The ATLAS Trigger in 2017 and 2018
developments and performance

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Introduction

- Trigger system is responsible for real-time selection of subset of proton-proton collisions to be recorded and analysed offline
  - design driven by physics priorities and resource/system limitations (eg *processing time, processing units and storage rate*)
- In 2017/2018, LHC delivered collisions at both *record high instantaneous luminosity* (x2 design value) and at *record high number of simultaneous collisions per bunch crossing*, "pileup" or μ (x2.6 design value)
- This talk summarises how the ATLAS trigger system adapted successfully to this challenging conditions
  - taking advantage of new hardware and
  - optimising trigger menu and reducing processing costs

Trigger System

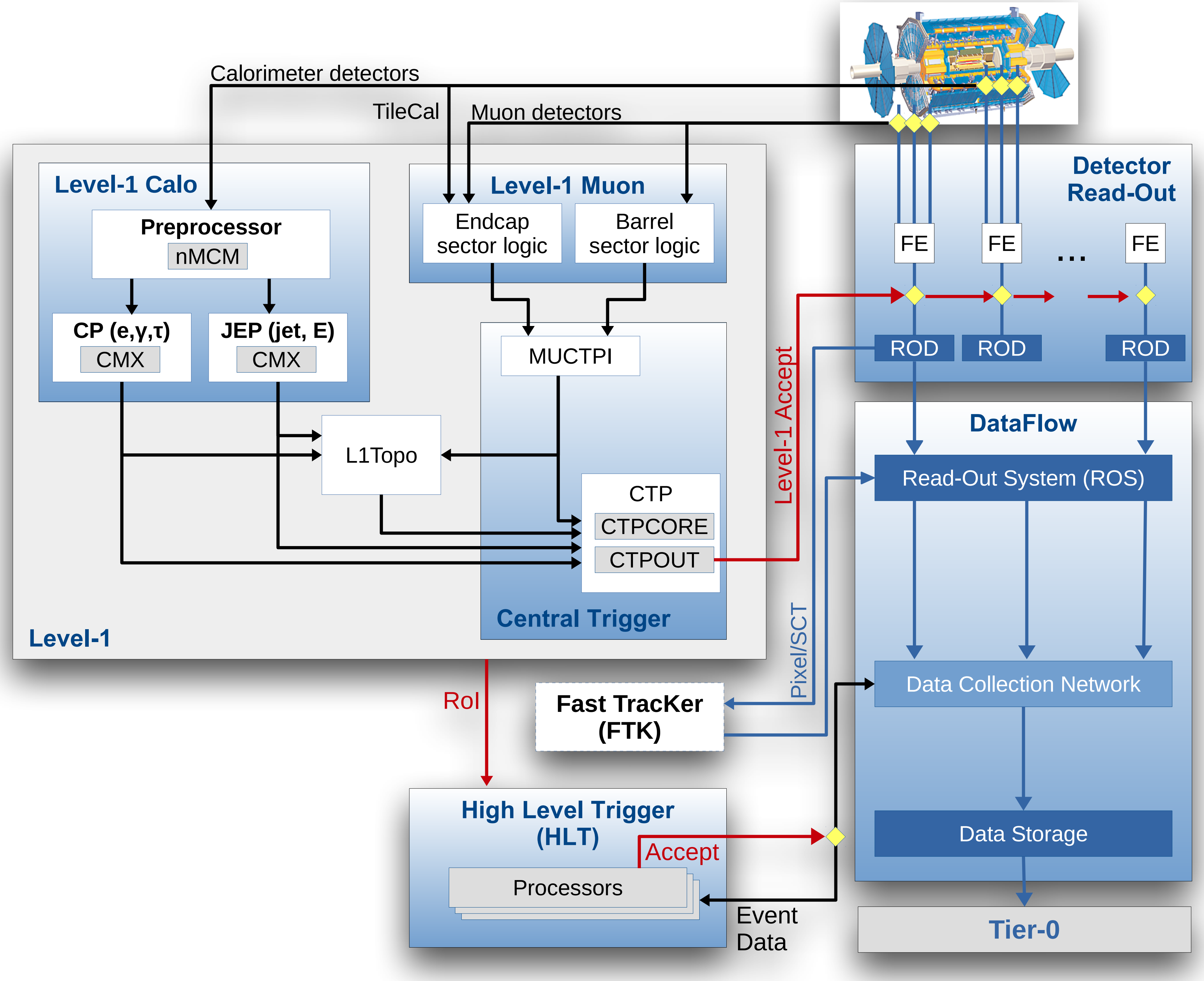
40 MHz
LHC bunch crossing frequency

Level-1 Trigger (L1)
hardware-based with 2.5 μs fixed processing time, finds Regions of Interest (RoI) using muon detectors and calorimeters with low granularity

100 kHz

High-Level Trigger (HLT)
software-based (~40-50k processing units), reconstruct features in the event using full-granularity detector data in RoI or in full event with offline-like algorithms and selections (average latency ~400 ms at 2.0×10^{34} lumi and mu~55)

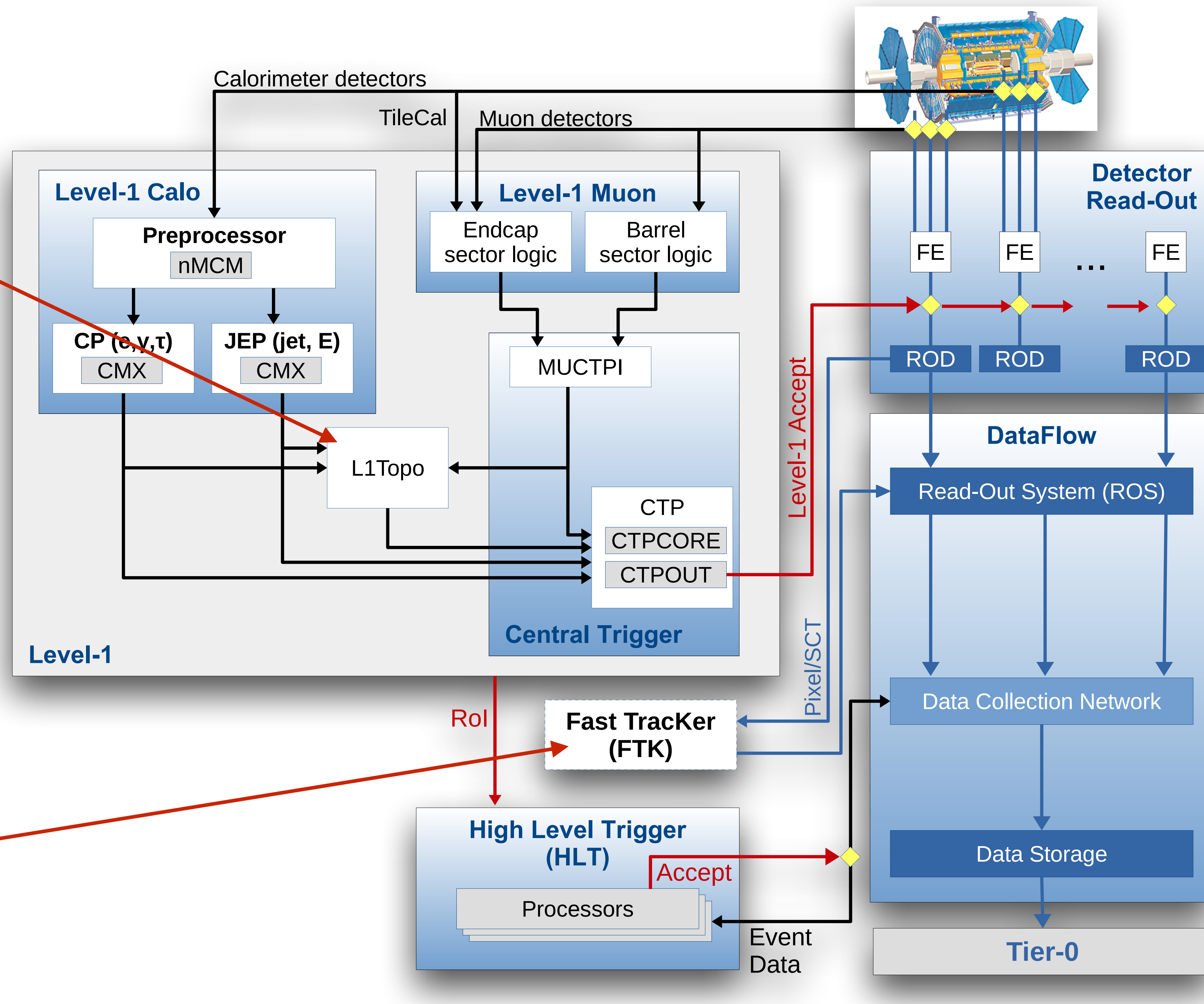
~1.5 kHz average
data recording rate
(~1.2MB/evt average over fill)



