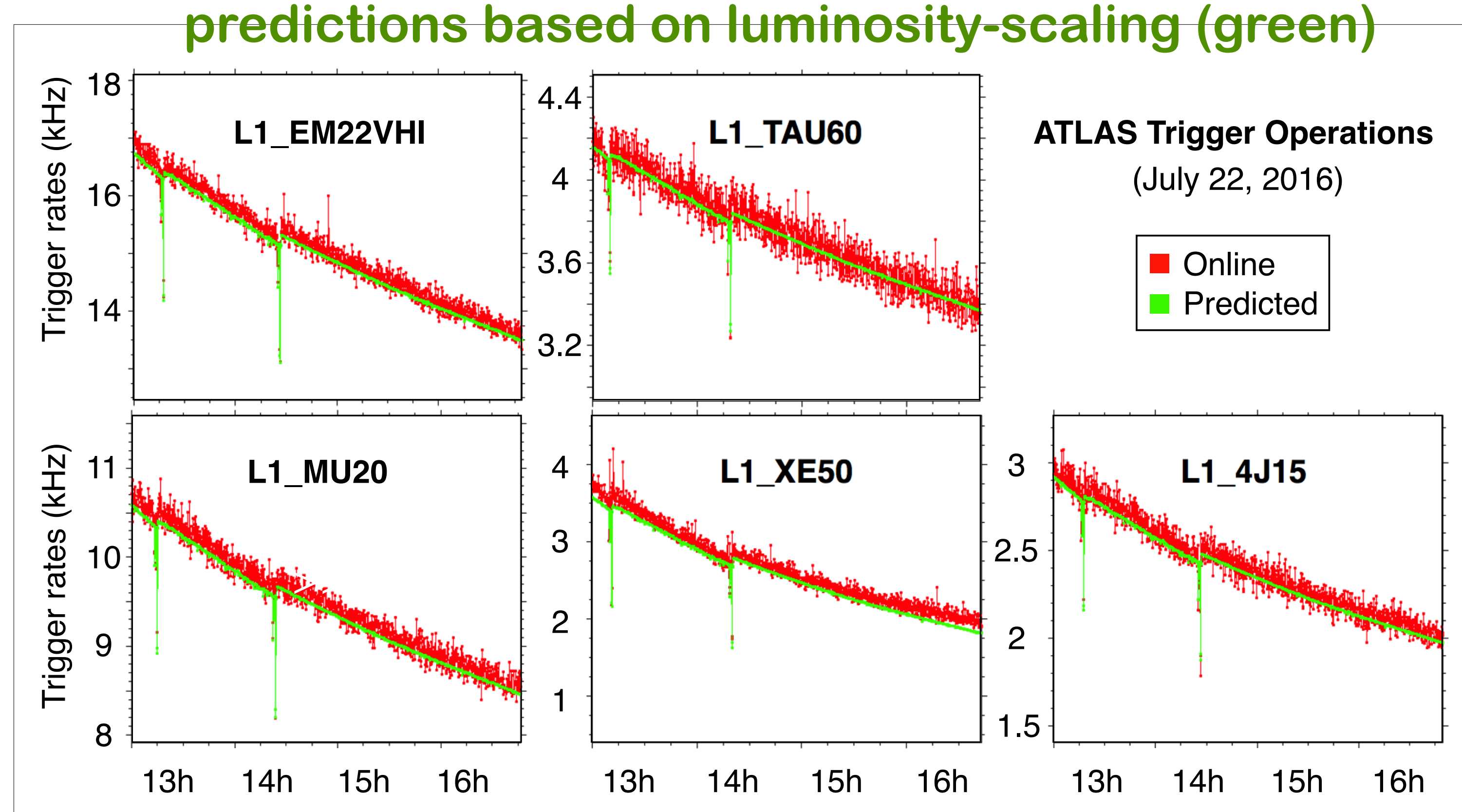
- Distributions of HLT-level quantities monitored online
- Automatic data quality (DQ) checks applied based on standardised histogram analyses and comparisons to reference histograms
- Track performance of the HLT via red (alarm), yellow (warning) and green (OK) DQ
- Similar procedure followed offline to declare data good for physics
- Menu-aware monitoring scheme allows to update monitoring configuration out-of-sync with software releases with very small latency (~hr)

