ATLAS Run-2 Trigger Menu

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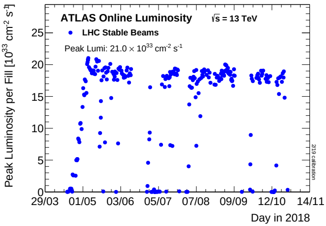
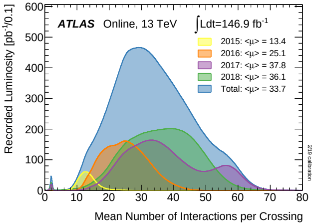
Introduction

Excellent performance of ATLAS during Run 2 (2015-2018):

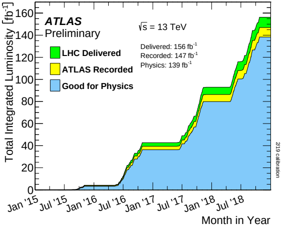
- Peak luminosity: $2 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ in 2018
- Peak interaction per bunch crossing: ~ 56
- Total recorded luminosity with high efficiency: $\sim 140\ \mathrm{fb}^{-1}$

Many challenges: high pileup, limited bandwidth and CPU resources, $\cdots$





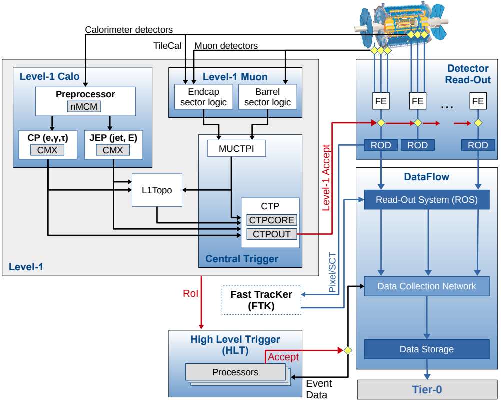
LuminosityPublicResultsRun2



ATLAS trigger system

Two-level trigger system used to reduce the bunch crossing rate of **40 MHz** to an average recording rate of **1 kHz**:

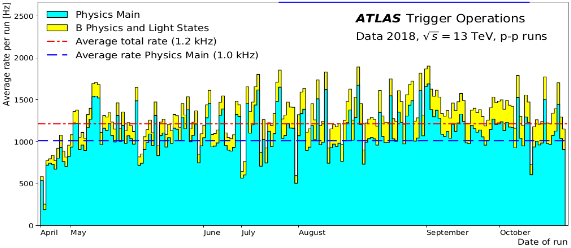
- Level-1 (L1) trigger (40 MHz $\rightarrow$ 100 kHz): hardware-based, simple selection (energy threshold), topological selection with L1Topo.
- High-level trigger (HLT, 100 kHz $\rightarrow$ 1 kHz) after L1 acceptance: software-based, selection close to offline (isolation, likelihood, topology,...)



Trigger menu design

- Trigger: chain of algorithms and selections at L1 and HLT
- Trigger Menu: the collection of all triggers, e.g. $\sim$ 500 L1 triggers and $\sim$ 1500 HLT triggers in 2018
  1. balance between selection of different objects
  2. specify which triggers are used and allocate reasonable rate and bandwidth
  3. design for different beam conditions
- Design goal: maximize coverage of ATLAS physics within the constraint of detectors and trigger system.
- Trigger menu has to respect all technical limitations: detector readout $\sim$100 kHz, limited CPU resources, limited offline storage $\sim$1 kHz from HLT output

TriggerOperationPublicResults

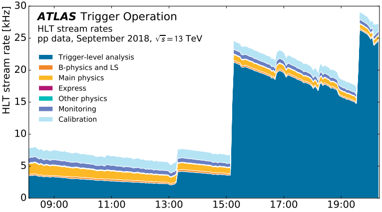


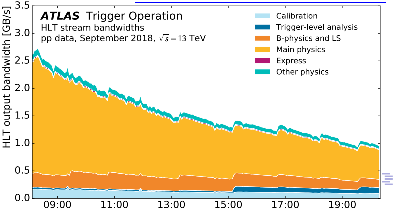
Trigger menu design

- Menu building blocks:
  1. Primary triggers for physics analysis
  2. Support triggers for efficiency and performance measurements, background estimate and monitoring, run at a small rate (~ 0.5 Hz) and 15 % HLT bandwidth
  3. Calibration triggers for detector calibration, partial-event building with limited detector information (allow high rate but store small events)
  4. Trigger-level-analysis, only record objects reconstructed in HLT (allow high rate but store small events)
  5. Backup triggers, Alternative triggers