Trigger System

New hardware installed in Run2:

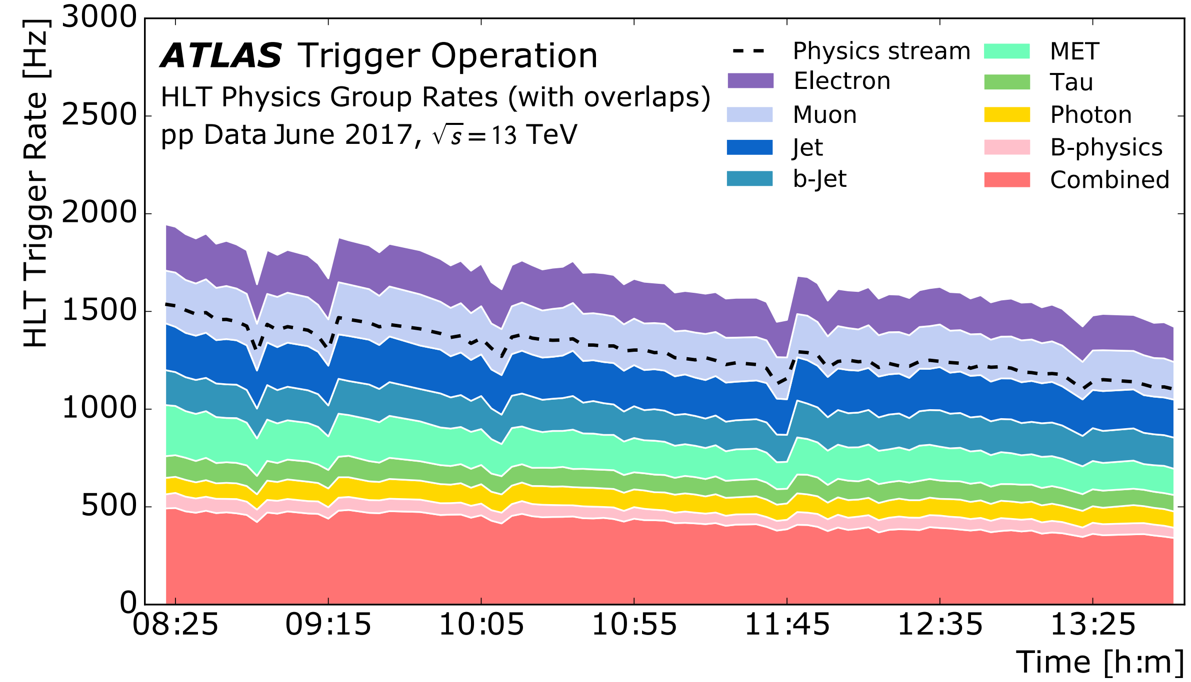
L1Topo
event-topology-based
selections based on L1Calo and L1 Muon inputs.
Used to collect physics data since 2017
(see next)



FTK
Currently under commissioning (see talk by T. R. Holmes)

Trigger Menu

- Set of algorithms and selections ("chains") running at the L1 and HLT
- O(1500) chains targeting different signatures and topological phase spaces
- Designed such that resources (rate, memory/timing and output) are allocated based on physics priorities
- Despite higher peak luminosity in 2017 than in 2016 (1.7 vs 1.4 $\times 10^{34}$ cm^{-2}s^{-1}), minimum pt thresholds for *single lepton chains kept unchanged*



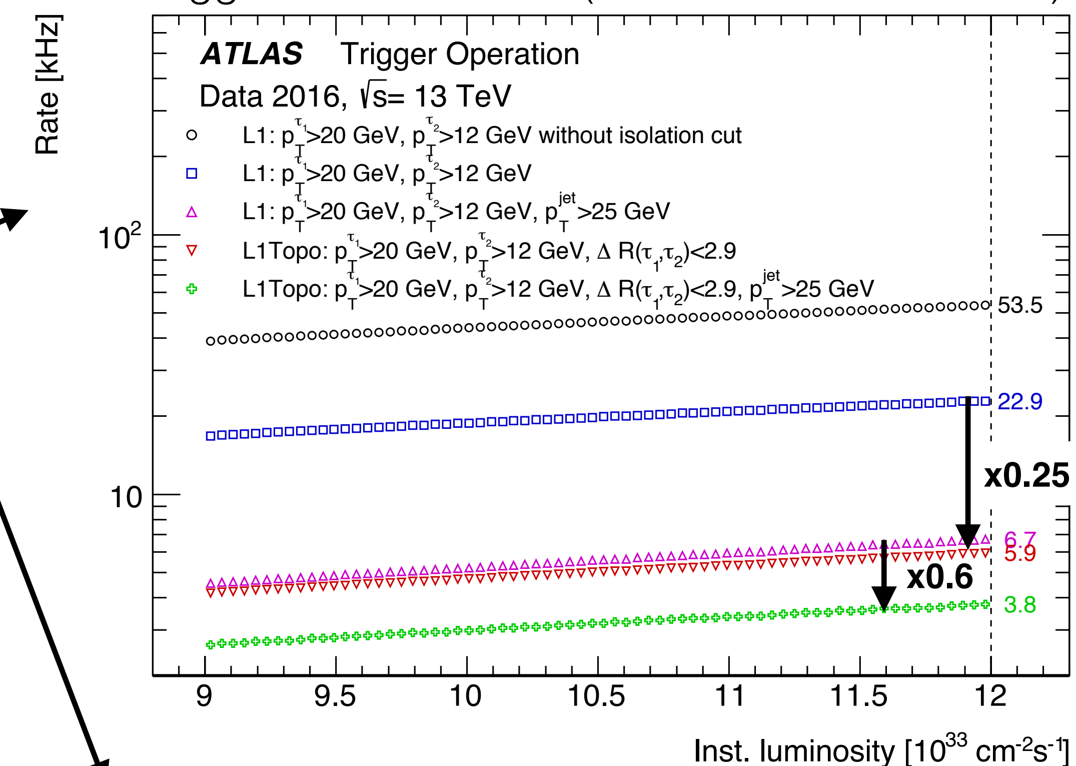
Selection of 2017 menu (ATL-DAQ-PUB-2018-002), full table in backup