ATLAS Trigger **Rates & CPU usage**

- Trigger rate predictions and HLT farm performance studies essential for all menu developments and validation of HLT algorithms
  - Special dataset (EnhancedBias) collected every time data-taking condition changes to provide rate predictions
    - For the EB dataset, events are selected by the L1 trigger system that emphasises **higher energies and object multiplicities**, and the selection bias is corrected for with event weights
- Significant improvement in timing for tracking ID trigger



Online rate monitoring:
Level-1 trigger rates online (red) **compared with predictions based on luminosity-scaling (green)**



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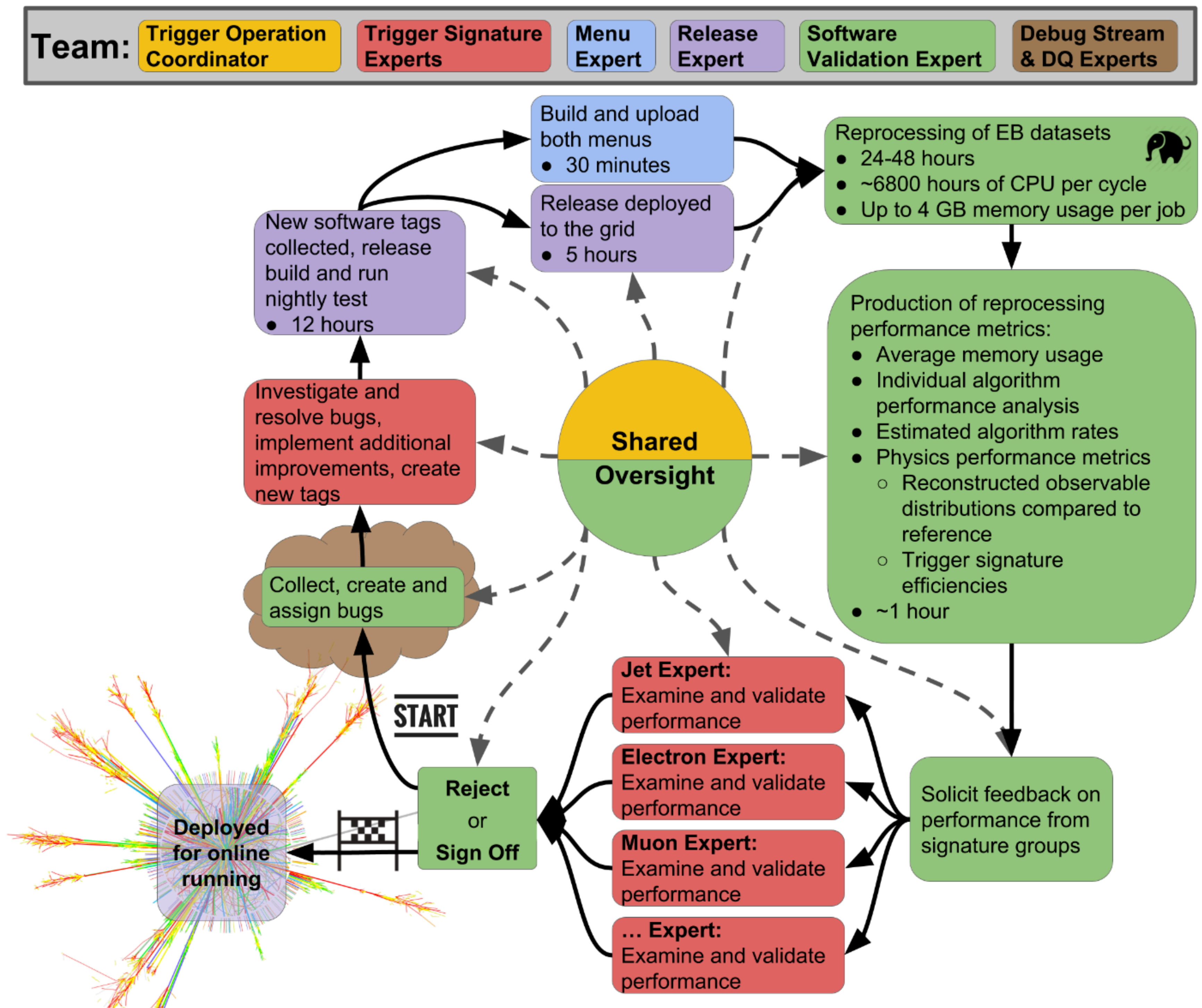
ATLAS Trigger **software validation**

