The ATLAS Trigger Menu design for higher luminosities in Run 2

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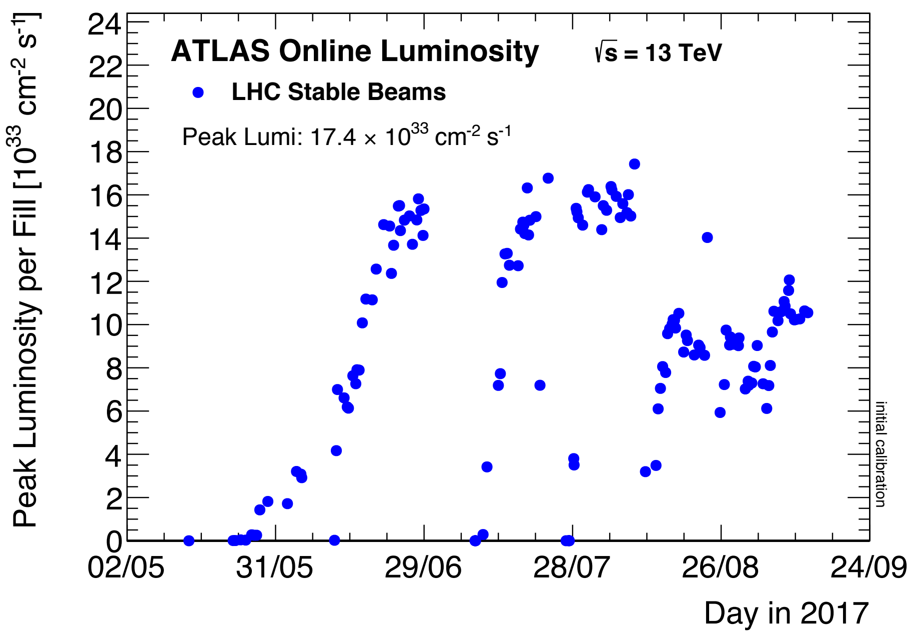
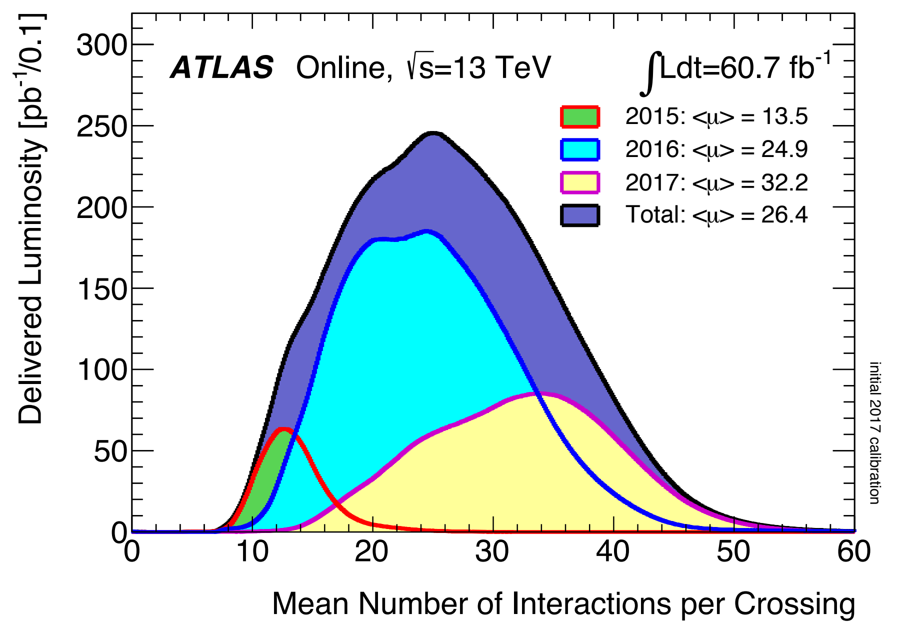
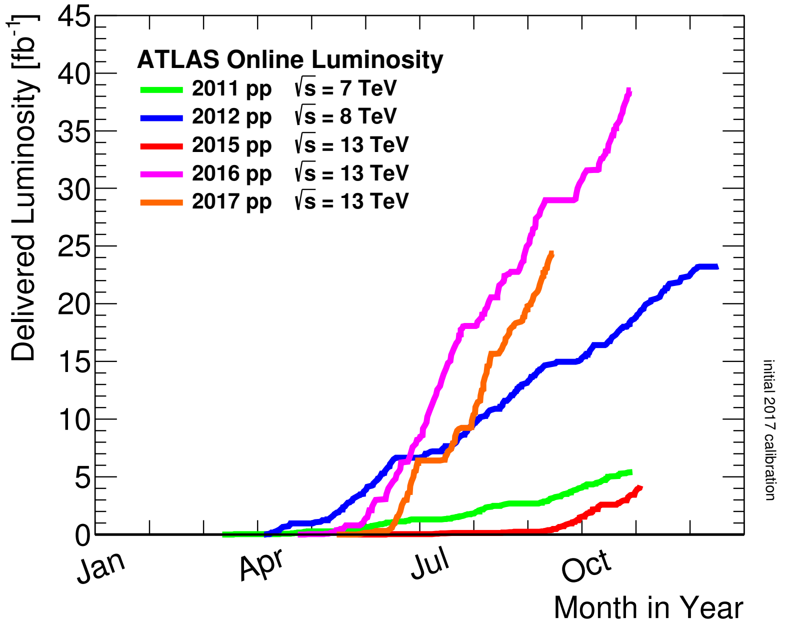
NEC 2017
Budva
25-29 Sept. 2017