Trigger	Typical offline selection	Trigger Selection Level-1 (GeV)	Trigger Selection HLT (GeV)	Level-1 Peak Rate (kHz) $L = 1.7\times10^{34}$ cm^{-2}s^{-1}	HLT Peak Rate (Hz) $L = 1.7\times10^{34}$ cm^{-2}s^{-1}
Single leptons	Single isolated μ, $p_T > 27$ GeV	20	26 (i)	15	180
	Single isolated tight e, $p_T > 27$ GeV	22 (i)	26 (i)	28	180
	Single μ, $p_T > 52$ GeV	20	50	15	61
	Single e, $p_T > 61$ GeV	22 (i)	60	28	18
	Single τ, $p_T > 170$ GeV	100	160	1.2	47
Two leptons	Two μ, each $p_T > 15$ GeV	2×10	2×14	1.8	26
	Two μ, $p_T > 23, 9$ GeV	20	22, 8	15	42
	Two very loose e, each $p_T > 18$ GeV	2×15 (i)	2×17	1.7	12
	One e & one μ, $p_T > 8, 25$ GeV	20 (μ)	7, 24	15	5
	One e & one μ, $p_T > 18, 15$ GeV	15, 10	17, 14	2.0	4
	One e & one μ, $p_T > 27, 9$ GeV	22 (e, i)	26, 8	28	3
	Two τ, $p_T > 40, 30$ GeV	20 (i), 12 (i) (+jets, topo)	35, 25	5	61
	One τ & one isolated μ, $p_T > 30, 15$ GeV	12 (i), 10 (+jets)	25, 14 (i)	2.1	10
	One τ & one isolated e, $p_T > 30, 18$ GeV	12 (i), 15 (i) (+jets)	25, 17 (i)	4	15
One photon	One loose γ, $p_T > 145$ GeV	22 (i)	140	28	43
Two photons	Two loose γ, $p_T > 55, 55$ GeV	2×20	50, 50	2.6	6
	Two medium γ, $p_T > 40, 30$ GeV	2×20	35, 25	2.6	17
	Two tight γ, $p_T > 25, 25$ GeV	2×15 (i)	2×20 (i)	1.7	14
Single jet	Jet ($R = 0.4$), $p_T > 435$ GeV	100	420	3.3	33
	Jet ($R = 1.0$), $p_T > 480$ GeV	100	460	3.3	24
	Jet ($R = 1.0$), $p_T > 450$ GeV, $m_{jet} > 50$ GeV	100	420, $m_{jet} > 40$	3.3	29
E_T^{miss}	$E_T^{miss} > 200$ GeV	50	110	5	110

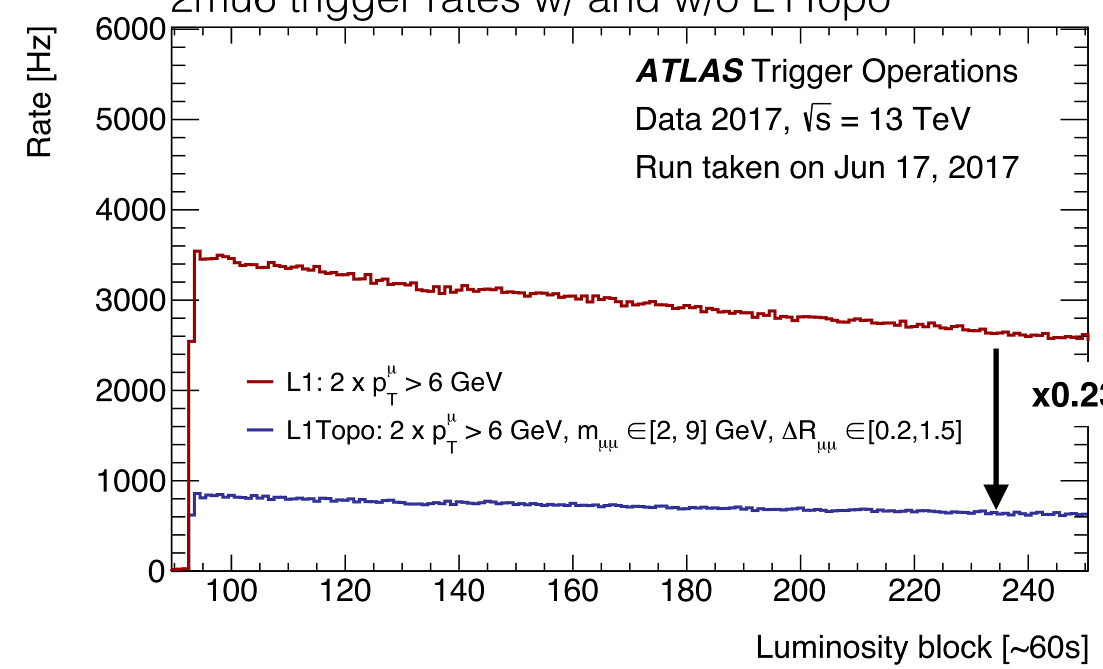
2017 Improvements at L1

- L1Topo:
  - event-topology-based selections (eg angular and invariant mass cuts) in real time using L1Calo and L1Muon inputs
  - critical for rate-demanding signals, like H→ττ and B physics measurements
  - allows to trigger on difficult signatures, eg VBF H→bb, long-lived particles, and Higgsino to soft leptons
- At L1Muon:
  - single muon trigger rate significantly reduced at no efficiency loss thanks to improved chamber-by-chamber coincidence windows and new coincidence between Tile calorimeter and TCG muon chambers
- At L1Calo,
  - filter coefficients and noise cuts optimised for high pileup conditions and different LHC filling schemes
  - significantly reduced rates and pileup dependence at L1 for jet and missing energy chains
  - reduced calorimeter occupancy and consequently improved reconstruction time at HLT

di-tau trigger rates for H→ττ (ATLAS-CONF-2017-061)



