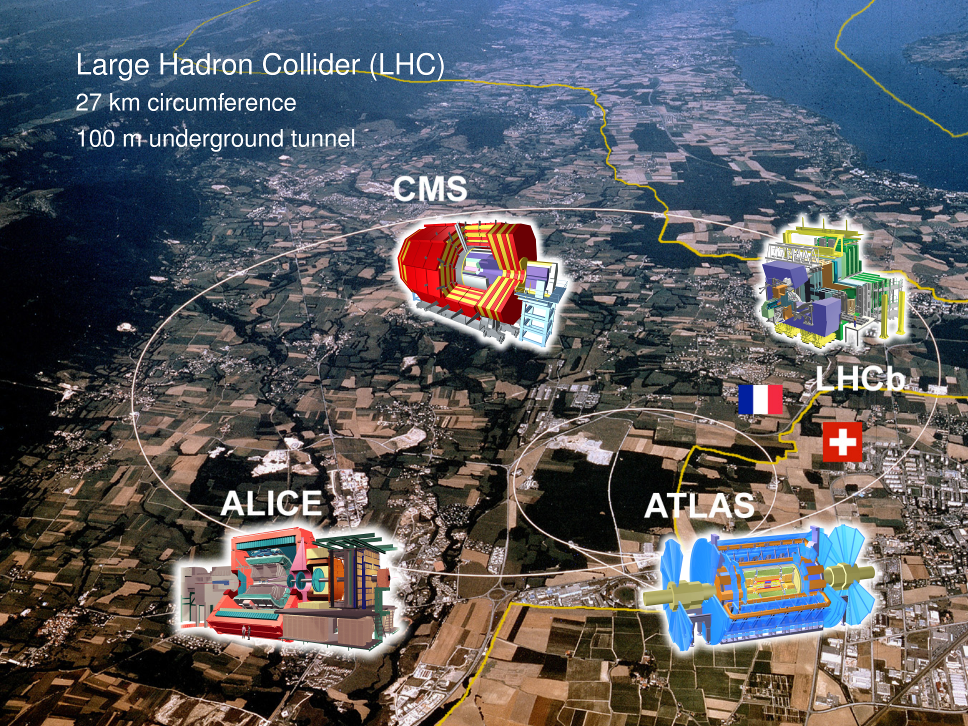
ATLAS Trigger in Run-3

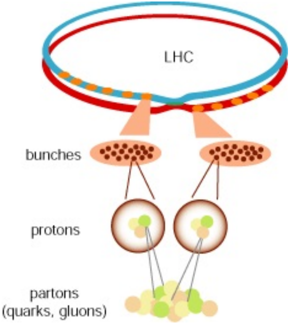
Arantxa Ruiz Martínez

HEP Seminar, Queen Mary University of London

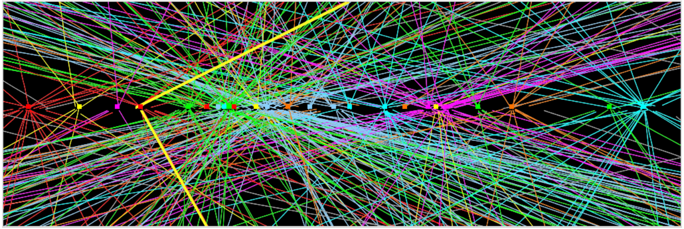
21 January 2021


Large Hadron Collider (LHC)
27 km circumference
100 m underground tunnel
CMS
LHCb
ALICE
ATLAS

LHC collisions

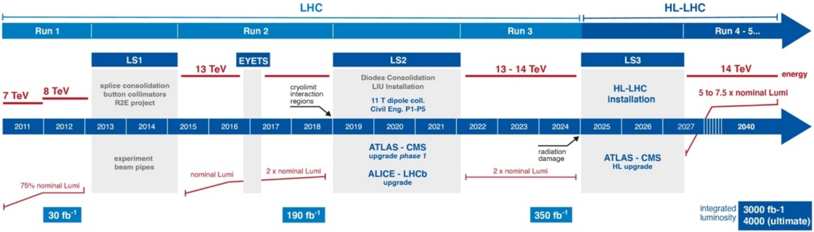


- Crossing of the two proton beams at an interaction point is called Event
- 2808 bunches/beam with 1.1×10^{11} protons/bunch
- 7.5 cm $\times$ 16 μm bunch size (human hair: $\sim$50 μm)
- $\sim$30 MHz bunch crossing (40 MHz if the machine is full with 1 bunch crossing every 25 ns)
- Up to 60 collisions per bunch crossing (pileup) in 2018
- Collisions at $\sqrt{s} = 13$ TeV (6.5 TeV per beam) in Run 2 $\rightarrow$ to be potentially increased to $\sqrt{s} = 14$ TeV in Run 3 (LHC designed maximum collision energy)

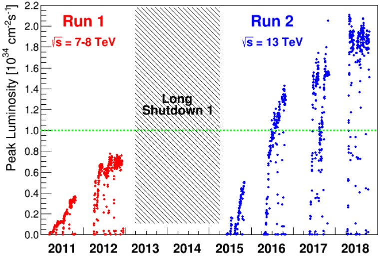


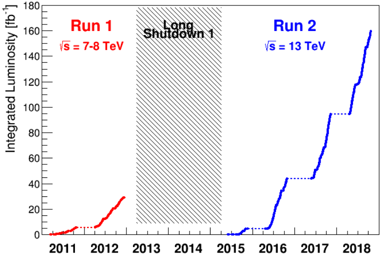
LHC schedule

LHC schedule recently updated, Run-3 start in Feb 2022 and extended to 2024



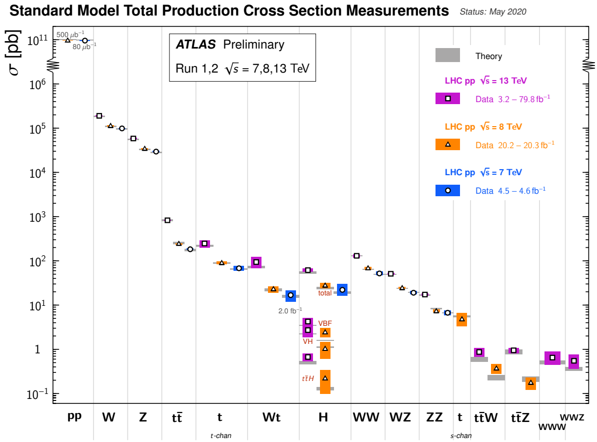
- Nominal design luminosity of 1×10^{34} cm^{-2}s^{-1} achieved on 26 June 2016
- Record peak luminosity of 2.1×10^{34} cm^{-2}s^{-1} achieved on 5 May 2018