- Full trigger menu and HLT software run **offline** over the EnhancedBias dataset for algorithm validation
- **Weekly** HLT release validation involving experts in trigger menu, HLT release, software validation, and trigger signature experts
- **High memory** consumption jobs run in the Grid
- **New in 2017**:
  - Improved CPU usage of trigger chains
  - Automation of release build and distributed every night w/o expert action



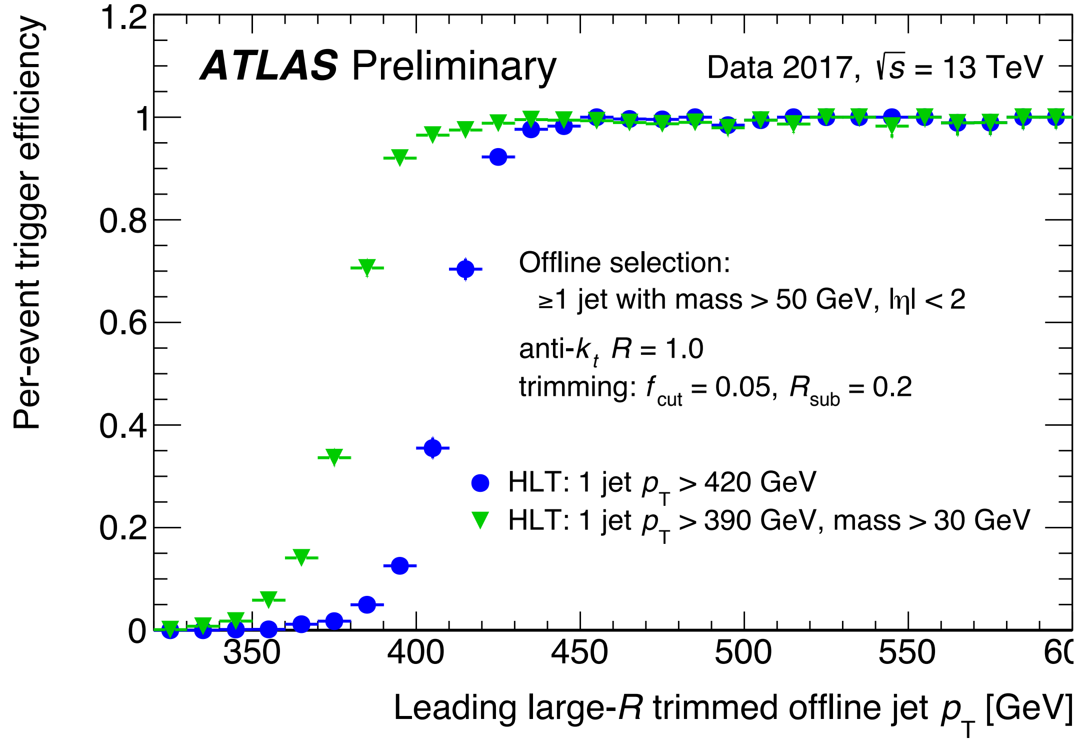
[ATL-DAQ-PROC-2016-040]