- Streams: Main physics (collect events for most physics analyses), express, calibration

TriggerOperationPublicResults

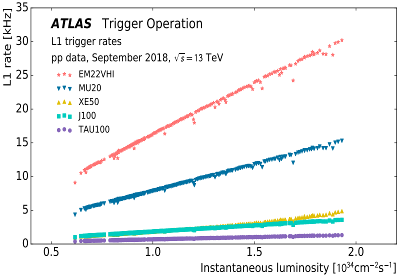


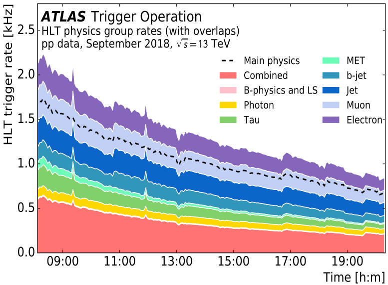


Trigger menu operation

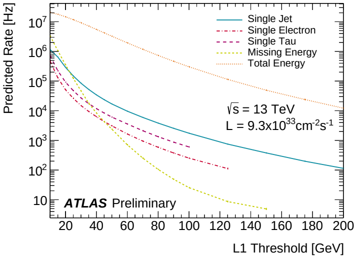
- All trigger chains are properly validated and simulated in Monte Carlo before deployment online.
- Menus are deployed every few weeks with new trigger chains and adjustments.
- Depending on the instantaneous luminosity, adjust the prescale sets for individual triggers to optimize the bandwidth usage.

TriggerOperationPublicResults





- Need precise predictions for rate and CPU usage to design the prescale sets for different luminosity conditions and to study new triggers
- Use special data samples called Enhanced bias
  1. selected by Level 1 trigger system (emphasize higher energies and object multiplicities), remove selection bias with event weights, no bias at HLT
  2. recorded every time when data taking conditions change significantly
  3. predict the rates of HLT trigger chains with complex combinations for different instantaneous luminosities and predict trigger CPU usage



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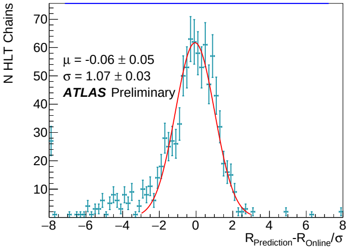
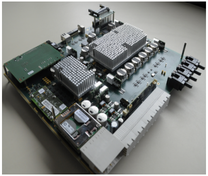
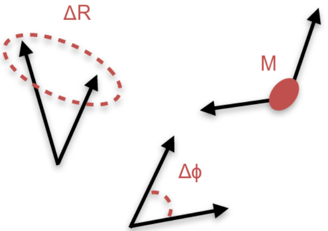


Improvements on L1 trigger

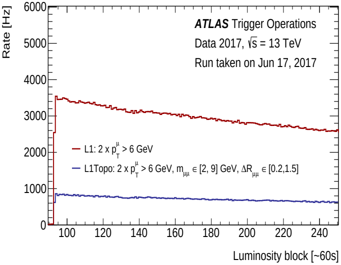
Constant improvements of trigger algorithms and trigger menu to ensure efficient triggering in high pileup conditions.

- L1Muon: require spatial and temporal coincidence on hits in muon end-cap chamber and tile calorimeter (see Antonio's talk).
- L1Calo: update filter coefficients and noise cuts for high pile-up condition with 8 % reduction on L1 rate and improving reconstruction time at HLT.
- L1Topo: topological information, like angular separation and invariant mass, used to enhance background rejection at L1 with p_T thresholds unchanged, critical for B physics ($B_s \to \mu\mu$), di-tau analysis with low p_T





TriggerOperationPublicResults



Improvements on HLT trigger

Constant improvements of trigger algorithms and trigger menu to ensure efficient triggering in high pileup conditions.