Introduction

- Excellent performance of LHC and ATLAS during 2017:
  - record peak luminosity: **1.74×10^{34} cm^{-2} s^{-1}**
  - peak interactions/bunch crossing (pileup) : **μ~56**
  - recorded luminosity during 2017 to date: **~22fb^{-1}**







- The ATLAS trigger system operated successfully in Run-1 and Run-2
- Conditions become more and more challenging:

	bunch spacing	√s	luminosity	peak pileup
Run-1	50 ns	8 TeV	< 1e34	~30
Run-2	25 ns	13 TeV	1 - 2e34	~56

- Many improvements in the ATLAS Trigger system for Run-2 - see talk by Savanna Shaw

Trigger Chain definition

- Rate of collisions in ATLAS: 40MHz ⟶ only events considered interesting are kept for analysis
- Selection of events is done following physics criteria in two steps:
  - Level-1 (L1) trigger:
    - First and simple preselection based on coarse information from the detector
    - Determine Regions-of-Interest (RoI) from calorimeter and muon system.
    - Require presence of muons, calorimeter energy deposits consistent with e/gamma, taus, jets, MET, etc. E.g:
      - EM22: require a signal in EM calorimeter with E_T>22 GeV
      - MU20: require a signal in the muon system with a muon of E_T > 20 GeV
    - Many possible combinations of object selections
  - High-level Trigger (HLT) algorithm
    - Activated if L1 is passed
    - Fast algorithms run on RoIs with full event information
    - Designed to be as close to offline as possible
- Sequence Level 1 criteria + HLT criteria form a trigger chain.
- Example: single electron trigger chain

40 MHz Read-Out → Peak of 100kHz @ L1 → Average of 1kHz @ HLT

L1 trigger EM22 → [OBJECT RECO: Tracking, Electron clustering, electron reconstruction] + [SELECTION: Energy calibration, electron selection]

HLT trigger

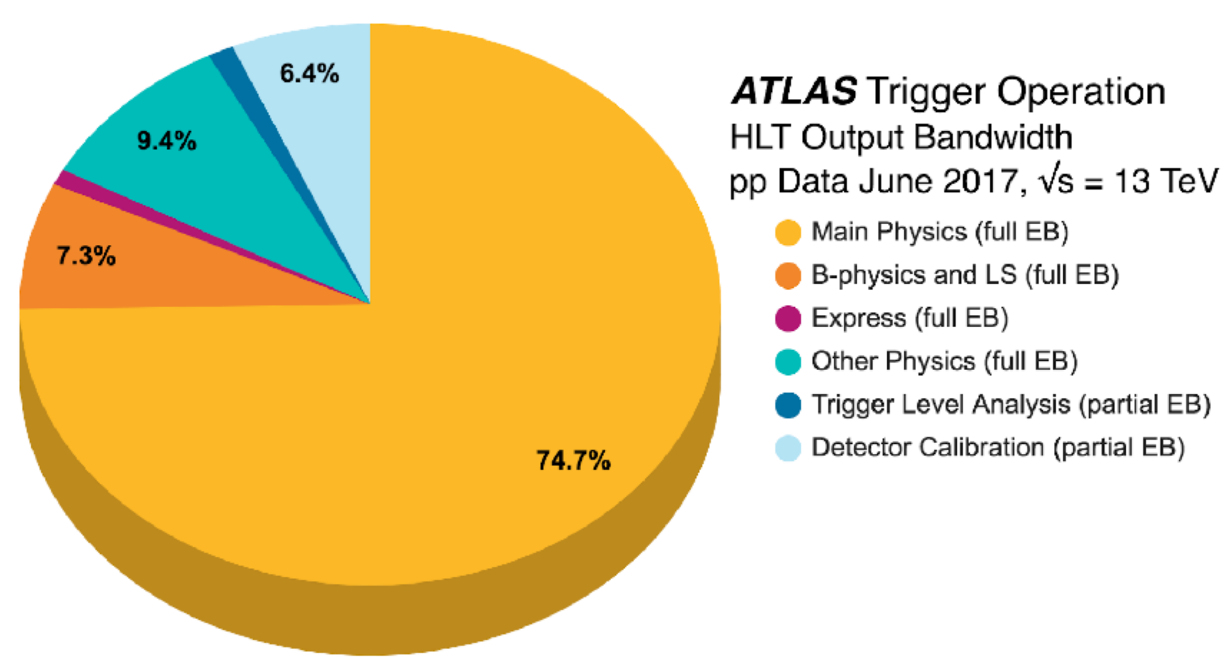
Trigger Menu Design criteria

- Trigger Menu: list of chains to be used in data-taking, together with rate allocation depending on luminosity

- Objective in menu design: cover the wide ATLAS physics program with no gaps in physics coverage and within trigger system constraints

- The trigger menu needs to respect several limitations:
  - Detector readout: only 100kHz can be sent to the HLT
  - CPU limitations (cannot perform full ID tracking on every event)
  - Offline storage limitation: HLT physics output is limited to 1kHz average