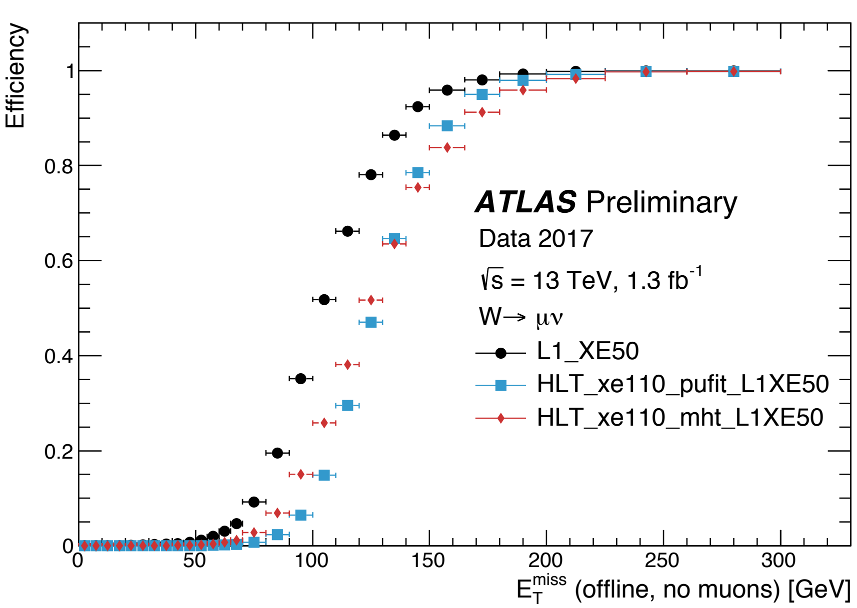
2mu6 trigger rates w/ and w/o L1Topo

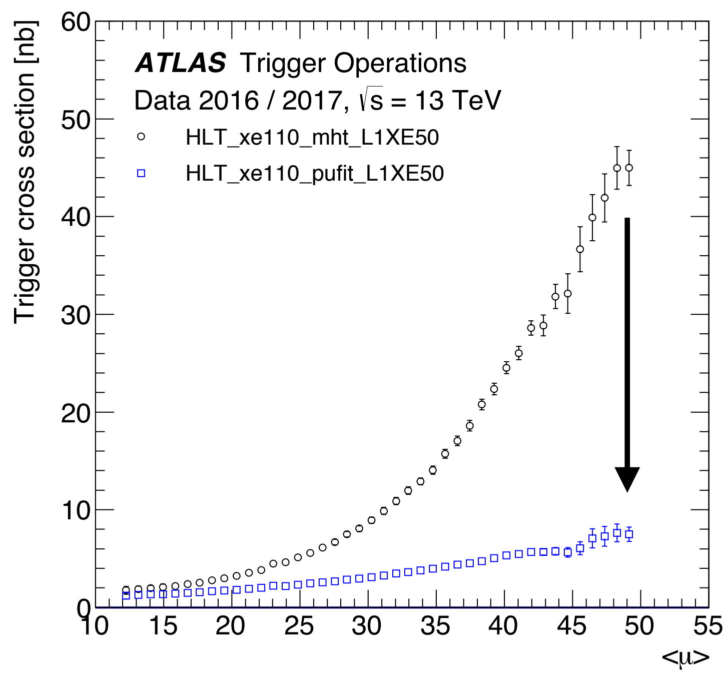


2017 Improvements at HLT

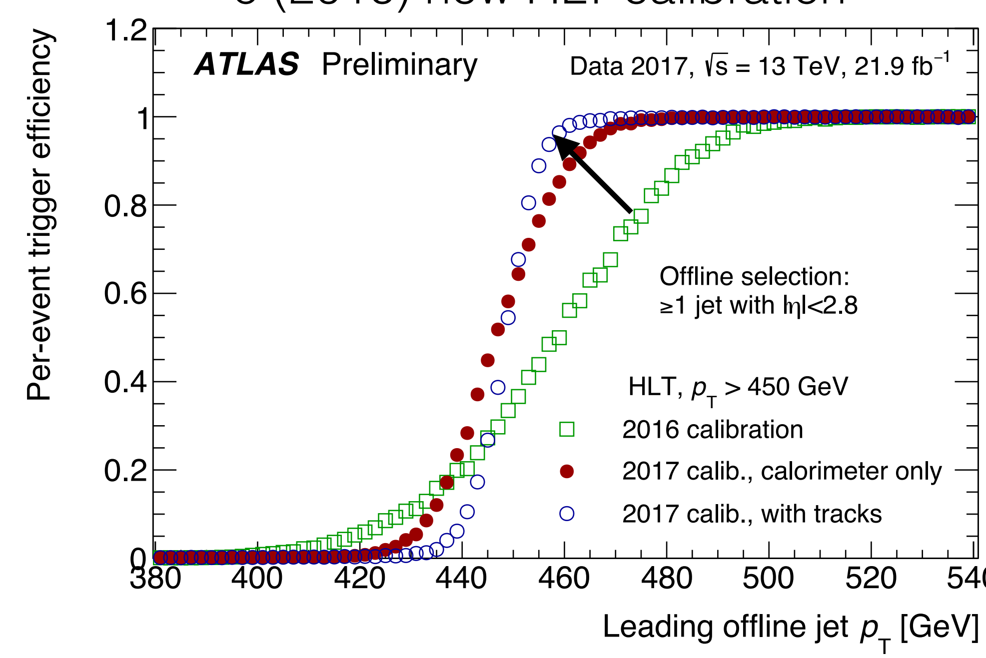
- Missing energy triggers:
  - new algorithm ("pufit") with improved pileup robustness
  - O(10) rate reduction at μ=50 with no efficiency loss allowed to keep 2017 threshold unchanged from 2016
- Offline-like calibration in HLT jet triggers:
  - based on both calorimeter-based and track-based inputs. Tracks cached from *b*-tagging algorithms used in *b*-jet triggers, so no additional CPU cost
  - reduces differences wrt offline jet reconstruction, i.e. higher efficiency and lower rate at same trigger pt threshold

missing energy trigger efficiencies and rates w/ (pufit) and w/o (mht) new HLT reconstruction algorithm





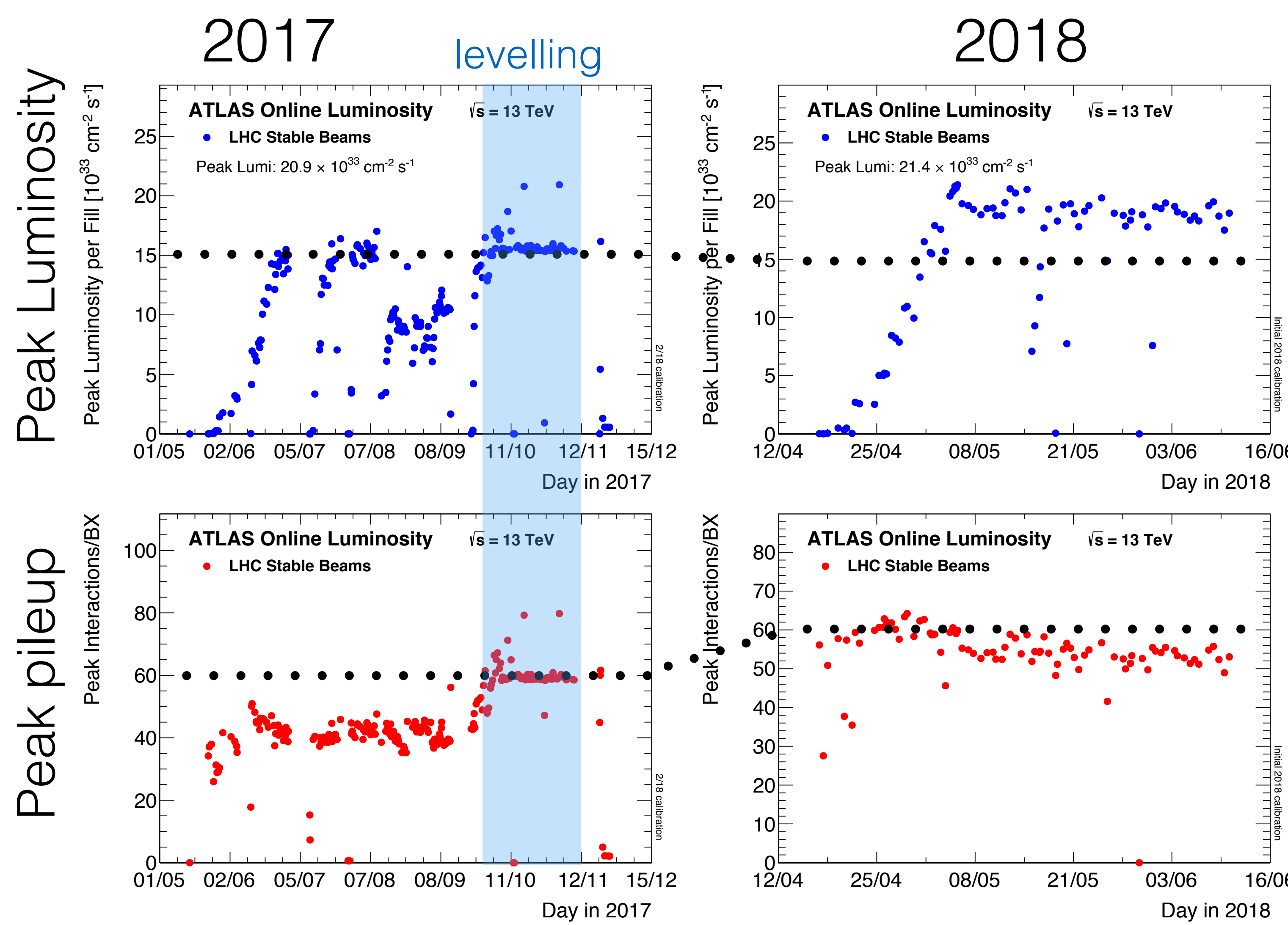
jet trigger efficiencies w/ (2017) and w/o (2016) new HLT calibration



Triggering at High Pileup

- Extensive work to reduce memory/timing usage, with particular focus on algorithms like tracking which requires resources that scale non-linearly with pileup
  - eg better caching information, preselections to reduce execution rates of tracking algorithms, further algorithm optimisation