- Muon: see Antonio's talk
- Electron/photon: see Dmitriy's talk
- Tau: new identification algorithm based on Recurrent Neural Network (RNN) to enhance jet rejection and signal acceptance

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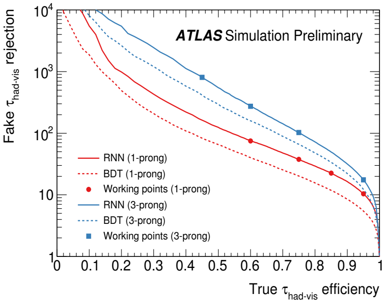
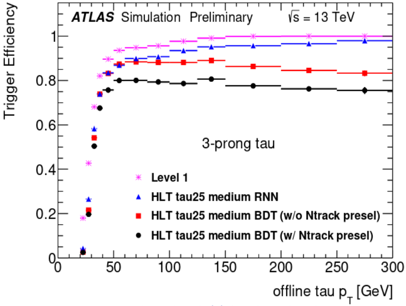


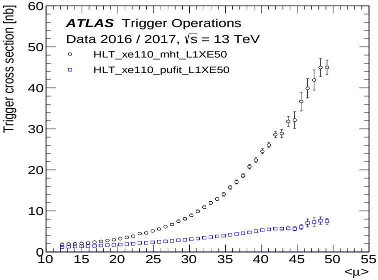


Improvements on HLT trigger

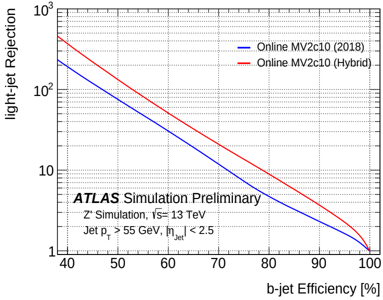
Constant improvements of trigger algorithms and trigger menu to ensure efficient triggering in high pileup conditions.

- E_T^{miss} triggers: strongly affected by pileup, a *pufit* algorithm developed to disentangle calorimeter deposits in hard scattering from those in pile-up interactions.
- $b-$ jets: flavour-tagging algorithm retuned with high-mass samples $Z' \rightarrow t\bar{t}$ to improve efficiency at high p_T(hybrid).

MissingEtTriggerPublicResults



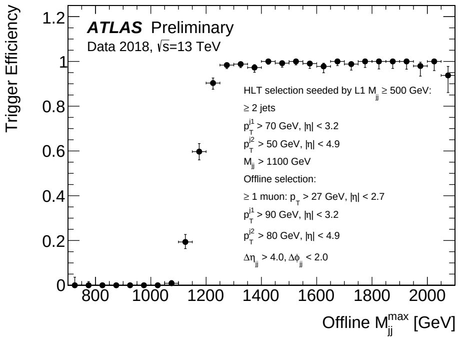
BJetTriggerPublicResults



New triggers

- New triggers in 2018:
  1. Vector boson fusion: require the mass of two jets greater than 500 GeV
  2. B-physics trigger for $B^0 \to K^* e^+ e^-$, run over all L1-accepted events below luminosity 1.85×10^{34} cm^{-2}s^{-1}
  3. stopped gluino: long-lived heavy particle (decay after hours or months, use bunch crossings without $p - p$ collisions)