- Trigger strategy for bandwidth allocation is developed to maximize physics coverage
  - Inputs from:
    - Physics program in ATLAS:
      - Most bandwidth given to generic triggers (e.g. MET or inclusive single electron/muon with low p_T thresholds)
      - More dedicated/multiobject triggers with smaller rates (a few Hz) in order to cover specific phase spaces.
    - Performance groups
    - Detector experts (monitoring, calibration)



Final Trigger Menu

- Large set of trigger chains implemented:
  - ~2000 types of chains
  - It needs to keep a **good balance** between the trigger signature groups

- Triggers may be prescaled by a factor of p (only 1/p events is considered by the trigger) in order to fulfil the tigger system limitations

- Physics analyses need trigger stability
  ⟶ Define Primary triggers which are never prescaled. When major change in luminosity, the primaries can change

- All chains properly validated and simulated in Monte Carlo

Trigger	Typical offline selection	Trigger Selection: Level-1 (GeV)	Trigger Selection: HLT (GeV)	Level-1 Peak Rate (kHz), $L = 5 \times 10^{33}$ cm^{-2}s^{-1}	HLT Peak Rate (Hz), $L = 5 \times 10^{33}$ cm^{-2}s^{-1}
Single leptons	Single iso μ, $p_{\rm T} > 21$ GeV	15	20	7	130
	Single e, $p_{\rm T} > 25$ GeV	20	24	18	130
	Single μ, $p_{\rm T} > 42$ GeV	20	40	5	[illegible]
	Single τ, $p_{\rm T} > 90$ GeV	60	80	2	[illegible]
Two leptons	Two μ's, each $p_{\rm T} > 11$ GeV	2×10	2×10	[illegible]	[illegible]
	Two μ's, $p_{\rm T} > 19, 10$ GeV	15	18, 8	[illegible]	[illegible]
	Two loose e's, each $p_{\rm T} > 15$ GeV	2×10	[illegible]	[illegible]	[illegible]
	One e & one μ, $p_{\rm T} > 10, 26$ GeV	20 (μ)	[illegible]	[illegible]	[illegible]
	One loose e & one μ, $p_{\rm T} > 19, 15$ GeV	[illegible]	[illegible]	[illegible]	[illegible]
	Two τ's, $p_{\rm T} > 40, 30$ GeV	[illegible]	[illegible]	[illegible]	[illegible]
	One τ, one μ, $p_{\rm T} > 30, 15$ GeV	[illegible]	[illegible]	[illegible]	[illegible]
	One τ, one e, $p_{\rm T} >$ [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Three leptons	Three loose [illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	0.2
	[illegible]	[illegible]	[illegible]	[illegible]	< 0.1
[illegible]	[illegible]	[illegible]	[illegible]	8	20
[illegible]	[illegible]	[illegible]	35, 25	1.5	12
	[illegible]	[illegible]	2×20	1.5	7
[illegible]	[illegible]	100	360	0.9	18
	[illegible]	100	360	0.9	23
[illegible]	[illegible]	50	70	0.7	55
[illegible]	[illegible] $p_{\rm T} > 95$ GeV	3×40	4×85	0.3	20
	[illegible], each $p_{\rm T} > 70$ GeV	4×20	5×60	0.4	15
	Six jets, each $p_{\rm T} > 55$ GeV	4×15	6×45	1.0	12
$b-$jets	One loose b, $p_{\rm T} > 235$ GeV	100	225	0.9	35
	Two medium b's, $p_{\rm T} > 160, 60$ GeV	100	150, 50	0.9	9
	One b & three jets, each $p_{\rm T} > 75$ GeV	3×25	4×65	0.9	11
	Two b & two jets, each $p_{\rm T} > 45$ GeV	3×25	4×35	0.9	9
$b-$physics	Two μ's, $p_{\rm T} > 6, 4$ GeV plus dedicated b-physics selections	6, 4	6, 4	8	52
Total				70	1400

~2000 trigger chains to maximize the reach of ATLAS physics program with 2017 high luminosity + pile-up

Rates and CPU tools

- The Trigger menu is designed for different luminosity conditions ⟶ different prescale sets for different luminosity points
- Need precise rate and CPU usage predictions in order to design the prescale sets for different beam conditions and to study new triggers
- Special datasets called Enhanced bias are used for rate and CPU estimations:
  - Only L1 triggers, select dataset enriched in medium and high-p_T physics.
  - Recorded every time data-taking conditions change significantly (increased pileup or lumi)
  - Can be used to study new HLT selections minimising input bias and for validation of existing triggers