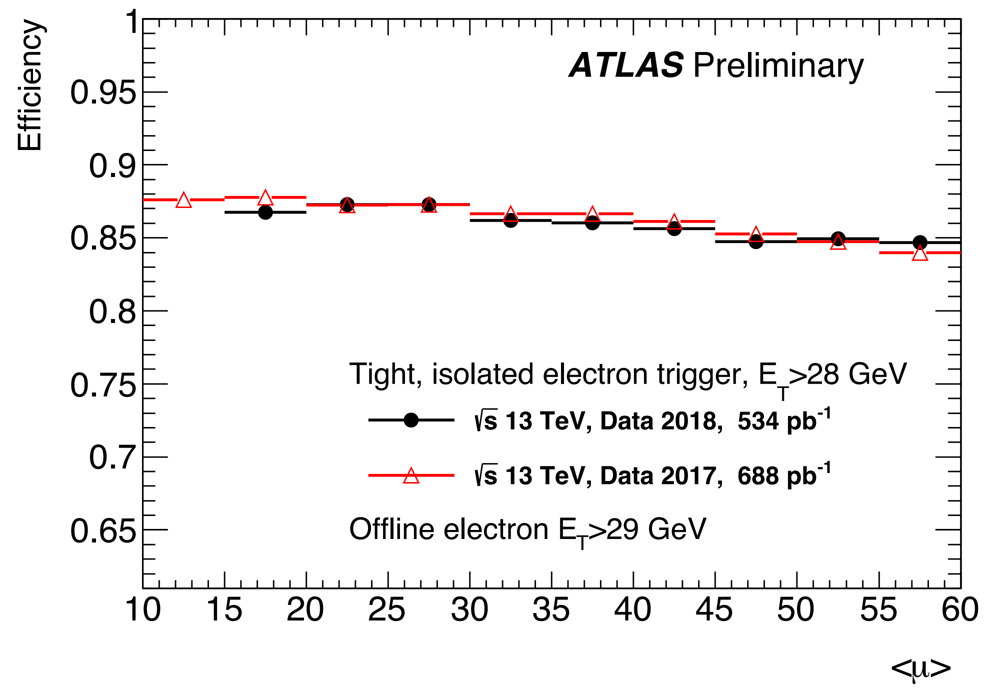
- In August 2017, issue in LHC sector 16L2 forced to run with reduced number of bunches
  - compensations for luminosity loss lead to lumi above 2.0×10^{34} at μ~80
  - HLT farm could not cope with this pileup. ATLAS decided to level at 1.56×10^{34}, μ~60
  - successful strategy: high data taking efficiency with little loss in integrated luminosity
- In 2018, LHC reached record peak lumi of 2.0×10^{34} with μ~55. No need to level thanks to
  - developments in HLT triggers to reduce inefficiencies at high pileup
  - 20% more HLT processing slots