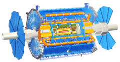
The ATLAS experiment

- ATLAS is a multipurpose experiment, targeting a large variety of Standard Model measurements over many orders of magnitude in cross section and searches for new physics (SUSY, Dark Matter, etc.)
- For 13 TeV proton-proton collisions at 2×10^{34} cm^{-2}s^{-1}, expect 600 Hz of $W(\rightarrow$ lep) and 0.01 Hz of ttH



The ATLAS Trigger System

- Trigger (online event selection for permanent storage) is of paramount importance since is the first cut applied to any physics analysis
- Two level trigger system



↓ 40 MHz

Level-1 (L1)

- Hardware-based trigger
- Inputs from Calorimeter and Muon systems with coarse detector granularity defining Regions of Interest (RoIs)
- Latency: $< 2.5\ \mu$s

↓ 100 kHz

High Level Trigger (HLT)

- Software-based trigger
- Full detector granularity
- Latency: $\sim$0.5 s average

↓ 1 kHz average $\times$ 1 MB/event = 1 GB/s

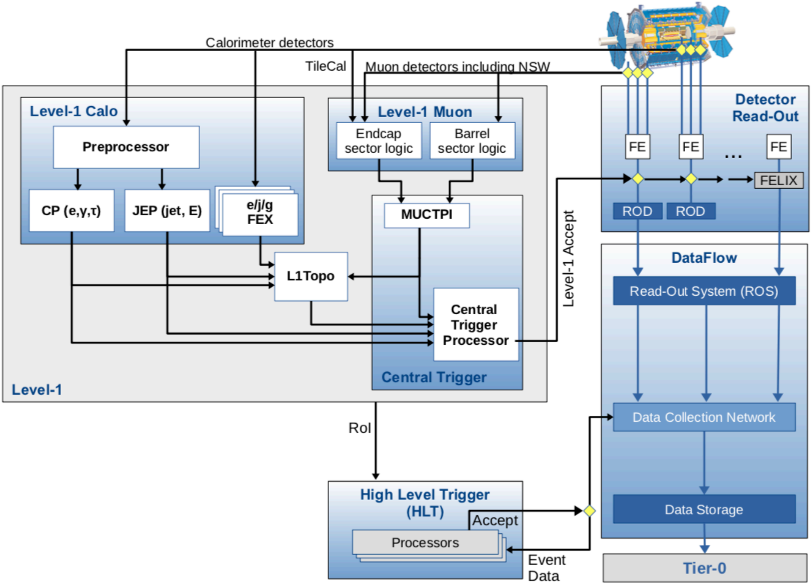
ATLAS Trigger evolution from Run-1 to Run-2

- Run-2 environment significantly harsher than Run-1:
  - Higher center-of-mass energy: 8 $\rightarrow$ 13 TeV
  - Higher peak luminosity: $0.76 \times 10^{34} \rightarrow 2.1 \times 10^{34}$ cm^{2}s^{-1}
  - Higher pileup: 35 $\rightarrow$ 60
  - Bunch spacing: 50 $\rightarrow$ 25 ns
- ATLAS TDAQ system improvements for Run-2:
  - Higher bandwidth:
    L1 from 60 to 100 kHz
    HLT from 400 to 1000 Hz
  - Possibility of topological selections at L1: L1Topo
  - Unified HLT (Level-2/EF) architecture
  - Deferred triggers: store subset of the events in the DAQ system, to be processed later during (between) fills
  - Data Scouting: write out events with only trigger objects

ATLAS Trigger evolution from Run-2 to Run-3

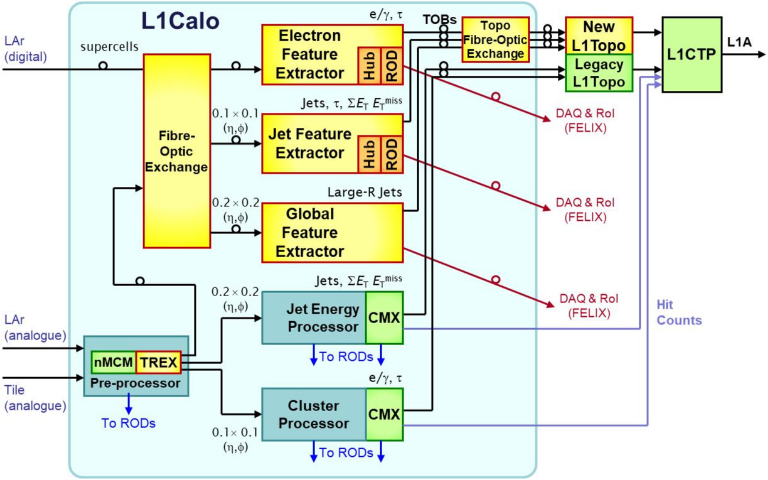
- Run-3 environment significantly harsher than Run-2:
  - Possibly higher center-of-mass energy: 13 $\rightarrow$ 13.5 - 14 TeV
  - Luminosity levelling at 2×10^{34} cm^{2}s^{-1}
- ATLAS Phase-1 upgrades and main improvements for Run-3:
  - L1 Calorimeter trigger (L1Calo)
  - L1 Topological trigger (L1Topo)
  - L1 Muon trigger (L1Muon) endcap sector logic
  - Muon to Central Trigger Processor Interface (MUCTPI)
  - New Small Wheel (NSW) (MicroMegas (MM) and small-strip TGC (sTGC))
  - New RPC detectors (RPC-BIS78)
  - New coincidences between TGC-BW and NSW/RPC-BIS78
  - Multi-threaded software framework (AthenaMT)

ATLAS Trigger and Data Acquisition System in Run-3



Run-3 L1Calo system

Both legacy and Phase-1 L1Calo systems will run in parallel for commissioning

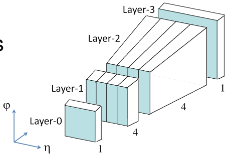


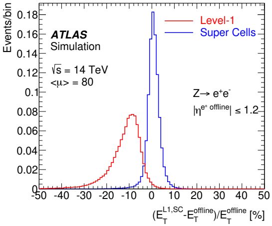
New for Run 3 | Legacy: Run 1 | Legacy: Run 2

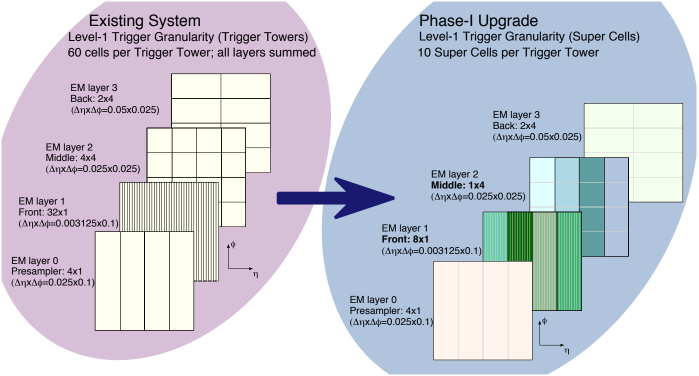
Run-3 L1Calo system

Finer-granularity LAr Calorimeter input:

- 0.1x0.1 trigger tower → 10 E_T values from "1-4-4-1" samples (SuperCells)
- Better resolution and background rejection



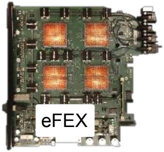




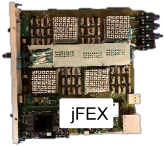
Run-3 L1Calo system

New ATCA-based Feature EXtractors (FEX):

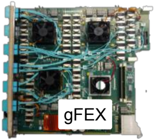
- **eFEX (electron feature extractor)**
  - 24 ATCA modules covering $|\eta| \leq 2.5$
  - Granularity: 0.025×0.1 (supercells)
  - Identifies electrons, photons and taus
  - More sophisticated clustering algorithms and isolation



- **jFEX (jet feature extractor)**
  - 7 ATCA modules covering $|\eta| \leq 4.9$
  - 0.1×0.1 input trigger-tower data
  - Identifies jet, E_T^{miss}, hadronically-decaying taus
  - Sophisticated “round” jet algorithms



- **gFEX (global feature extractor)**
  - 1 ATCA module to process the entire calorimeter data
  - 0.2×0.2 input tower-sum data
  - Full-scan algorithms to compute global event quantities
  - Many different MET algorithms to be explored



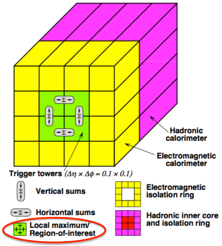
Run-2 L1Calo system performance

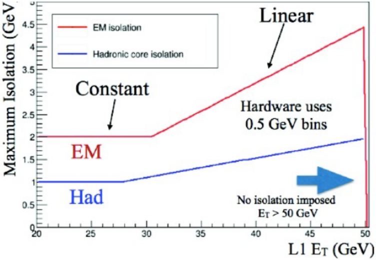
Run-2 L1_EM22VHI

V: η-dependent E_T threshold to correct for variations in material

H: Hadronic core isolation

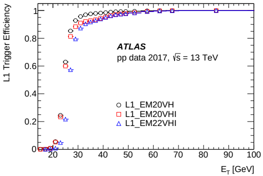
I: Electromagnetic isolation

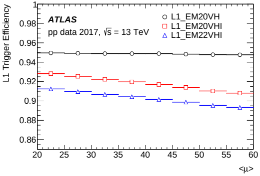


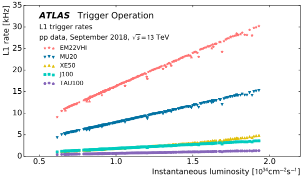


Single EM is the L1 trigger with the highest rate (> **30 kHz** at peak lumi 2E34)

$\rightarrow$ Generic trigger for inclusive $W \rightarrow e\nu$ measurements and analyses requiring at least a low-E_T electron



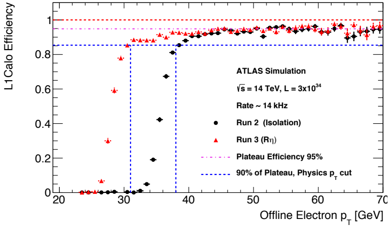


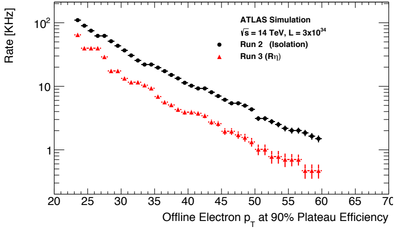


Run-3 L1Calo system performance

In Run-3, the main gain comes from the reduction of L1 electron trigger rate

ATLAS-TDR-023-2013



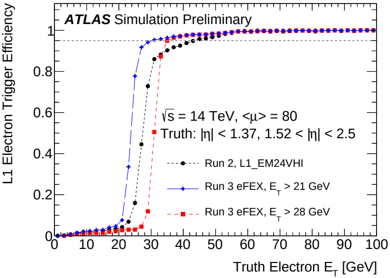


Exploring different shower shape variables (sharper turn-on curve, lower rate)

$$R_\eta = 1 - \frac{E_{\text{cluster}}}{E_{\text{environment}} + E_{\text{cluster}}}$$

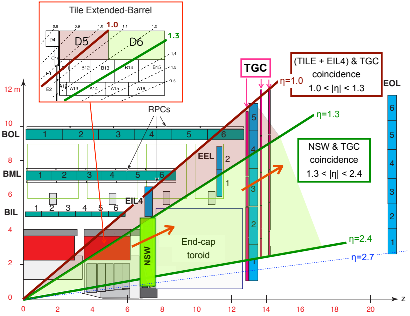
$$R_{\text{had}} = \frac{E_{\text{had}}}{E_{\text{had}} + E_0 + E_1 + E_2 + E_3}$$

$$w_{\text{stot}} = \sqrt{\frac{\sum E_{\mathrm{T},i}(\eta_i - \eta_{\max})}{\sum E_{\mathrm{T},i}}}$$



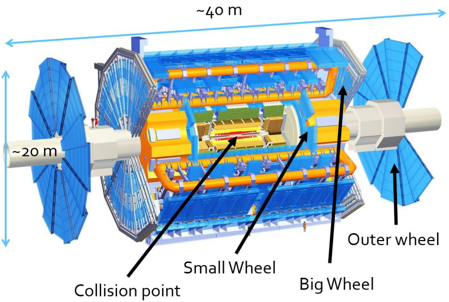
Muon system

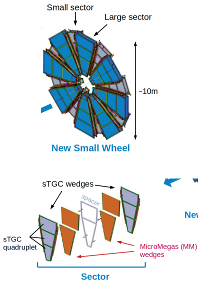
- Fast readout for triggering (no p_T measurement, only threshold passed and multiplicities):
  - Resistive Plate Chambers (RPCs) for barrel ($|\eta| < 1.05$)
  - Thin Gap Chambers (TGCs) for endcap ($1.05 < |\eta| < 2.4$)
- High resolution for precision tracking:
  - Monitored Drift Tubes (MDTs)
  - Cathode Strip Chambers (CSCs)
- Toroidal magnets provide average magnetic field of 0.5 T