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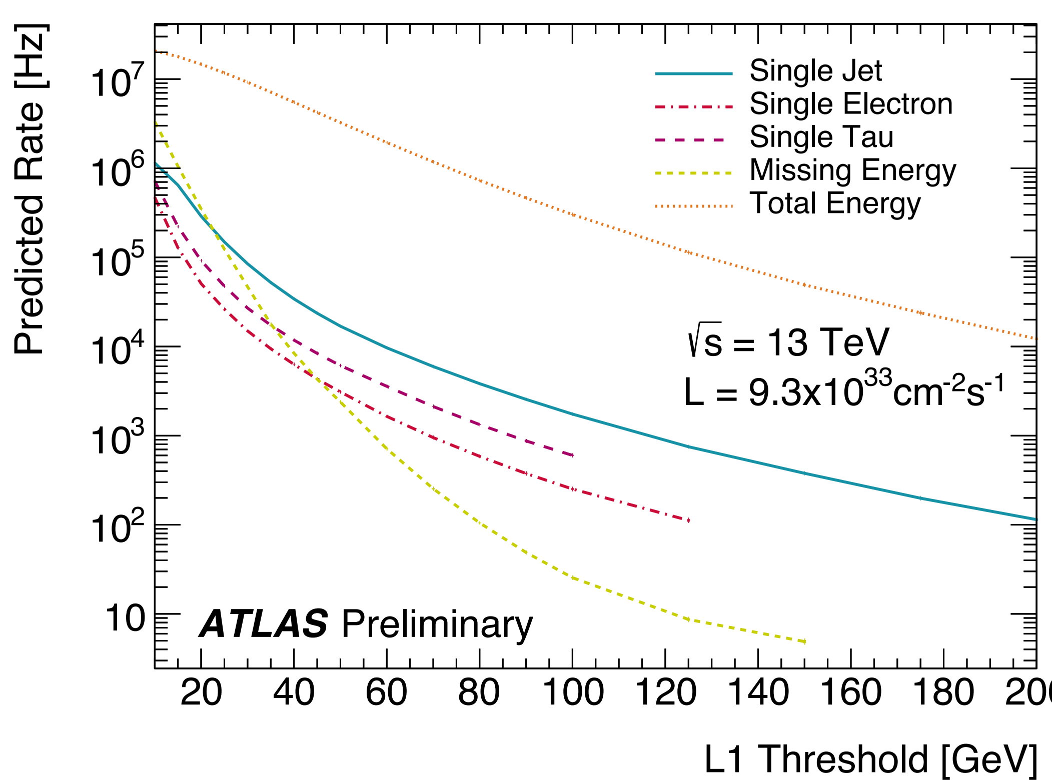
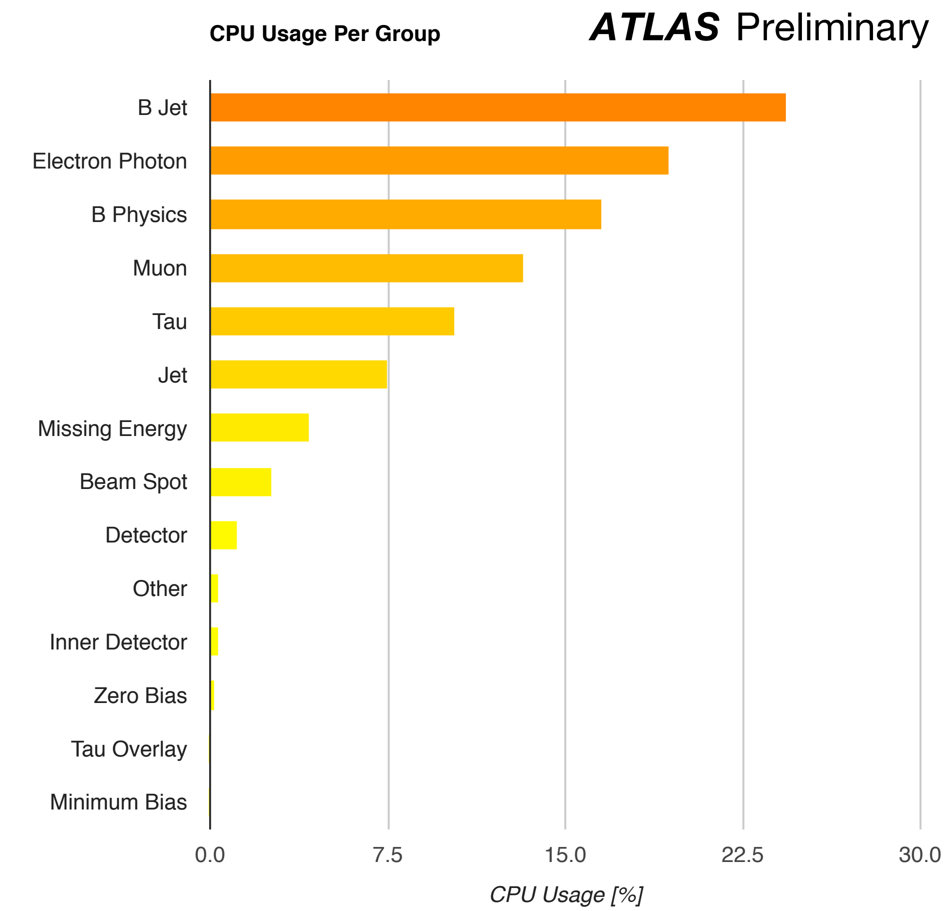
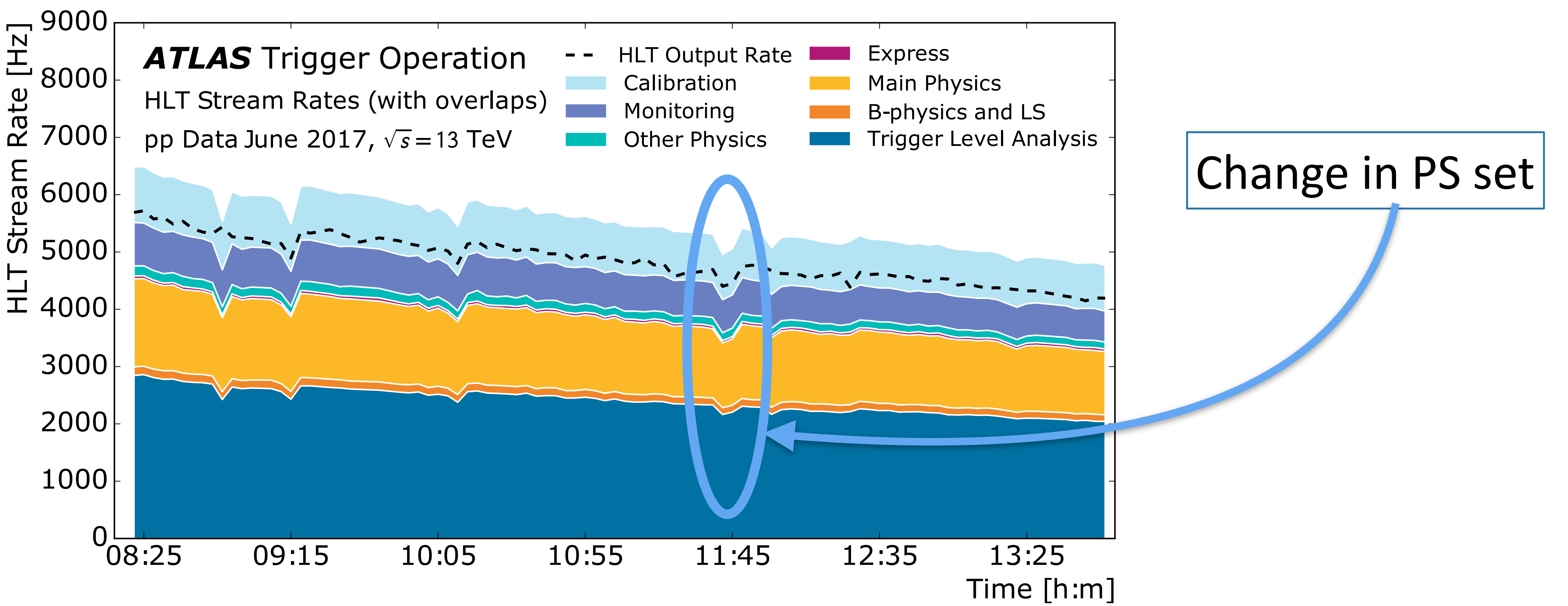