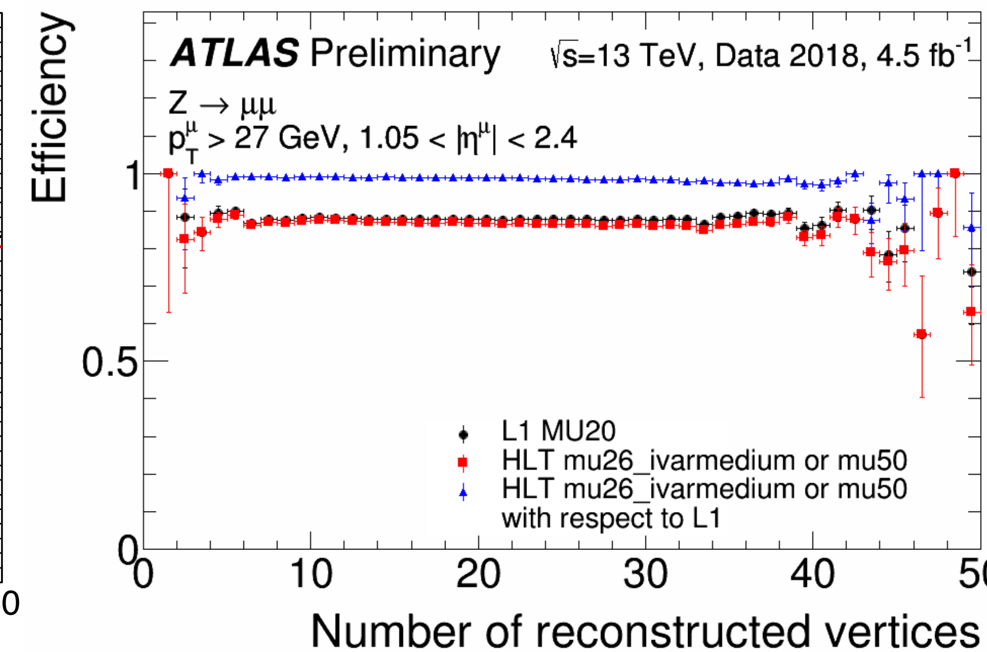
Trigger Efficiency in 2018

- Very good stability of trigger efficiencies as function of pileup

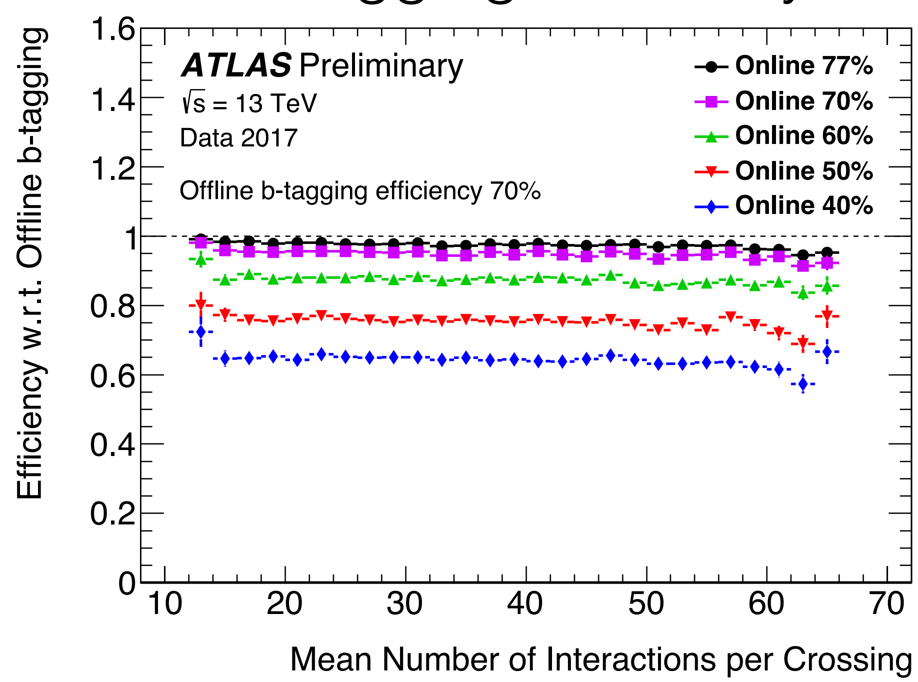
Electrons



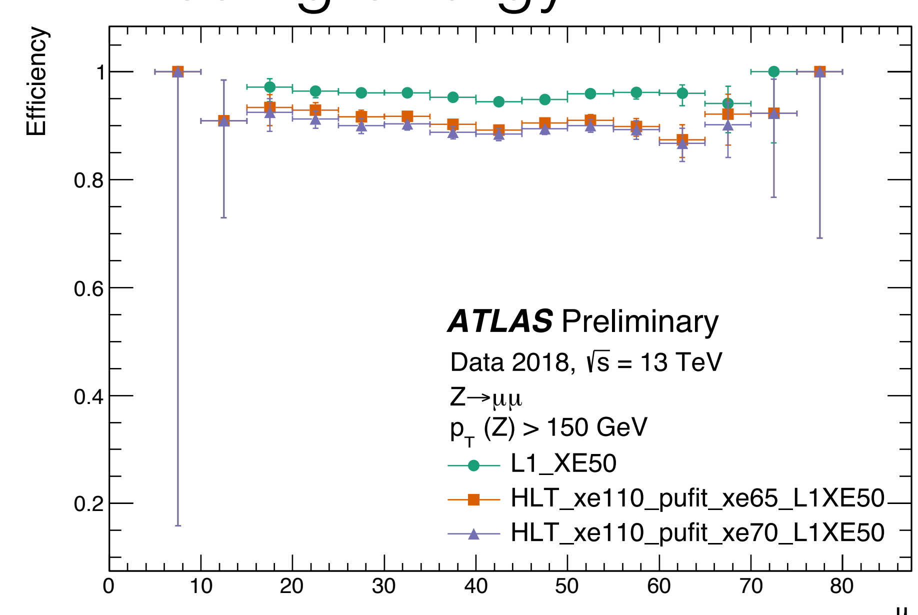
Muons



online b-tagging efficiency

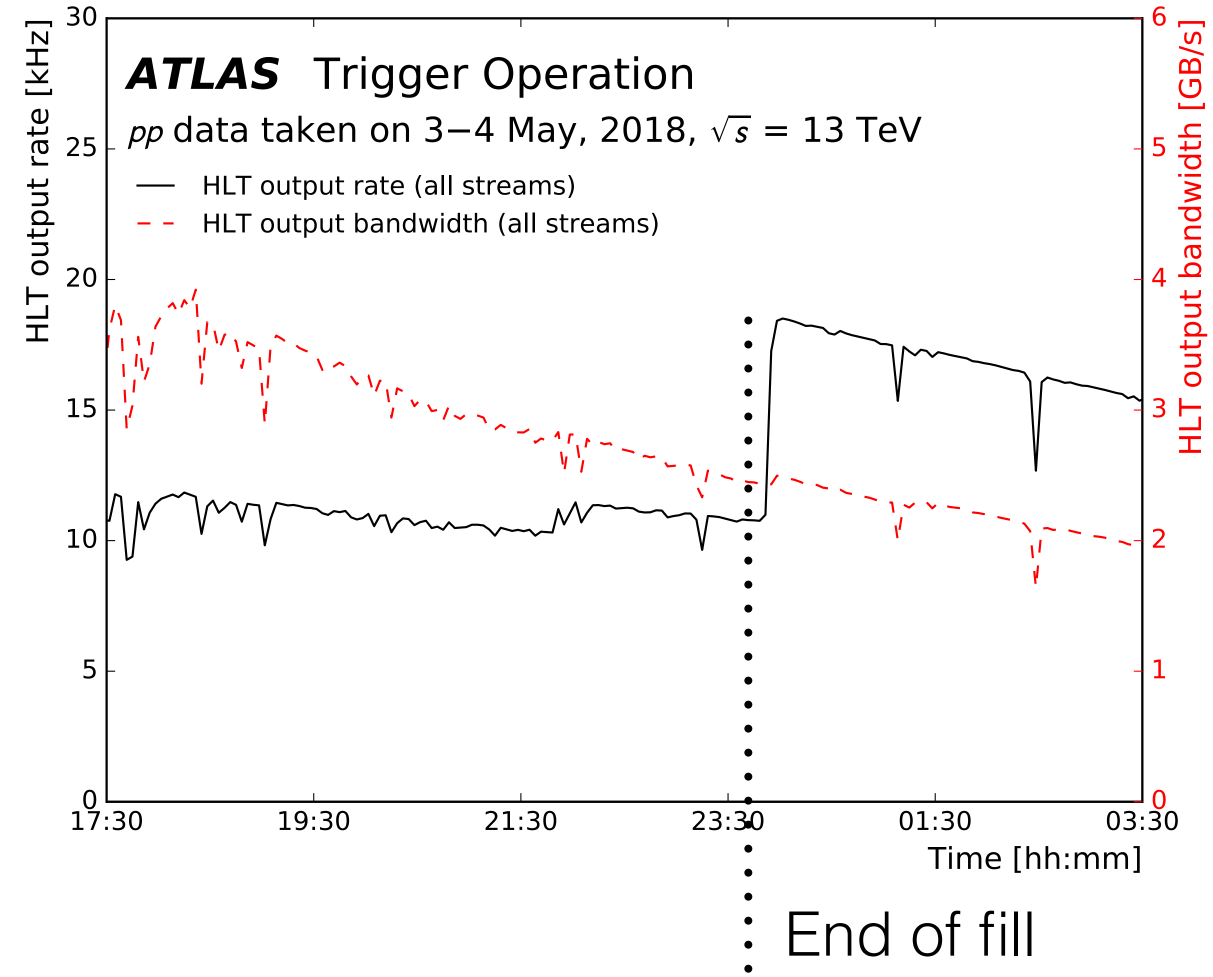


Missing energy



End-of-fill Triggers

- After few hours of collisions, L1 rate and HLT processing slots free up thanks to luminosity exponential decay
- High-rate and CPU-intensive triggers can be enabled within the data storage output limitation
- Strategy is used for the Trigger-level Analysis (ATL-DAQ-PUB-2017-003)
  - tiny event size with only information on HLT jets, collected by low-pt single jet trigger at an HLT rate up to 13 kHz when luminosity is below 1.0×10^{34}
  - total HLT output bandwidth is only marginally increased by these additional events
- End-of-fill strategy used for triggers for B-physics signals (high processing power needed)



Summary

- ATLAS trigger system maintains excellent performance even at LHC running conditions far beyond design values
  - continuous and prompt developments of trigger software to improve pileup robustness and optimise resource usage
  - fully exploitation of new L1 hardware
- In 2017, levelling successfully ensured a highly efficient data taking when pileup reached levels beyond the capabilities of the HLT farm
- Running at high pileup is precious testbed for further optimising the trigger systems for Run-3 and HL-LHC run

References:

- Trigger Public Results
- Performance of the ATLAS Trigger system in 2015, EPJC (2017) 77:317, 1611.09661
- Trigger Menu in 2017 (ATL-DAQ-PUB-2018-002)

Related talks/posters at ICHEP2018:

- the ATLAS Muon trigger (A. Held)
- the ATLAS FastTracker: Pioneering the next era of hardware track triggers (T. R. Holmes)
- the ATLAS Electron and Photon Trigger (P. Podberezko, poster)
- triggering on hadronic signatures in ATLAS - developments for 2017 and 2018 (S. Schramm, poster)