New muon detectors for Run-3

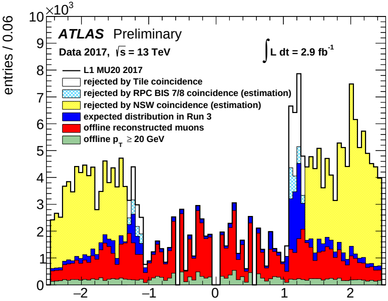
- **New Small Wheel (NSW):**
  - Designed to provide a ∼7 fold increase for fake muons rejection rate for the HL-LHC
  - Upgrade for Run 3 replacing the current first station of the muon end-cap system
  - The NSW exploits two detector technologies:
    - The **Micromegas (MM)** detectors optimized for precision tracking
    - The **small-strip TGC (sTGC)** optimized for triggering
- **New RPC detectors (RPC-BIS78)** will be added to the boundary region between barrel and endcap
- **New coincidences between TGC-BW and NSW/RPC-BIS78** will be introduced to mitigate fake triggers and to improve the p_T resolution





New muon detectors for Run-3

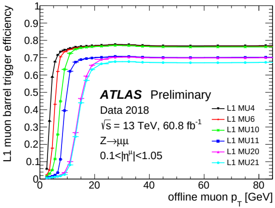
- **New Small Wheel (NSW):**
  - Designed to provide a ∼7 fold increase for fake muons rejection rate for the HL-LHC
  - Upgrade for Run 3 replacing the current first station of the muon end-cap system
  - The NSW exploits two detector technologies:
    - The **Micromegas (MM)** detectors optimized for precision tracking
    - The **small-strip TGC (sTGC)** optimized for triggering
- **RPC-BIS78:** new RPC detectors will be added to the boundary region between barrel and endcap
- **New coincidences between TGC-BW and NSW/RPC-BIS78** will be introduced to mitigate fake triggers and to improve the pT resolution

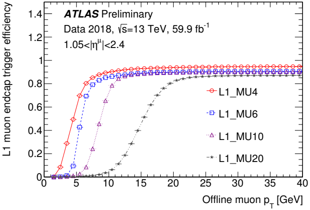


L1Muon system improvements

Run-2:

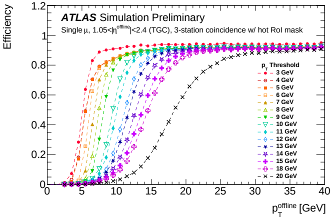
- 6 p_T thresholds combining RPC and TGC information at MUCTPI: MU4, MU6, MU10, MU11, MU20, MU21

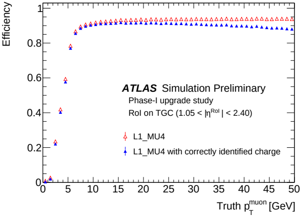




Run-3:

- RPC: 6 p_T thresholds (3 two-station for low p_T and 3 three-station for high p_T)
- TGC: 15 p_T thresholds, flags with track quality, charge information, etc.

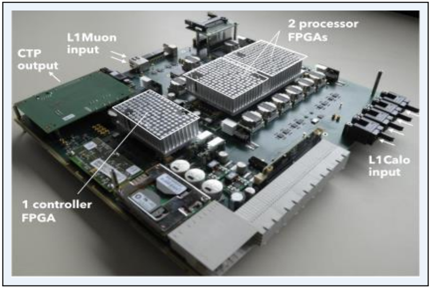




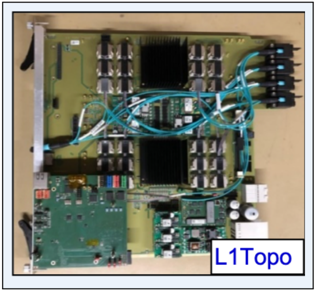
Level-1 Topological Trigger (L1Topo)

- The Level-1 topological processor (L1Topo) is a new system installed in 2016, operated in 2017 and 2018
- Applies topological selections on L1Calo and L1Muon inputs to reduce the L1 rate (invariant mass, angular cuts, etc.)
- In Run-2, L1Topo consisted of 2 ATCA modules with 2 processor FPGAs (Xilinx Virtex7) each
- In Run-3, L1Topo will consist of 3 ATCA modules with 2 FPGAs (Xilinx Ultrascale+) each with x3 processing power

Run-2 L1Topo module

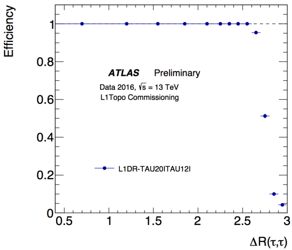


Run-3 L1Topo module

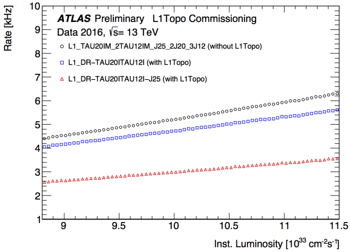


Level-1 Topological Trigger (L1Topo)

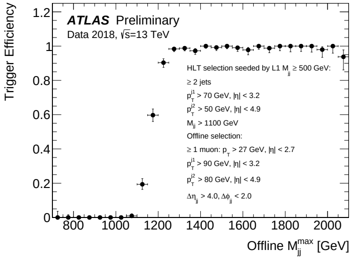
$H \to \tau\tau$ trigger efficiency



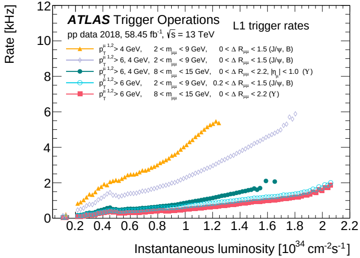
$H \to \tau\tau$ trigger rates



VBF L1Topo trigger efficiency



B-physics L1Topo trigger rates



High Level Trigger

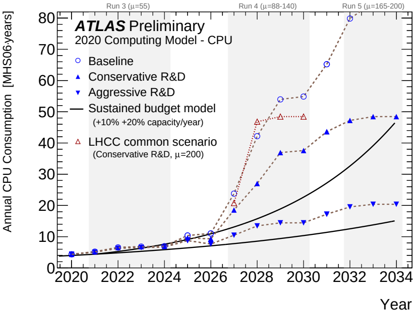
HLT software-based trigger (100 kHz $\rightarrow$ 1 kHz average)

- Large computing farm, O(45k) processing units in 2018
- Sophisticated selection algorithms run using full granularity detector information in either RoIs or the whole event using the ATLAS software framework Athena

ATLAS software framework for Run-3

Athena:

- Multi-purpose data processing framework of the ATLAS Experiment used for: Trigger, Simulation, Reconstruction and Analysis
- Designed in 2000s, based on Gaudi, core framework shared with LHCb
- The required CPU to run ATLAS reconstruction will increase dramatically for future LHC data taking (Run 4 and beyond)
- ATLAS is redesigning its core framework for native, efficient and user-friendly multi-threading support (AthenaMT) already for Run 3