Trigger Menu Operations

- New menus are deployed at P1 every few weeks, to add newly requested chains and adjustments.
- Before deployment, the menu is **carefully validated** by reprocessing and rate prediction
- Individual trigger rates are adjusted via **prescale (PS) sets** at L1 and at HLT to optimise the bandwidth usage, depending on the instantaneous **luminosity**
- In 2017, prescale sets are defined **up to 2.0x10^{34} cm^{-2} s^{-1}**



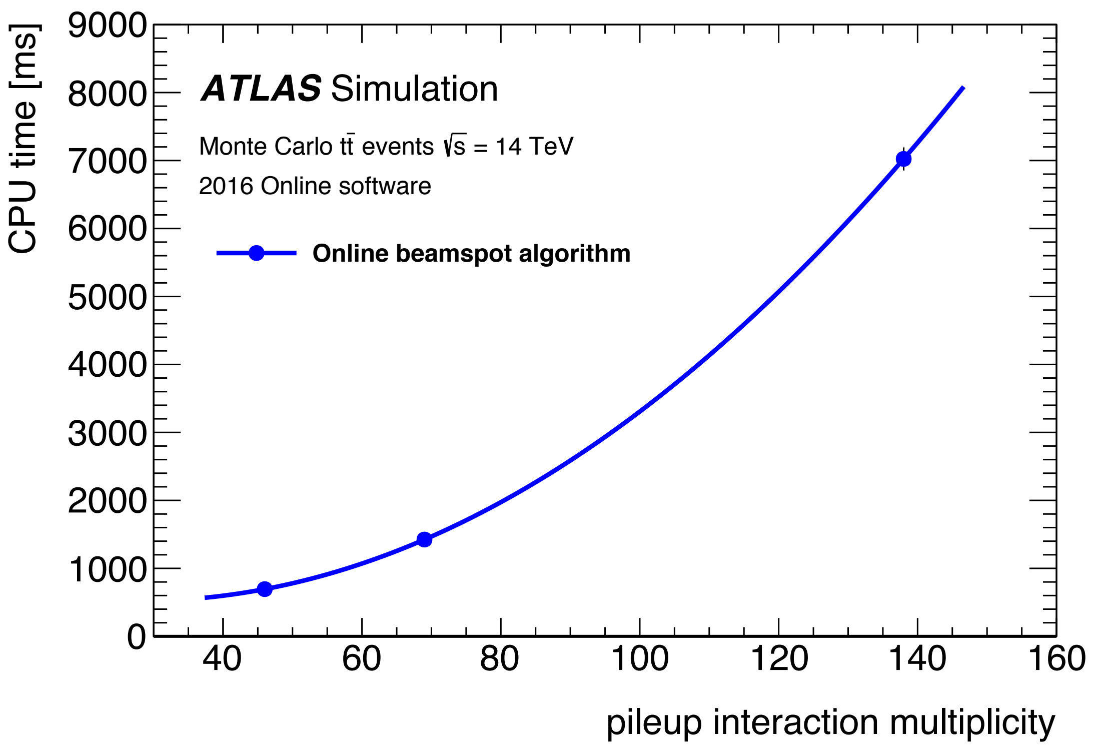
Performance in 2017

- Performance and efficiencies studies show **good trigger behaviour** that satisfy the requirements from the ATLAS physics program.
- Several **improvements** for higher luminosity and pile-up conditions