TriggerOperationPublicResults



Overview of Run2 trigger menu

Trigger	Typical offline selection	Trigger Selection: Level-1 (GeV)	Trigger Selection: HLT (GeV)	Level-1 Peak Rate (kHz)	HLT Peak Rate (Hz)
				$L = 1.7 \times 10^{34}$ cm^{-2}s^{-1}	
Single leptons	Single isolated μ, $p_T > 27$ GeV	20	26 (i)	16	187
	Single isolated tight e, $p_T > 27$ GeV	22 (i)	26 (i)	26	178
	Single μ, $p_T > 52$ GeV	20	50	16	65
	Single e, $p_T > 61$ GeV	22 (i)	60	26	17
	Single τ, $p_T > 170$ GeV	100	160	1.2	49
Two leptons	Two μ's, each $p_T > 15$ GeV	2×10	2×14	2.0	30
	Two μ's, $p_T > 23, 9$ GeV	20	22, 8	16	42
	Two very loose e's, each $p_T > 18$ GeV	2×15 (i)	2×17	1.6	11
	One e & one μ, $p_T > 8, 25$ GeV	20 (μ)	7, 24	16	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	26	2
	Two τ's, $p_T > 40, 30$ GeV	20 (i), 12 (i) (+jets, topo)	35, 25	5.1	59
	One τ & one isolated μ, $p_T > 30, 15$ GeV	12 (i), 10 (+jets)	25, 14 (i)	2.1	9
	One τ & one isolated e, $p_T > 30, 18$ GeV	12 (i), 15 (i) (+jets)	25, 17 (i)	3.9	16
Three leptons	Three loose e's, $p_T > 25, 13, 13$ GeV	$20, 2 \times 10$	$24, 2 \times 12$	1.2	< 0.1
	Three μ's, each $p_T > 7$ GeV	3×6	3×6	0.2	8
	Three μ's, $p_T > 21, 2 \times 5$ GeV	20	$20, 2 \times 4$	16	8
	Two μ's & one loose e, $p_T > 2 \times 11, 13$ GeV	2×10 (μ's)	2×10, 12	2.0	0.3
	Two loose e's & one μ, $p_T > 2 \times 13, 11$ GeV	2×8, 10	2×12, 10	1.6	0.2
One photon	One loose γ, $p_T > 145$ GeV	22 (i)	140	26	46
Two photons	Two loose γ's, $p_T > 55, 55$ GeV	2×20	50, 50	2.4	6
	Two medium γ's, $p_T > 40, 30$ GeV	2×20	35, 25	2.4	18
	Two tight γ's, $p_T > 25, 25$ GeV	2×15 (i)	2×20 (i)	2.4	15
Single jet	Jet ($R = 0.4$), $p_T > 435$ GeV	100	420	3.4	33
	Jet ($R = 1.0$), $p_T > 480$ GeV	100	460	3.4	24
E_T^{miss}	$E_T^{miss} > 200$ GeV	50	110	4.4	100
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	4.9	10
	Six jets, each $p_T > 80$ GeV	4×15	6×70	4.9	4
	Six jets, each $p_T > 60$ GeV, $\lvert\eta\rvert < 2.0$	4×15	6×55, $\lvert\eta\rvert < 2.4$	4.9	15
b–jets	One b ($\epsilon = 40\%$), $p_T > 235$ GeV	100	225	3.4	15
	Two b's ($\epsilon = 60\%$), $p_T > 185, 70$ GeV	100	175, 60	3.4	12
	One b ($\epsilon = 40\%$) & three jets, each $p_T > 85$ GeV	4×15	4×75	4.9	15
	Two b's ($\epsilon = 70\%$) & one jet, $p_T > 65, 65, 160$ GeV	2×30, 85	2×55, 150	2.7	15
	Two b's ($\epsilon = 60\%$) & two jets, each $p_T > 45$ GeV	4×15	4×35	4.9	13
B-Physics	Two μ's, $p_T > 11, 6$ GeV	11, 6	11, 6 (di-μ)	3.1	50
	Two μ's, $p_T > 6, 6$ GeV, $2.5 < m(\mu, \mu) < 4.0$ GeV	2×6 (J/ψ, topo)	2×6 (J/ψ)	1.8	59
	Two μ's, $p_T > 6, 6$ GeV, $4.7 < m(\mu, \mu) < 5.9$ GeV	2×6 (B, topo)	2×6 (B)	1.8	7
	Two μ's, $p_T > 6, 6$ GeV, $7 < m(\mu, \mu) < 12$ GeV	2×6 (Υ, topo)	2×6 (Υ)	1.5	10
Total Rate				85	1550