ATLAS Trigger **signature performance (I)**

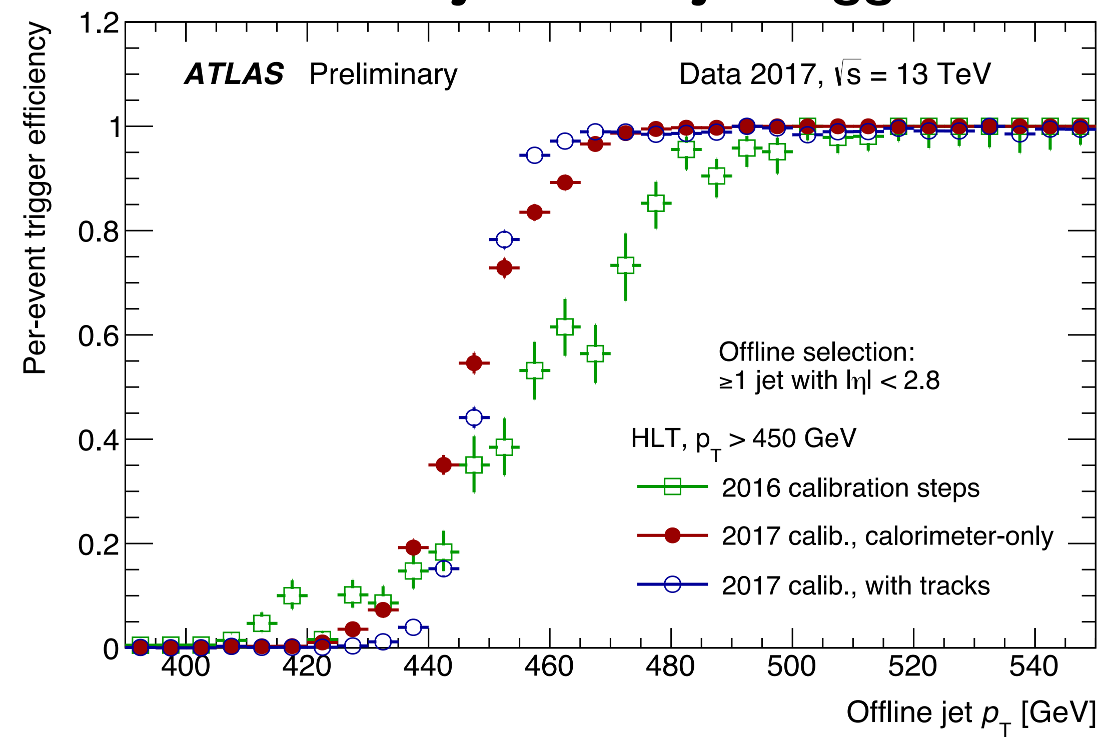
- Several improvements in L1 and HLT Trigger Systems reflected in the performance of the trigger objects, some examples new in 2017:

Trimming and mass-cut for large-R jet trigger

- Trimming: procedure to remove soft contamination (from pileup) in large-radius jets