CPU usage reduction

- HLT PC farm has a finite size (~40k processing slots)
- Running many complex trigger algorithms at higher luminosities & pile-up conditions
  → heavy CPU usage in the HLT farm.

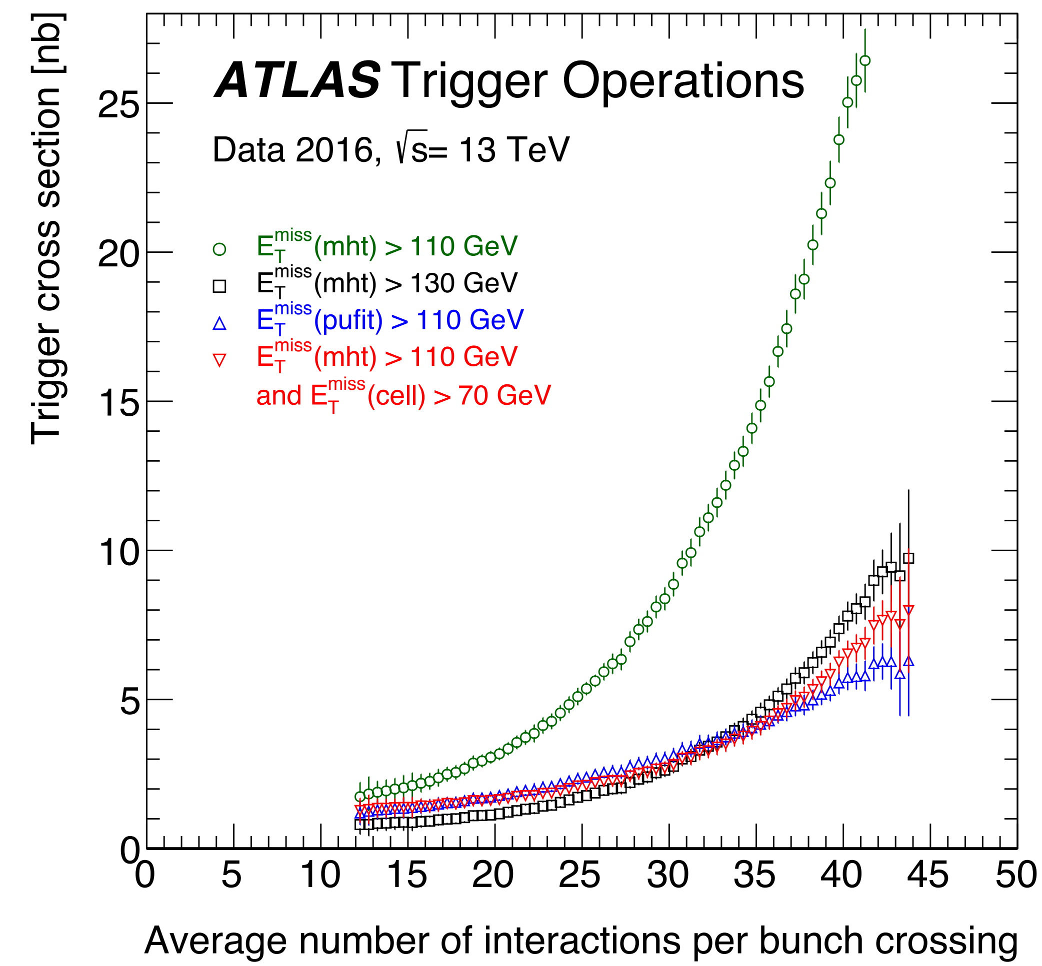
- Some algorithms scale exponentially with pileup.
- Large CPU reduction campaign was achieved successfully for 2017 data taking to keep CPU usage within the available resources
  - technical improvements to trigger software: software optimisation
  - algorithm improvements to speed up
  - menu/trigger-sequence-order optimisations
  - higher rejection at earlier stage
  - more effective usage of shared algorithms by multiple triggers