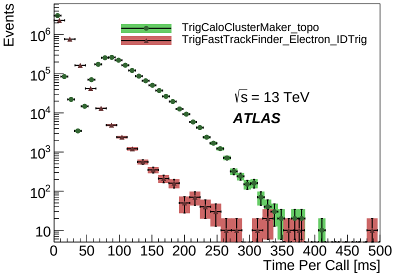


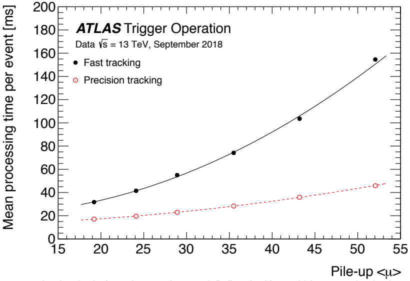
Run-3 HLT Framework

- ATLAS HLT Software requirements:
  - Needs to reconstruct physics objects and take decision within $\sim$0.5 s
  - Partially sharing of code with offline reconstruction, but cannot afford to reconstruct full event (up to 30 s)
  - Using partial event reconstruction in RoIs and early rejection
  - In Run2, HLT implemented custom trigger algorithm scheduling and data caching system
- Migration to AthenaMT for Run 3:
  - Major rewrite of HLT software
  - HLT trigger is not limited by memory, but will profit from the redesign in order to integrate more tightly with offline reconstruction
  - HLT requirements (partial event reconstruction in RoIs and early rejection) considered during design of AthenaMT from the beginning
    - Inter-event: multiple events are processed in parallel
    - Intra-event: multiple algorithms can run in parallel for an event
    - In-algorithm: algorithms can utilize multi-threading and vectorisation
  - Replacing own scheduling and caching by native Gaudi Scheduler, but still aided by HLT-specific Control Flow logic to ensure early termination
  - Partial event reconstruction provided by Event Views

HLT calorimeter and tracking software

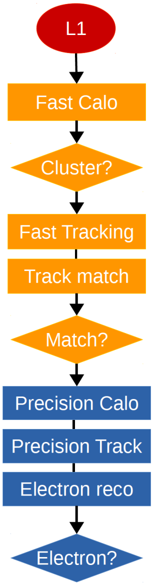
- Run 2:
  - **HLT calorimeter topological clustering:** can run either within an RoI (i.e., τ) or in full scan mode (i.e., jets) $\rightarrow$ double-peak in processing time distribution
  - **HLT tracking:** computationally/readout/network traffic intense to run tracking on complete event, RoI-based tracking only used up to now (electrons, muons, taus, b-jets, ...)
- Run 3:
  - **Regional tracking for leptonic signatures**
  - **Full Scan tracking for hadronic signatures** explored (Particle Flow jets, track-based MET)
    - Track reconstruction speed up pursued to be able to run in full scan mode





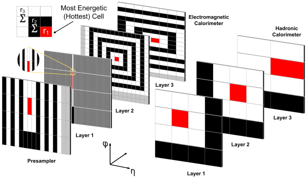
HLT sequences

- Trigger signature reconstruction is formed in several steps to achieve early rejection and meet HLT rate and processing time constraints
- Two types of algorithms:
  - Feature Extraction: builds objects (tracks, clusters, ...)
  - Hypothesis: apply selection cuts (p_T, invariant mass, ...)
- Typical HLT chain:
  1. Fast reconstruction:
     - Access to RoIs or full detector (e.g. jets, MET)
     - Often trigger-specific algorithms
  2. Precision reconstruction:
     - Full detector information available
     - Sophisticated offline-like algorithms

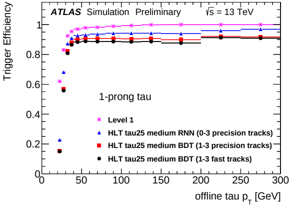


Machine learning at HLT

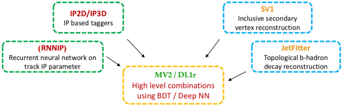
- Electron triggers:
  - Neural-network based Ringer algorithm used by default for electron triggers with $E_T > 15$ GeV since 2017
  - Fast decision and more discrimination power than simple linear cuts

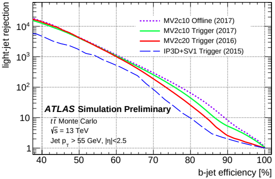


- Tau triggers:
  - The algorithm to identify the visible decay products of hadronic tau decays ($\tau_{\text{had-vis}}$) based on recurrent neural networks (RNN)
  - RNN employing information from reconstructed tracks and clusters as well as high-level discriminants



- b-jet triggers:
  - BDT based algorithm to separate b-jets from light and c-jet backgrounds, training performed with MC $t\bar{t}$
  - Move to DL1r in Run 3





ATLAS Trigger strategy and content of menus

- **Trigger strategy driven by the physics priorities** of the experiment
- During LS1, the trigger menu for Run-2 was widely discussed in the collaboration and defined after collecting the necessary feedback from the different groups
- Trigger menu considerations:
  - Fit within hardware, rate and CPU constraints
  - Trigger algorithms/selections close to offline reconstruction to maximize efficiency
  - Keep menus as inclusive as possible
  - Access corners of the phase space
  - Keep some margin for new ideas
- **Trigger menu evolution** carefully designed to maximize the physics output considering **different benchmark scenarios** (0.5e34, 1e34, 1.5e34, 2e34): higher thresholds and tighter identifications progressively applied
- General reluctance to change thresholds during the year
- During Run-2, menu reviewed every year, incorporating signature deliverables, improvements and brand new triggers
- During physics production years, **data taking stability becomes the dominating criteria**, ensure the continuity of the main triggers to minimize disruption of physics analyses
- Similarly in LS2 for Run 3 data taking

ATLAS Trigger Menu in Run-2

- Trigger Menu: collection of triggers and corresponding prescales
- Prescales are used to reduce the rate, prescale of N (e.g. N=100): only accept 1 out of N events