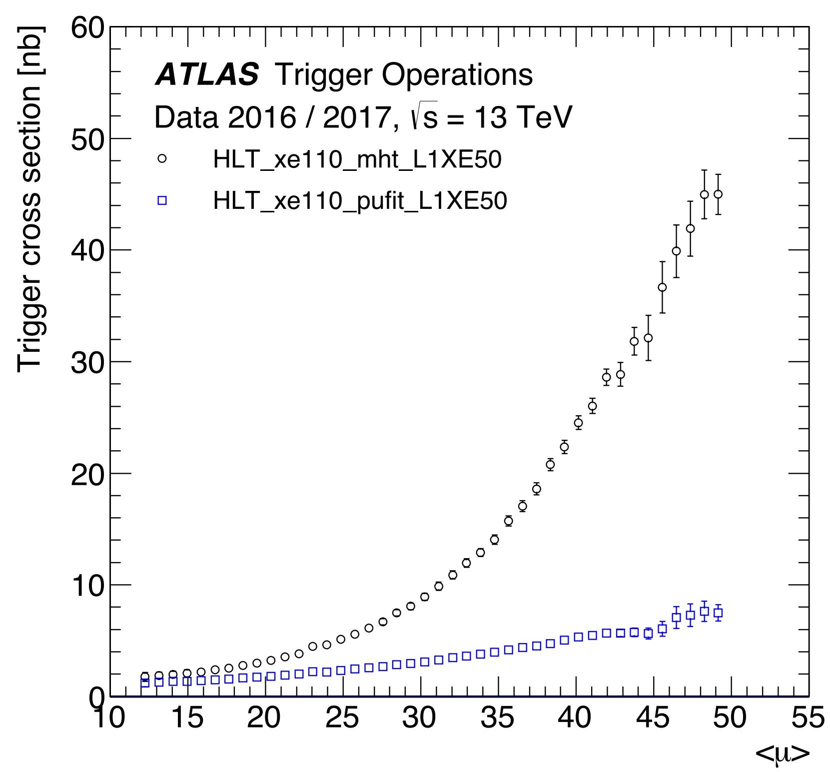


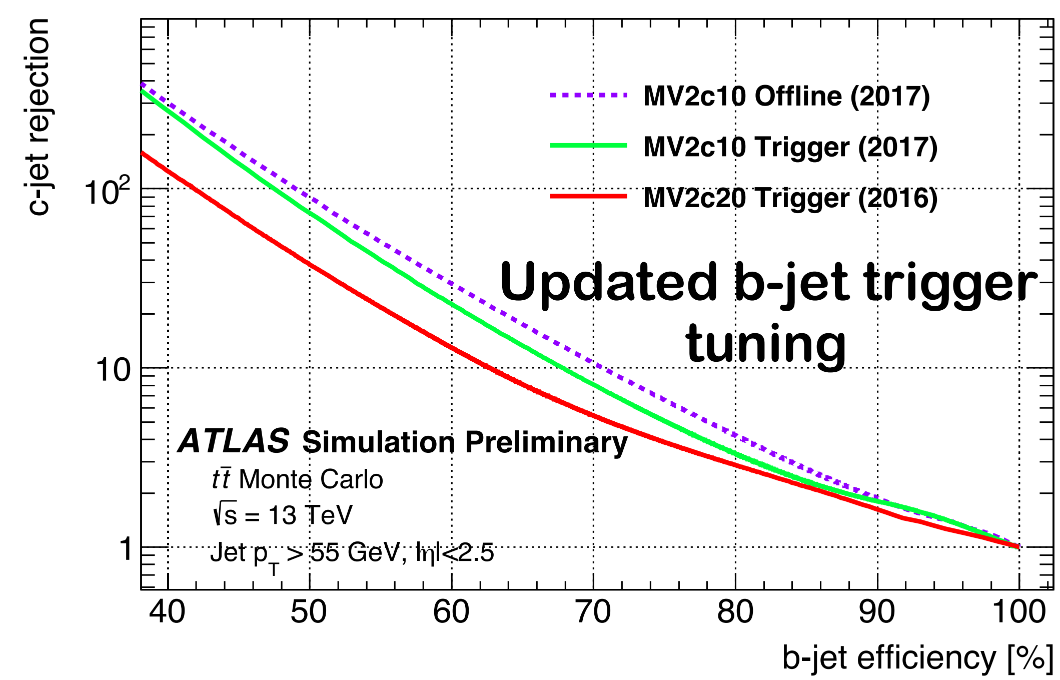
Global Sequential Calibration (GSC) calibration for jet and b-jet triggers



Pile-up mitigation is main challenge for E_T^{miss} triggers

- MHT algorithm based on p_T sum of HLT jets default in 2016
- pufit: new baseline in 2017 (pileup estimated event-by-event and subtracted)