Additional Material

Trigger Menu

Trigger	Typical offline selection	Trigger Selection		Level-1 Peak Rate (kHz)	HLT Peak Rate (Hz)
		Level-1 (GeV)	HLT (GeV)	$L = 1.7 \times 10^{34}$ cm^{-2}s^{-1}	
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	Single μ, $p_T > 52$ GeV	20	50	15	61
	Single e, $p_T > 61$ GeV	22 (i)	60	28	18
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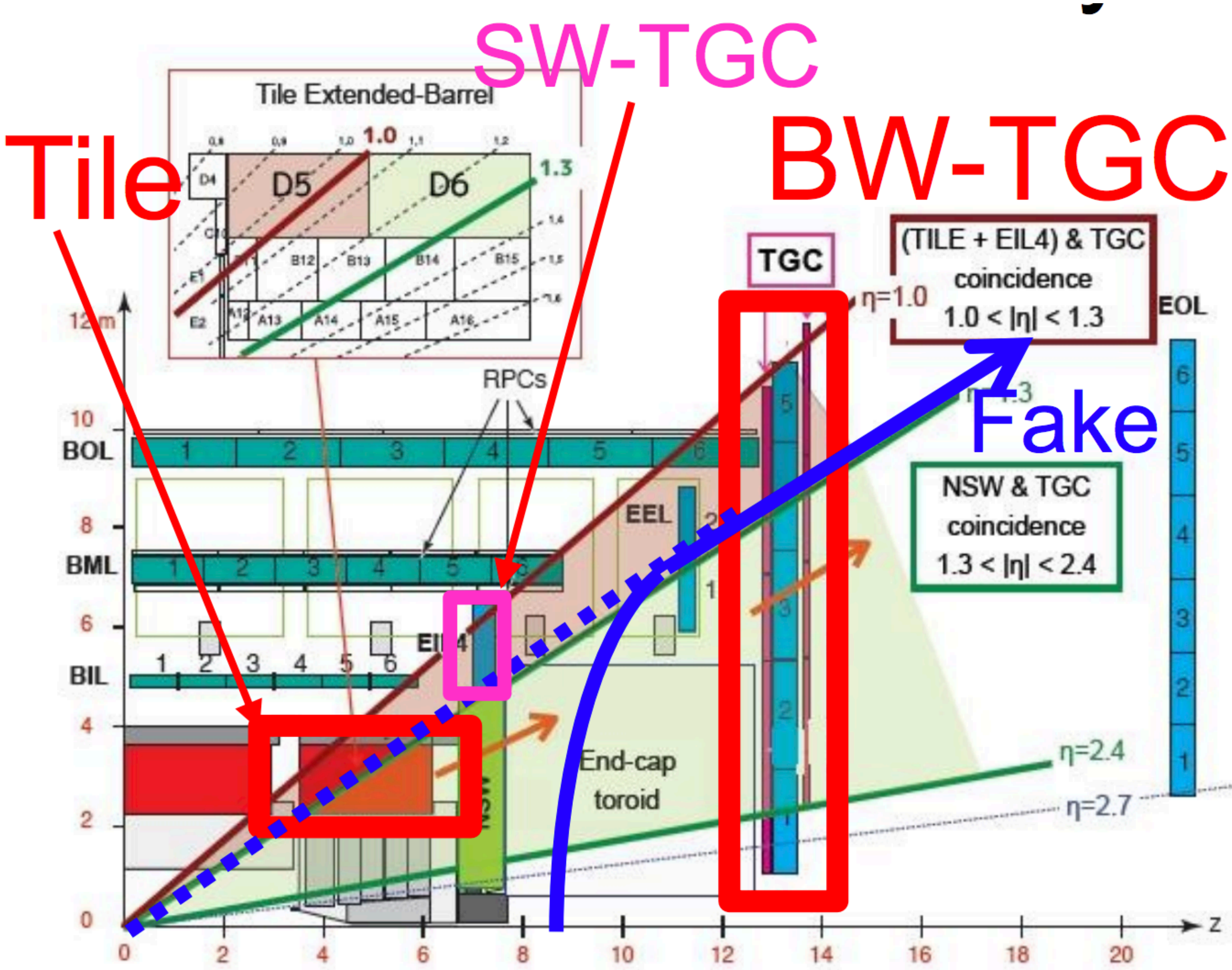
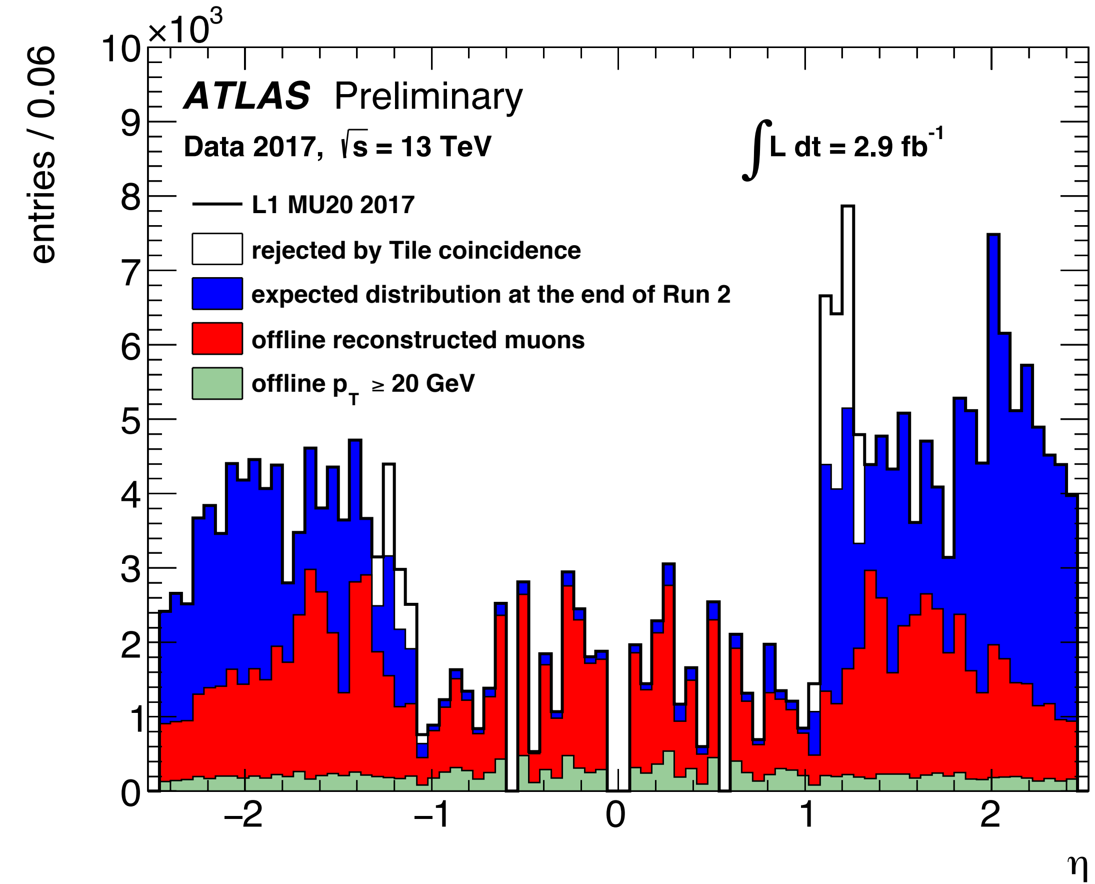
Two leptons	Two μ, each $p_T > 15$ GeV	2×10	2×14	1.8	26
	Two μ, $p_T > 23$, 9 GeV	20	22, 8	15	42
	Two very loose e, each $p_T > 18$ GeV	2×15 (i)	2×17	1.7	12
	One e & one μ, $p_T > 8$, 25 GeV	20 (μ)	7, 24	15	5
	One e & one μ, $p_T > 18$, 15 GeV	15, 10	17, 14	2.0	4
	One e & one μ, $p_T > 27$, 9 GeV	22 (e, i)	26, 8	28	3
	Two τ, $p_T > 40$, 30 GeV	20 (i), 12 (i) (+jets, topo)	35, 25	5	61
	One τ & one isolated μ, $p_T > 30$, 15 GeV	12 (i), 10 (+jets)	25, 14 (i)	2.1	10
	One τ & one isolated e, $p_T > 30$, 18 GeV	12 (i), 15 (i) (+jets)	25, 17 (i)	4	15
Three leptons	Three loose e, $p_T > 25$, 13, 13 GeV	20, 2×10	24, 2×12	1.3	< 0.1
	Three μ, each $p_T > 7$ GeV	3×6	3×6	0.2	6
	Three μ, $p_T > 21$, 2×5 GeV	20	20, 2×4	15	8
	Two μ & one loose e, $p_T > 2 \times 11$, 13 GeV	2×10 (μ)	2×10, 12	1.8	0.3
	Two loose e & one μ, $p_T > 2 \times 13$, 11 GeV	2×8, 10	2×12, 10	1.7	0.1
One photon	One loose γ, $p_T > 145$ GeV	22 (i)	140	28	43
Two photons	Two loose γ, $p_T > 55$, 55 GeV	2×20	50, 50	2.6	6
	Two medium γ, $p_T > 40$, 30 GeV	2×20	35, 25	2.6	17
	Two tight γ, $p_T > 25$, 25 GeV	2×15 (i)	2×20 (i)	1.7	14
Single jet	Jet ($R = 0.4$), $p_T > 435$ GeV	100	420	3.3	33
	Jet ($R = 1.0$), $p_T > 480$ GeV	100	460	3.3	24
	Jet ($R = 1.0$), $p_T > 450$ GeV, $m_{jet} > 50$ GeV	100	420, $m_{jet} > 40$	3.3	29
E_T^{miss}	$E_T^{miss} > 200$ GeV	50	110	5	110
Multi-jets	Four jets, each $p_T > 125$ GeV	3×50	4×115	0.5	16
	Five jets, each $p_T > 95$ GeV	4×15	5×85	5	10
	Six jets, each $p_T > 80$ GeV	4×15	6×70	5	4
	Six jets, each $p_T > 60$ GeV, $\lvert\eta\rvert < 2.0$	4×15	6×55, $\lvert\eta\rvert < 2.4$	5	15
b−jets	One b ($\epsilon = 40\%$), $p_T > 235$ GeV	100	225	3.3	15
	Two b ($\epsilon = 60\%$), $p_T > 185$, 70 GeV	100	175, 60	3.3	12
	One b ($\epsilon = 40\%$) & three jets, each $p_T > 85$ GeV	4×15	4×75	5	15
	Two b ($\epsilon = 70\%$) & one jet, $p_T > 65$, 65, 160 GeV	2×30, 85	2×55, 150	1.2	15
	Two b ($\epsilon = 60\%$) & two jets, each $p_T > 65$ GeV	4×15, $\lvert\eta\rvert < 2.5$	4×55	3.2	13
B-Physics	Two μ, $p_T > 11$, 6 GeV	11, 6	11, 6 (di-μ)	2.5	47
	Two μ, $p_T > 6$, 6 GeV, $2.5 < m(\mu, \mu) < 4.0$ GeV	2×6 (J/ψ, topo)	2×6 (J/ψ)	1.6	48
	Two μ, $p_T > 6$, 6 GeV, $4.7 < m(\mu, \mu) < 5.9$ GeV	2×6 (B, topo)	2×6 (B)	1.6	5
	Two μ, $p_T > 6$, 6 GeV, $7 < m(\mu, \mu) < 12$ GeV	2×6 (Υ, topo)	2×6 (Υ)	1.4	10
Total Rate				85	1550