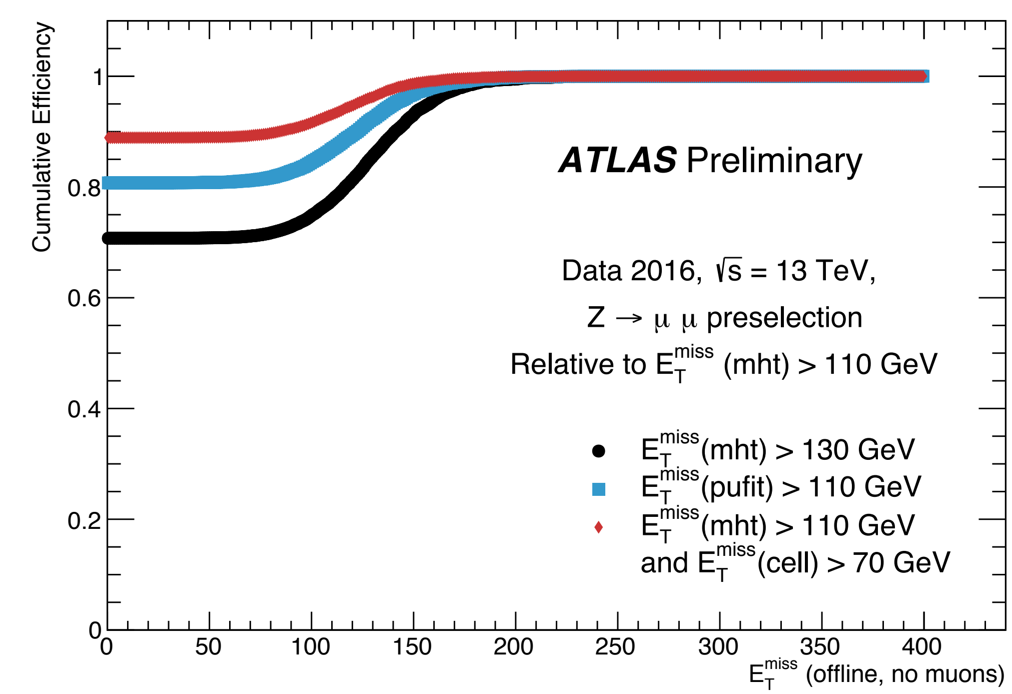


Performance in 2017

Missing Transverse Energy (MET)

- MET triggers rates present a dependence on pile-up.
- By mitigating it we can lower the thresholds (gain in efficiency) with no increase in rates
- Several new algorithms studied:
  - mht: cut on the negative sum of transverse energy of jets (missing H_T)
  - cell: cut on the negative sum of transverse energy of cells above noise threshold
  - pufit: identify calorimeter energy deposits from pile-up and subtract them from MET
- Best performance given by **pufit**:
  - strongest reduction in rate as a function of pile-up
  - reaches an efficiency plateau as quickly as mht+cell combination to speed up
  - **pufit used by default in 2017**



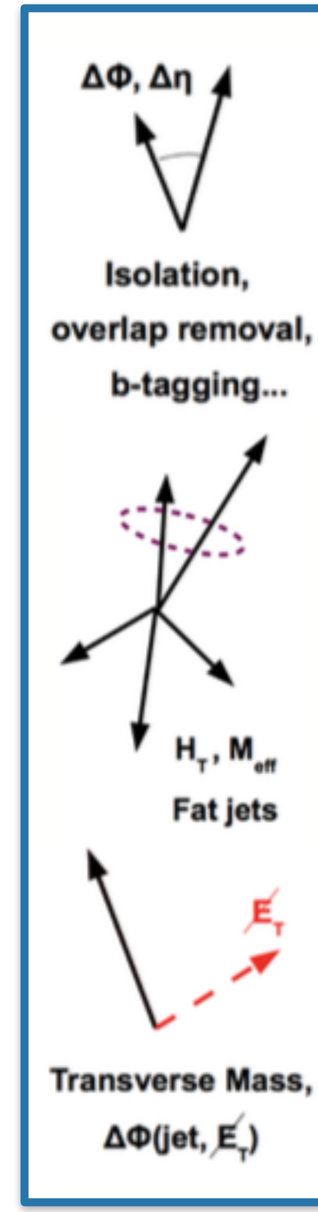


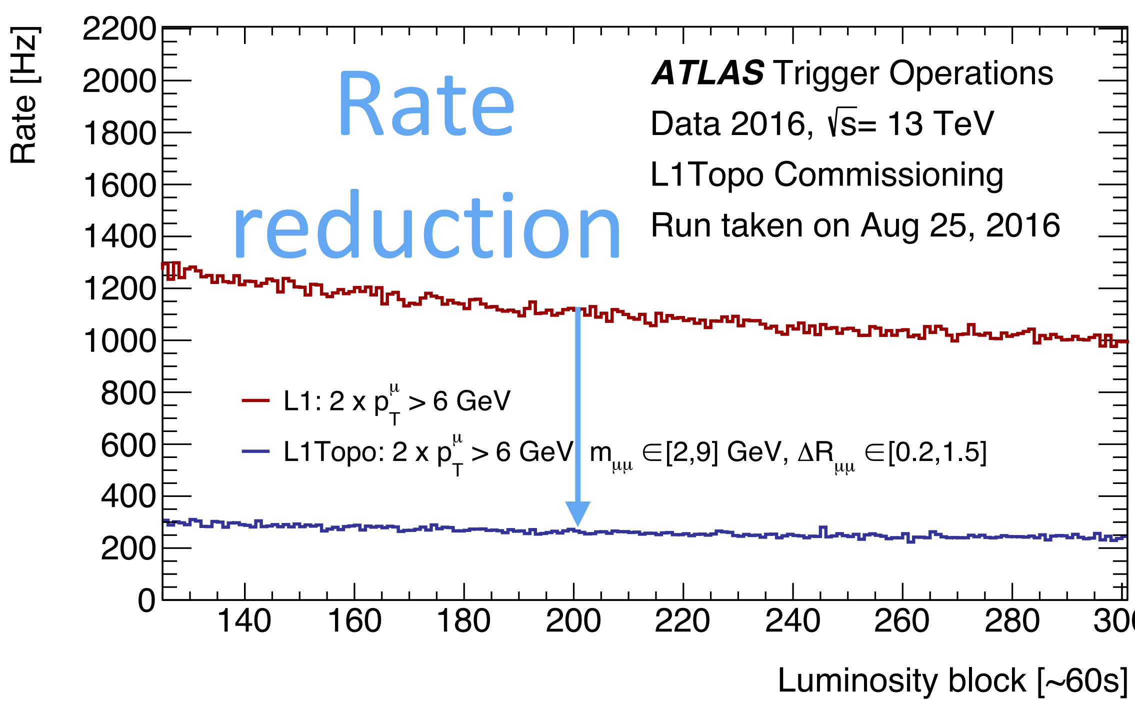
- This is an example of an exercise done in many triggers to improve their performances