2015 Menu: ATL-DAQ-PUB-2016-001

2016 Menu: ATL-DAQ-PUB-2017-001

2017 Menu: ATL-DAQ-PUB-2018-002

2018 Menu: ATL-DAQ-PUB-2019-001

Standard high-μ pp menu in 2018

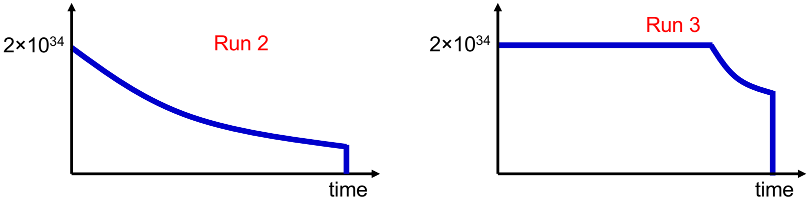
Trigger	Typical offline selection	Trigger Selection L1 [GeV]	Trigger Selection HLT [GeV]	L1 Peak Rate [kHz] $L=2.0\times10^{34}$ cm^{-2}s^{-1}	HLT Peak Rate [Hz] $L=2.0\times10^{34}$ cm^{-2}s^{-1}
Single leptons	Single isolated μ, $p_T > 27$ GeV	20	26 (i)	16	218
	Single isolated tight e, $p_T > 27$ GeV	22 (i)	26 (i)	31	195
	Single μ, $p_T > 52$ GeV	20	50	16	70
	Single e, $p_T > 61$ GeV	22 (i)	60	28	20
	Single τ, $p_T > 170$ GeV	100	160	1.4	42
Two leptons	Two μ, each $p_T > 15$ GeV	2×10	2×14	2.2	30
	Two μ, $p_T > 23, 9$ GeV	20	22, 8	16	47
	Two very loose e, each $p_T > 18$ GeV	2×15 (i)	2×17	2.0	13
	One e & one μ, $p_T > 8, 25$ GeV	20 (μ)	7, 24	16	6
	One loose e & one μ, $p_T > 18, 15$ GeV	15, 10	17, 14	2.6	5
	One e & one μ, $p_T > 27, 9$ GeV	22 (e, i)	26, 8	21	4
	Two τ, $p_T > 40, 30$ GeV	20 (i), 12 (i) (+jets, topo)	35, 25	5.7	93
	One τ & one isolated μ, $p_T > 30, 15$ GeV	12 (i), 10 (+jets)	25, 14 (i)	2.4	17
	One τ & one isolated e, $p_T > 30, 18$ GeV	12 (i), 15 (i) (+jets)	25, 17 (i)	4.6	19
Three leptons	Three very loose e, $p_T > 25, 13, 13$ GeV	$20, 2\times10$	$24, 2\times12$	1.6	0.1
	Three μ, each $p_T > 7$ GeV	3×6	3×6	0.2	7
	Three μ, $p_T > 21, 2\times5$ GeV	20	$20, 2\times4$	16	9
	Two μ & one loose e, $p_T > 2\times11, 13$ GeV	2×10 (μ)	$2\times10, 12$	2.2	0.5
	Two loose e & one μ, $p_T > 2\times13, 11$ GeV	$2\times8, 10$	$2\times12, 10$	2.3	0.1
Signle photon	One loose γ, $p_T > 145$ GeV	24 (i)	140	24	47
Two photons	Two loose γ, each $p_T > 55$ GeV	2×20	2×50	3.0	7
	Two γ, $p_T > 40, 30$ GeV	2×20	35, 25	3.0	21
	Two isolated tight γ, each $p_T > 25$ GeV	2×15 (i)	2×20 (i)	2.0	15
Single jet	Jet ($R = 0.4$), $p_T > 435$ GeV	100	420	3.7	35
	Jet ($R = 1.0$), $p_T > 480$ GeV	111 (topo: $R = 1.0$)	460	2.6	42
	Jet ($R = 1.0$), $p_T > 450$ GeV, $m_{jet} > 45$ GeV	111 (topo: $R = 1.0$)	420, $m_{jet} > 35$	2.6	36
b−jets	One b ($\epsilon = 60\%$), $p_T > 285$ GeV	100	275	3.6	15
	Two b ($\epsilon = 60\%$), $p_T > 185, 70$ GeV	100	175, 60	3.6	11
	One b ($\epsilon = 40\%$) & three jets, each $p_T > 85$ GeV	4×15	4×75	1.5	14
	Two b ($\epsilon = 70\%$) & one jet, $p_T > 65, 65, 160$ GeV	$2\times30, 85$	$2\times55, 150$	1.3	17
	Two b ($\epsilon = 60\%$) & two jets, each $p_T > 65$ GeV	4×15, $\lvert\eta\rvert < 2.5$	4×55	3.2	15
Multijets	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	4.8	10
	Six jets, each $p_T > 80$ GeV	4×15	6×70	4.8	4
	Six jets, each $p_T > 60$ GeV, $\lvert\eta\rvert < 2.0$	4×15	6×55, $\lvert\eta\rvert < 2.4$	4.8	15
E_T^{miss}	$E_T^{miss} > 200$ GeV	50	110	5.1	94
B-physics	Two μ, $p_T > 11, 6$ GeV, $0.1 < m(\mu,\mu) < 14$ GeV	11, 6	11, 6 (di-μ)	2.9	55
	Two μ, $p_T > 6, 6$ GeV, $2.5 < m(\mu,\mu) < 4.0$ GeV	2×6 (J/ψ, topo)	2×6 (J/ψ)	1.4	55
	Two μ, $p_T > 6, 6$ GeV, $4.7 < m(\mu,\mu) < 5.9$ GeV	2×6 (B, topo)	2×6 (B)	1.4	6
	Two μ, $p_T > 6, 6$ GeV, $7 < m(\mu,\mu) < 12$ GeV	2×6 (Υ, topo)	2×6 (Υ)	1.2	12
Main Rate B-physics and Light States Rate				86	1750 200