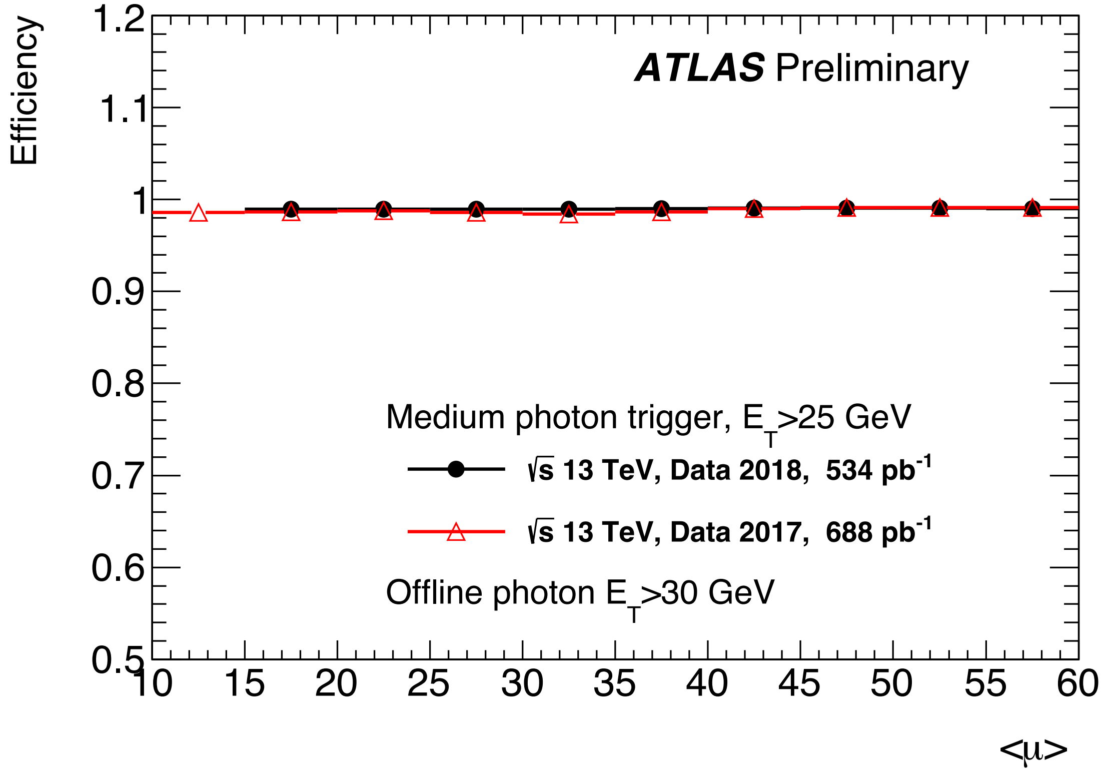
L1 Muon: Tile-Muon Coincidence



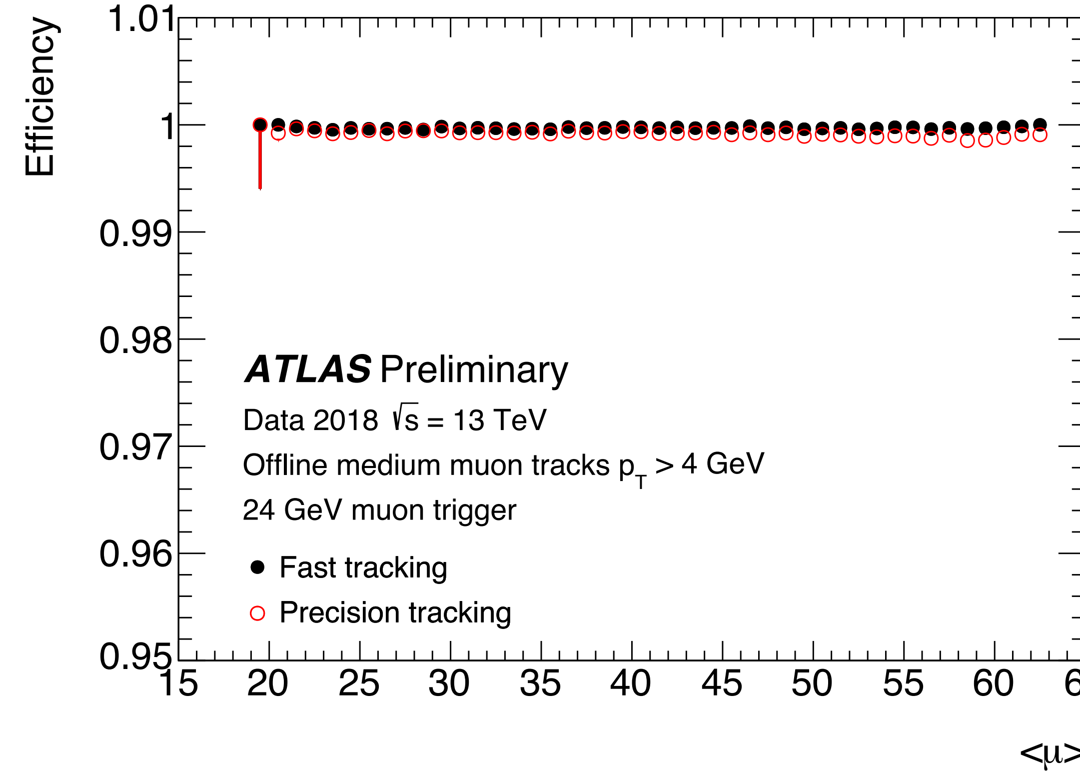


Trigger Performance

Photons



tracking efficiency in muon trigger



tracking efficiency in tau trigger