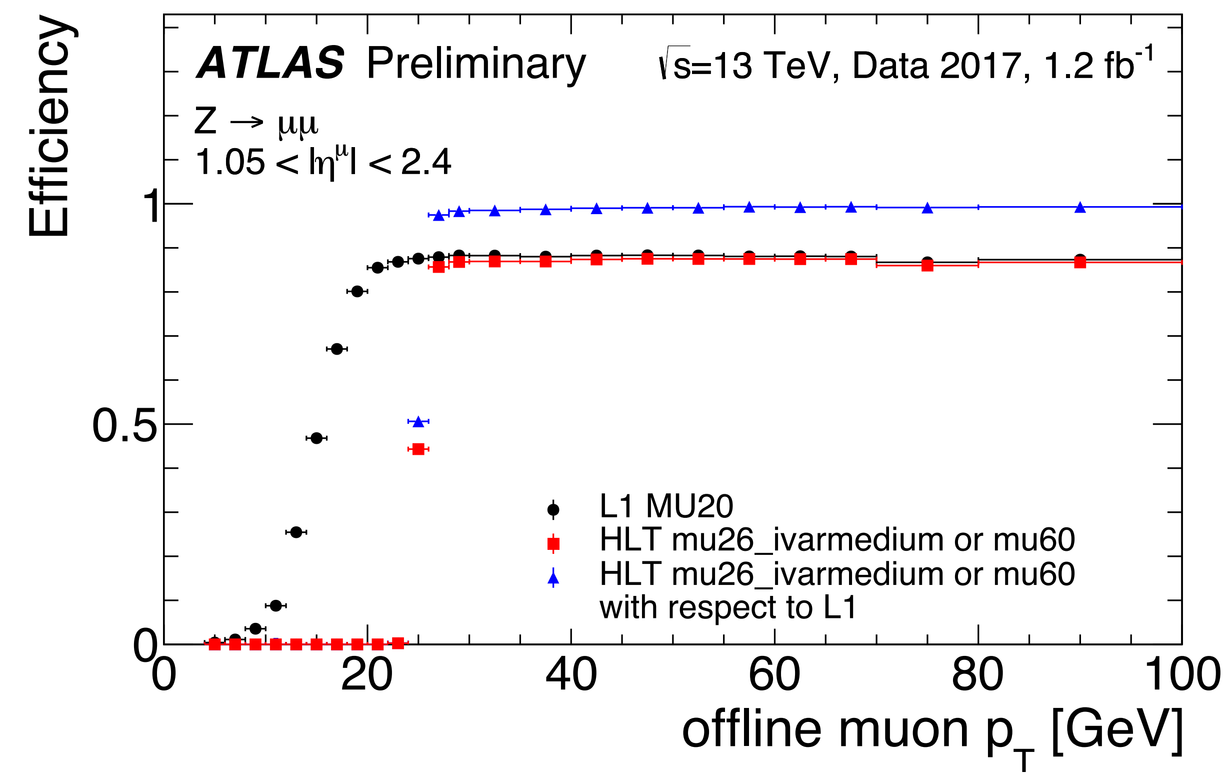


[More details: 4 posters about trigger performance]

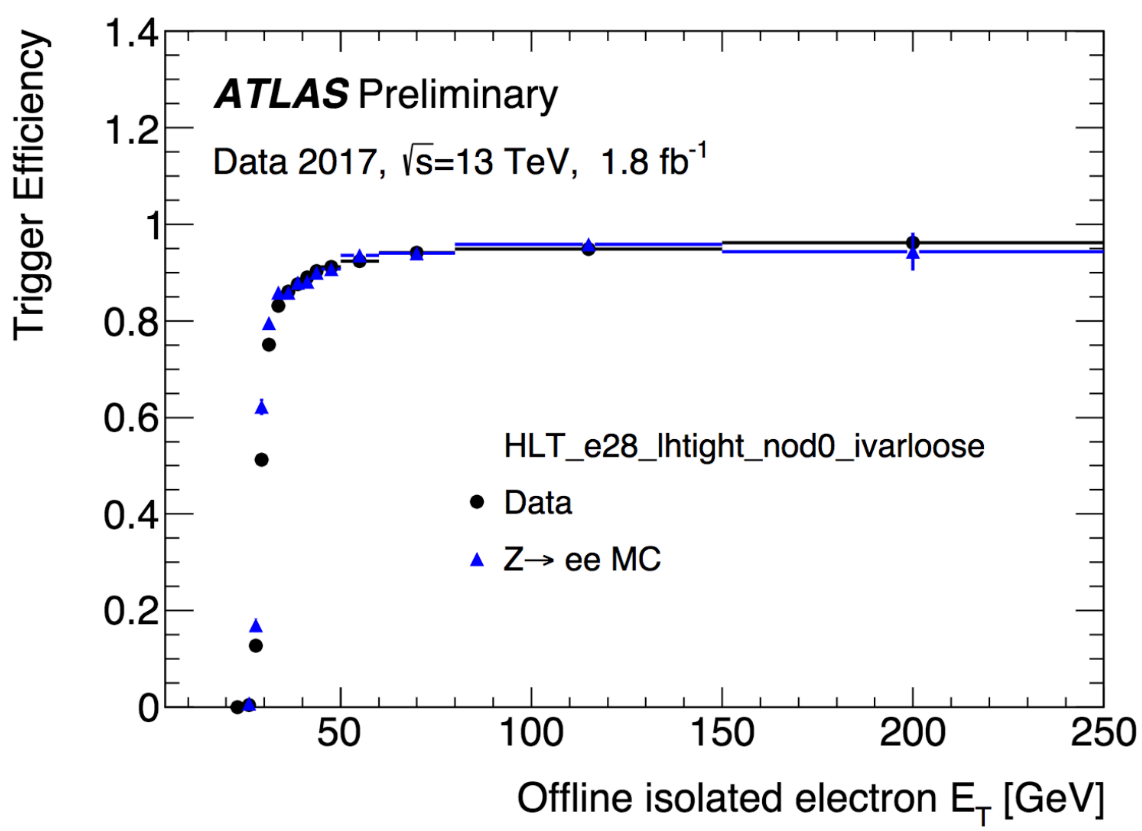
ATLAS Trigger **signature performance (II)**

- Electron, photon, and muon triggers performing well in 2017!
- L1Topo is default in 2017 trigger