HI menu in 2018

Trigger	Signature	Trigger Selection L1 [GeV]	Trigger Selection HLT [GeV]	L1 Rate [kHz] $L=5.0\times10^{27}$ cm^{-2}s^{-1}	HLT Rate [Hz] $L=5.0\times10^{27}$ cm^{-2}s^{-1}	L1 Rate [kHz] $L=2.0\times10^{27}$ cm^{-2}s^{-1}	HLT Rate [Hz] $L=2.0\times10^{27}$ cm^{-2}s^{-1}
Leptons	Single μ	6	8	0.47	54	0.21	23
	Two μ	2×4	2×3	0.16	38	0.071	15
	Two $\mu^\dagger$	4	2×4	1.5	28	0. 93	15
	Single e (lhloose)	12	15	2.5	11	0.97	4.4
	Single e (loose)	16	20	0.93	35	0.36	14
	Two e (loose)	2×16	2×20	0.29	0.2	0.11	0.13
Photons	Single γ	12	20	2.5	61	0.97	25
Jets	Single jet ($R = 0.4$)	30	85	17.1	120	6.6	47
	Single jet ($R = 0.4$)†	12	60	0.24	13	1.3	69
	Single jet ($R = 1.0$)	50	180	14.4	66	5.6	26
	Single jet ($R = 0.4$, $\lvert\eta\rvert > 3.2$)	15	55	12.5	25	9.7	19
b-jets	Jet ($R = 0.4$) & μ	4 (μ), 15 (jet)	4 (μ), 60 (jet)	1.8	7	0.7	3
	Jet ($R = 0.4$) & $\mu^\dagger$	4 (μ)	4 (μ), 50 (jet)	-	-	0.93	6
	Jet ($R = 0.3$) & $\mu^\dagger$	4 (μ)	4 (μ), 40 (jet)	-	-	0.93	6
	Jet ($R = 0.2$) & $\mu^\dagger$	4 (μ)	4 (μ), 30 (jet)	-	-	0.93	6
MB	Very peripheral coll.	TE < 50, ZDC A & C	1 (#tracks)	1.4	95	1.2	261
	Peripheral coll.†	50 < TE < 600	none	0.034	34	0.12	116
	Central coll.†	TE > 600	none	0.029	29	1.2	120
MB PEB	Very peripheral coll.	TE < 50, ZDC A & C	1 (#tracks)	5.4	786	9.6	2048
	Peripheral coll.†	50 < TE < 600	none	0.3	298	0.9	920
	Central coll.†	TE > 600	none	0.8	822	0.23	2251
Global	Ultra central coll.	12000 < TE	4450 (ΣE_T^{FCal})	2.3	81	0.89	32
	Event shape†	600 < TE	top 0.1% v_2 in A/C side	-	-	1.2	0.6
	Event shape†	600 < TE	top 0.1% v_3 in A/C side	-	-	1.3	0.6
UPC	$\gamma+\gamma\to\gamma+\gamma$	4 < TE < 200 & 1 (γ)	FgapAC & < 15 (PH)	7.7	34	3.1	34
	$\gamma+\gamma\to\gamma+\gamma$	TE < 50 & 2×1 (γ)	FgapAC & < 15 (PH)	1.8	3	0.66	2.7
	$\gamma+\gamma\to\mu+\mu$	TE < 50 & 4 (μ)	4 (μ)	0.27	5	0.19	2.1
	$\gamma+\gamma$(A) $\to$ HF	TE< 200 & 4 (μ) & (!ZDC A or !ZDC C)	4 (μ)	0.25	1.5	0.19	0.6
	$\gamma+\gamma\to e+e$	TE < 200 & 7 (e)	12 (e)	0.09	1	0.03	0.5
	$\gamma+\gamma\to\gamma+$jet	TE < 200 & 7 (γ)	12 (γ)	0.09	6	0.03	2.4
	$\gamma+A\to$ jets	5 < TE < 200 & ((ZDC A & !ZDC C) or (ZDC C & !ZDC A))	20 (jet)	0.93	69	0.40	24
	$\gamma+\gamma\to$ jets	4 < TE < 200 & (!ZDC A & !ZDC C)	15 (jet, $R = 0.4$)	0.65	22	0.74	11
	$\gamma+\gamma\to$ jets	4 < TE < 200 & (!ZDC A & !ZDC C)	15 (jet, $R = 1.0$)	0.65	36	0.74	20
	high multiplicity	4 < TE < 200 & ZDC A & !ZDC C	FgapC & 35 (#tracks)	0.48	2.4	0.20	0.7
	high multiplicity	4 < TE < 200 & ZDC C & !ZDC A	FgapA & 35 (#tracks)	0.47	2.4	0.20	0.9
	$\gamma+A\to X^\dagger$	TE< 200 & ((ZDC A & !ZDC C) or (ZDC C & !ZDC A))	1 (#tracks)	0.56	15	0.50	12
	$\gamma+A\to VM^\dagger$	TE < 20	1-15 (#tracks)	-	-	16.5	60

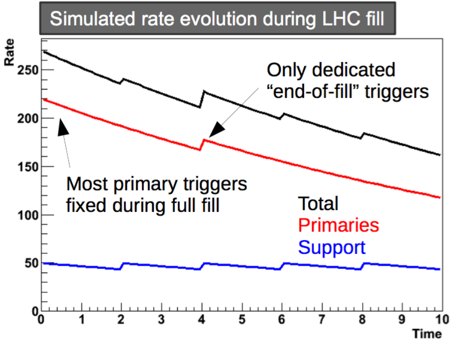
ATLAS Trigger Menu

- ATLAS Trigger Menu in Run 2:
  - **L1 menu** constrained to a maximum of **512 L1 items**
    - Maximum L1 output rate of 100 kHz
  - **HLT menu** consists of **O(1500) HLT chains**, out of which 300 primaries
    - Average HLT output rate of 1000 kHz (1500 kHz at peak luminosity)
- Average HLT output rate depends on the fill pattern and is limited by storage capacity:
  - In Run 2, HLT average rate $\sim$ 2/3 HLT peak rate
  - In Run 3, luminosity levelling expected for a long fraction of the run:
    - HLT average rate becoming closer to HLT peak rate
    - Need alternative strategy for end-of-fill triggers (B-physics)



ATLAS Trigger categories

- **Primary triggers:** used for physics analyses, typically running unprescaled
- **Support triggers:** used for bkg estimation and performance measurements
- **End-of-fill triggers:** used typically for B-physics, TLA, where can be activated at lower instantaneous luminosities where there is bandwidth available
- **Alternative triggers:** used for alternative online reconstruction algorithms
- **Backup triggers:** used to reduce the rate applying tighter selections
- **Calibration triggers:** used for detector calibrations



Trigger menu design

- Chains require either **full event building** or **partial event building (PEB)** with only subdetector information for recording into data streams
- Rate assignment rule of thumb:
  - **Generic triggers** serving multiple analyses are allowed to have a significant fraction of the rate: **O(10 Hz)**
  - **Specific triggers** targeting individual analysis: **O(1 Hz)** or higher rate accommodated at the end of fill
  - **Support triggers** get **O(0.5 Hz)** and represent 15% of the HLT bandwidth at peak lumi
- Triggers are accommodated to the menu with target rates achieved tightening selection requirements, applying isolation criteria, raising thresholds, or combining different objects

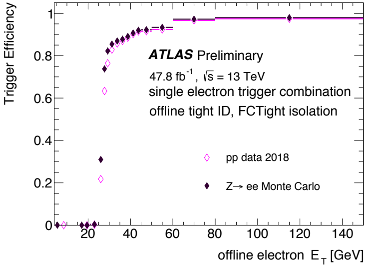
ATLAS Trigger Menu strategy

Lowest unprescaled single lepton triggers:

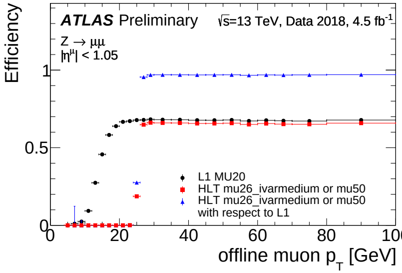
- Most expensive triggers in terms of rates, **O(200 Hz) each at peak lumi 2e34**, due to the large number of clients
- Using tight identification requirements and track-based isolation criteria at HLT

Typical offline selection	Trigger Selection		L1 Peak Rate [kHz]	HLT Peak Rate [Hz]
	L1 [GeV]	HLT [GeV]	$L=2.0\times10^{34}$ $cm^{-2}s^{-1}$	
Single isolated μ, $p_T > 27$ GeV	20	26 (i)	16	218
Single isolated tight e, $p_T > 27$ GeV	22 (i)	26 (i)	31	195