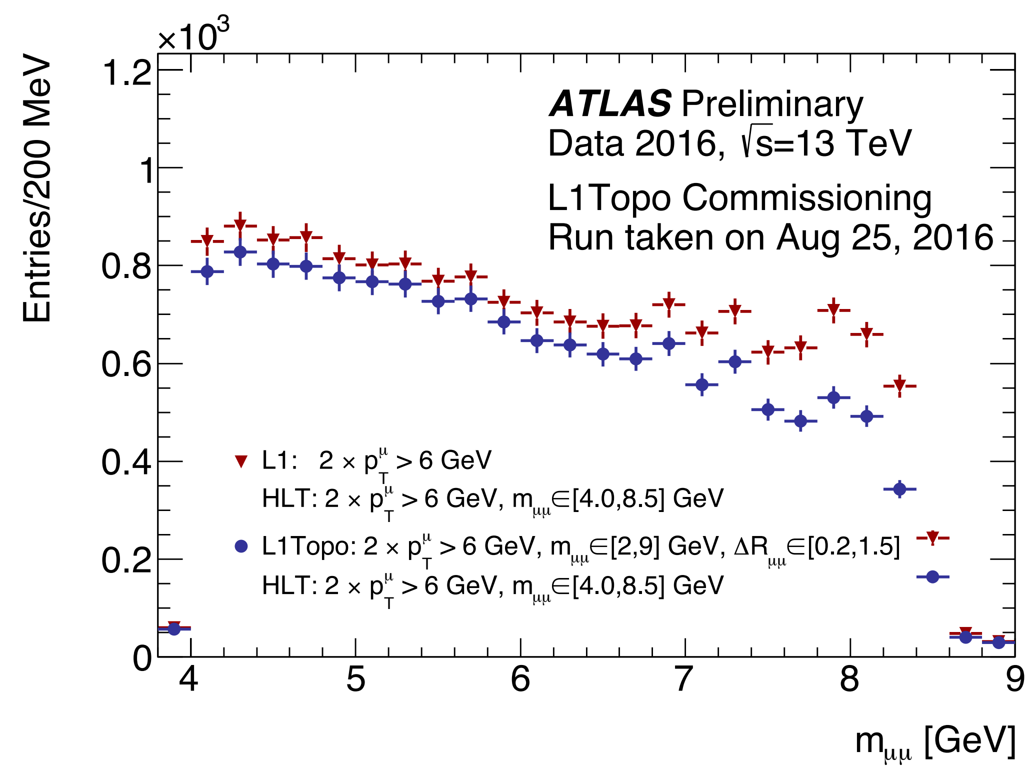
L1 Topological Triggers

- FPGA-based algorithms that analyse geometrical information on candidate trigger objects
- Event topological selections using **muon and calorimeter information at Level-1**
- Suppresses backgrounds and **reduces rates** at L1, allowing to keep thresholds more optimally low.
- Essential for some signatures with 2017 luminosity conditions.

- Physics examples
  - High mass di-jet pairs from VBF processes → $M_{inv}(j_1, j_2)$
  - Di-muons with a limited opening angle from *B*-hadrons → $\Delta R(\mu_1, \mu_2)$:
    - L1 rate reduced by a factor of 4 with only 10% loss in HLT efficiency







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Summary

- The definition of the trigger menu is a complex procedure
  - take into account inputs from several groups: physics analyses, detector calibration, monitoring, etc
  - respect technical limitations: bandwidth, CPU usage, etc.

- The ATLAS trigger system has been upgraded
  - to cope with the challenging conditions it's facing in Run2 with higher luminosity.
  - to have no significant efficiency loss despite the challenging conditions

- Several steps in monitoring and validation ensure correct behaviour of the trigger menu after every adjustment or inclusion of new triggers to the system

- The Trigger Menu evolves with changing conditions and the increasing luminosity conditions at the end of 2017

- The performance has been successful so far during Run-2, allowing for collection of lots of good data used by analyses in ATLAS

Backup

Links to ATLAS public results

- ATLAS public results:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- ATLAS public results on the Trigger System:
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TriggerPublicResults