Heavy-Ion trigger menus

Heavy-ion collidions differ significantly from $p-p$. Triggers are designed for collisions with different centralities (from ulta-central to ultra-peripheral). Main features on the trigger design:

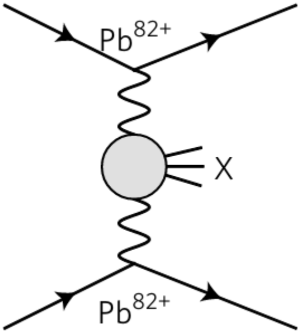
- Total transverse energy (TE) in the calorimeter at L1
- Energy correction for underlying events (UE) for HLT triggers in central collisions.
- Coincidence triggers in Zero-Degree Calorimeters (ZDC, one ZDC on each side, detecting neutrons from nucleus dissociation)
- Dedicated triggers designed for different interests, examples:
  1. TE > 12 TeV at L1 and total $E_T^{FCal} > 3.61$ TeV at HLT for ultra-central collisions (UCC)
  2. TE > 600 GeV at L1 and top 10 % of events with largest 2nd order flow harmonic for azimuthal anisotropies (central collisions)
  3. TE < 200 GeV at L1, no signal in both ZDCs for $\gamma + \gamma \to X$ or signal in only one ZDC for $\gamma + A \to X$ (ultra-peripheral collisions).

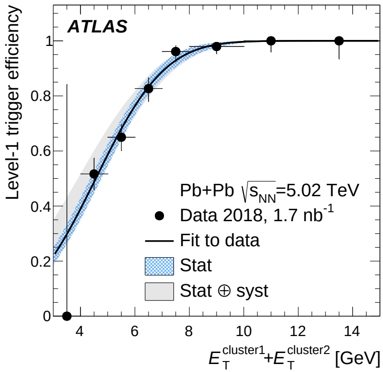
Heavy-Ion trigger menus

Heavy-ion collidions differ significantly from $p-p$. Triggers are designed for collisions with different centralities (from ulta-central to ultra-peripheral).

- Example: TE $<$ 200 GeV at L1, neither of ZDCs is triggered for $\gamma\gamma \to \gamma\gamma$ (ultra-peripheral collisions).

HION-2018-19





Summary

- ATLAS trigger system updated to cope with the challenging conditions (high luminosity, high pile up)
- Trigger menu designed to cover broad ATLAS physics program and to respect technical limitations (CPU, bandwidth, ...)
- Software tools developed for monitoring and validation to ensure good operations
- Excellent performance of trigger system guarantees stable data taking by ATLAS detector during Run2.

BACK UP

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ATLAS trigger system

Two-level trigger system used to reduce the bunch crossing rate of **40 MHz** to an average recording rate of **1 kHz**:

- Level-1 (L1) trigger (40 MHz $\to$ 100 kHz):
  1. hardware-based, 2.5 μs processing time
  2. use coarse information from calorimeter (L1Calo) and muon (L1Muon) systems to define ($\eta \times \phi$) Region-of-interest (RoI) for feature extraction
  3. simple selection on different signatures (muon, calorimeter energy deposits consistent with electron/photon, tau, jet, MET), e.g. L1_MU20
- High-level trigger (HLT, 100 kHz $\to$ 1 kHz) after L1 acceptance:
  1. software-based, 400 ms processing time ($\sim$40k commercial CPU cores),
  2. comprised of steps: run multiple feature-extraction algorithms within RoI; run offline-like reconstruction algorithms over a subset of event data; each step terminates on a hypothesis algorithm to decide whether the trigger condition is satisfied.
  3. selection conditions designed as close to offline as possible (energy, isolation, likelihood, topologic configuration, $\cdots$)
  4. events passing HLT transferred to CERN computing center for offline reconstruction

tau RNN

The RNN uses a combination of low-level input variables for individual tracks and clusters associated to the tau candidate (e.g. track p_{T}, impact parameter, number of hits, cluster depth, ...) and high-level observables calculated from track and calorimeter quantities (e.g. p_{T} of the seed jet, central energy fraction, maximum track ΔR, mass of the tracking system, ...). The BDT only uses high-level observables.