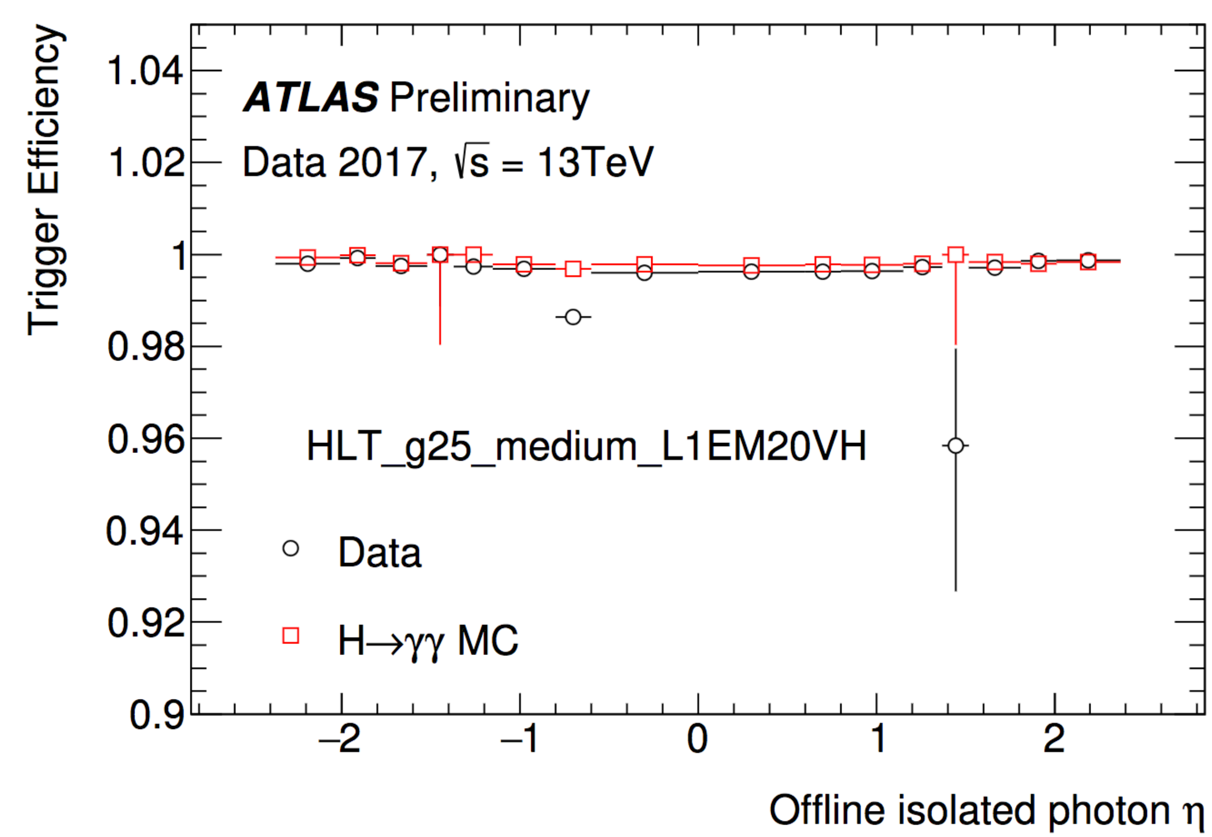
Muon triggers



Likelihood-based identification for electrons



Photon triggers



Conclusions

* Hardware and software modified and improved during the shutdown to cope with challenges during LHC Run 2