Single electron trigger 26 GeV

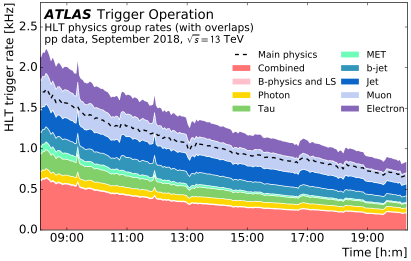


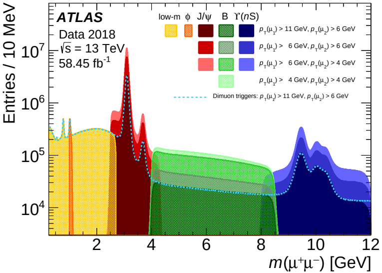
Single muon trigger 26 GeV



ATLAS Trigger Menu strategy

- Aiming for a trigger menu as inclusive as possible, with generic triggers and specific triggers targeting a large variety of final states!
- Physics use cases:
  - **Electron:** Generic analyses (W, Z, dibosons, $t\bar{t}$, etc.)
  - **Muon:** Generic analyses (W, Z, dibosons, $t\bar{t}$, etc.)
  - **Jet:** jet production, dijet resonances searches, etc.
  - **b-jet:** $H \to b\bar{b}$, $t\bar{t}$, etc.
  - **Missing E_T (MET):** SUSY searches, etc.
  - **Tau:** $H \to \tau\tau$, searches, etc.
  - **Photon:** $H \to \gamma\gamma$, γ production, etc.
  - **B-physics and Light States:** J/ψ, Υ, etc.



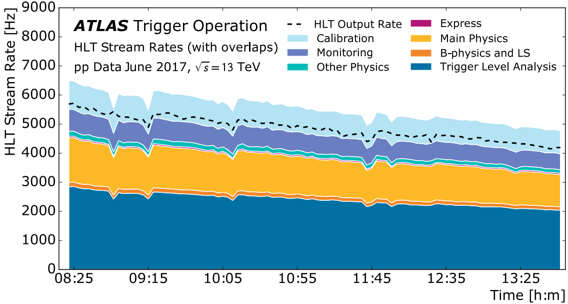


Trigger rates and bandwidth allocation

Different streams defined such as:

- **Express**: stream for fast offline monitoring and detector calibration (few Hz)
- **Main Physics**: including majority of the events using full event building
- **B-physics and Light States (LS)**: fraction of the data acquired and parked (delayed stream)
- **Trigger Level Analysis (TLA)**: circumvent the bandwidth limitation using PEB ($<5\%$ standard event size recorded) for instance for di-jet resonance searches

Expect more felxibility to accomodate high-rate triggers in dedicated delayed streams for Run-3

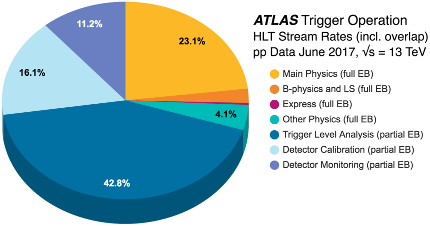


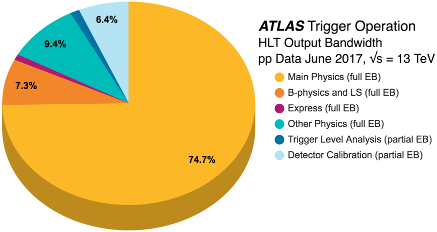
Trigger rates and bandwidth allocation

Different streams defined such as:

- **Express**: stream for fast offline monitoring and detector calibration (few Hz)
- **Main Physics**: including majority of the events using full event building
- **B-physics and Light States (LS)**: fraction of the data acquired and parked (delayed stream)
- **Trigger Level Analysis (TLA)**: circumvent the bandwidth limitation using PEB ($<$ 5% standard event size recorded) for instance for di-jet resonance searches

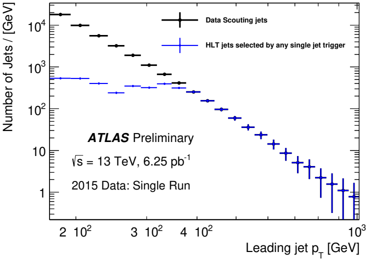
Expect more felxibility to accomodate high-rate triggers in dedicated delayed streams for Run-3



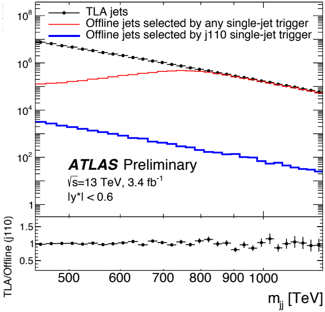


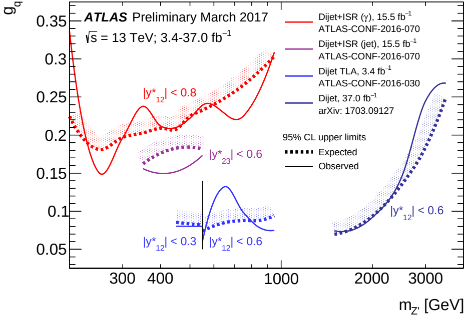
Trigger Level Analysis (TLA)

- **Novel idea to circumvent the bandwidth limitation using partial event building** ($<$ 5% standard event size recorded)
- Prescale factors normally applied to the HLT jet triggers in the standard stream
- Large gain in statistics for the data scouting stream for $p_T < 400$ GeV
- Important for low mass dijet searches $\rightarrow$ **Increase sensitivity**



ATLAS-CONF-2016-030





Summary

- ATLAS TDAQ system very successfully and efficiently recording data in Run 1 and Run 2, under tight constraints and challenging conditions
- TDAQ hardware upgrades and software improvements needed to keep excellent performance for physics in terms of acceptance and efficiency
- Run 3 improvements: new L1 hardware and improved HLT algorithms
  - Upgraded L1Calo and L1Muon system The Run 3 trigger system will exploit all of the capabilities that the new hardware components will bring.
  - Better harmonization with respect to offline reconstruction with AthenaMT
- Flexible trigger menu to select the data used in a wide range of physics analyses
  - Make best possible use of the available bandwidth for physics: more precise measurements, extend phase space for new physics searches
- Run-3 trigger priorities will be twofold in the coming months:
  - Define a robust commissioning strategy for the brand-new systems
  - Support physics from day 1

References

- ATLAS public results:
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults
  https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ComputingandSoftwarePublicResults
- ATLAS Liquid Argon Calorimeter Phase-I Upgrade Technical Design Report: ATLAS-TDR-022, https://cds.cern.ch/record/1602230
- Technical Design Report for the Phase-I Upgrade of the ATLAS TDAQ System: ATLAS-TDR-023, https://cds.cern.ch/record/1602235