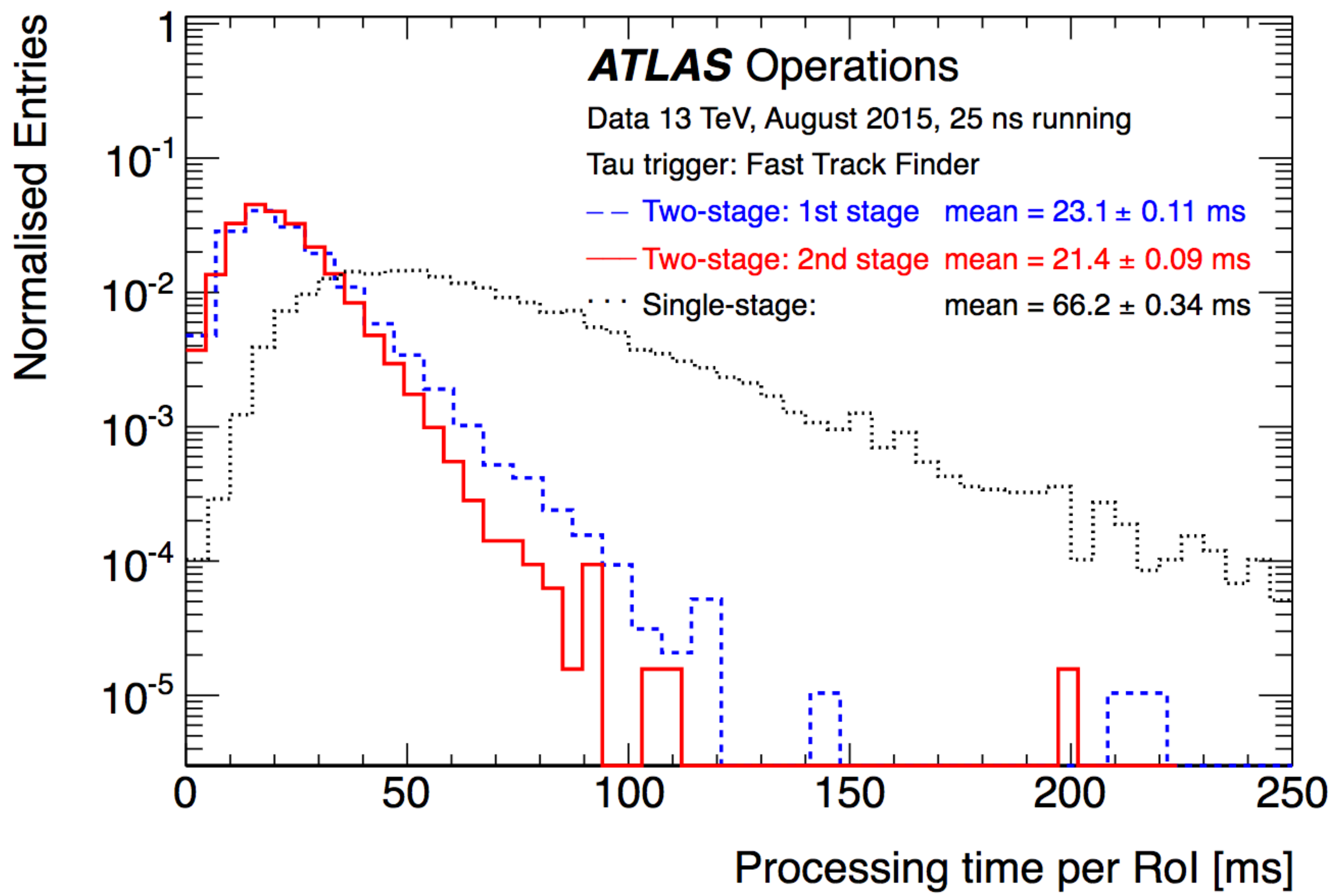
* Trigger successfully commissioned in 2015

* Smooth trigger operation in 2016 despite the very challenging LHC conditions

* Impressive improvements were made in preparation for the expected highest ever luminosities and pileup in the 2017/18 LHC run

* Further improvements ahead:
    - Integration of FTK

Supporting material



The Run 2 HLT Inner Detector tracking trigger processing time for the Fast Track Finder stage for the tau signature. Shown are the times for the *single-stage*, and the *two-stage* tracking. In the *single-stage* tracking, the tracking is performed in a single, large Region of Interest (RoI) with $\Delta\eta = 0.4$, $\Delta\varphi=0.4$ and $\Delta z = 225$ mm with respect to the RoI direction and position z=0 along the beamline. In the *two-stage* tracking, the tracking is first performed in an RoI with $\Delta\eta = 0.1$, $\Delta\varphi=0.1$ and $\Delta z = 225$ mm with respect to the RoI direction, to identify the core tracks, and then a second tracking stage is performed in an updated RoI centred on the highest p_T track with $\Delta\eta = 0.4$, $\Delta\varphi=0.4$ and $\Delta z = 10$ mm with respect to that track. The total mean time for the two-stage tracking is 44.5 ms corresponding to a fractional saving in processing time for the fast tracking with respect to the single-stage tracking of greater than 30%. The data were taken during collisions in August 2015 with the LHC colliding with a 25 ns bunch spacing. The mean number of interactions per bunch crossing was $\langle\mu\rangle \sim 14$.