The ATLAS Trigger in 2017

Improvements, Performance and Challenges

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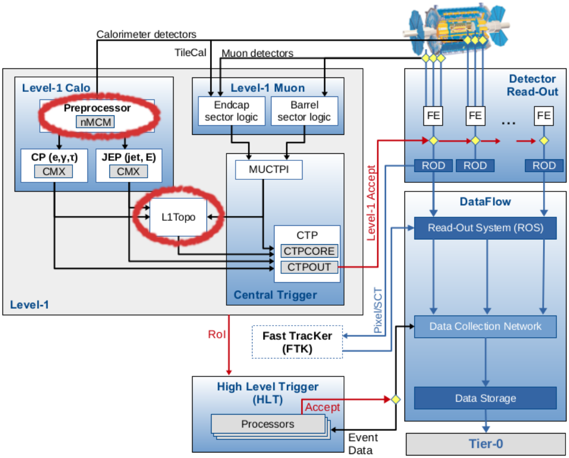
July 11, 2018

The ATLAS Trigger System[1]

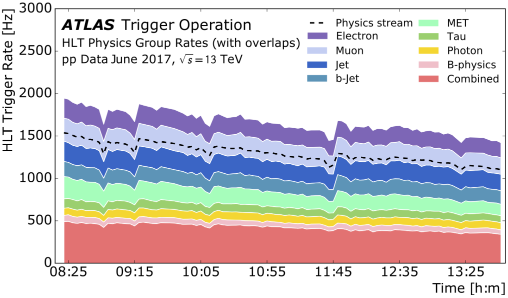
- ATLAS runs a two level trigger system
- Level-1:
  - A hardware based trigger, using low granularity muon and calorimeter objects
  - 100kHz output, 2.5μs latency
- High Level Trigger (HLT):
  - A software based trigger, using full detector information
  - $\approx$ 1kHz physics output, 1.3 MB event size, 400ms latency @$\mu = 55$



- Better selection at Level-1 added in 2017
  - L1Topo (event-topology based selection using L1 objects) was brought fully online
  - Bunch-crossing dependent pileup subtraction and better noise calibration added to L1Calo
- HLT updates made to combat increased pileup and save CPU usage

2017 Trigger Menu [2] [3]

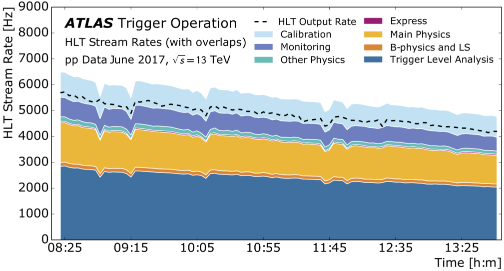
- The main physics stream attempts to match bandwidth usage to the ATLAS' physics priorities
  - Simple single object triggers dominate the rate
  - Full menu >2000 chains
- As much as possible, aim to keep main trigger thresholds stable between successive runs: analysis stability
  - For example, single electron/muon p_{T} thresholds stable through 2015 → 2018
  - Requires updates to stay ahead of pileup: algorithmic improvements, isolation (i), etc.

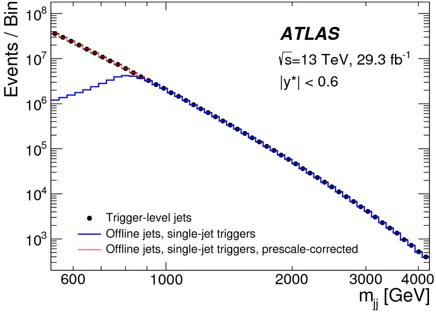


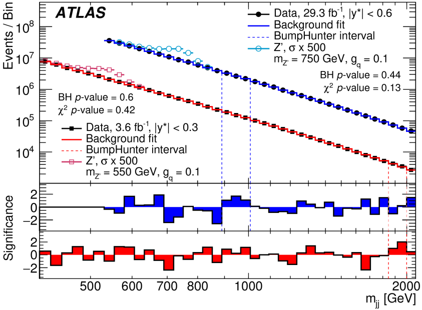
Object	Threshold [GeV]
Electron	26 (i)
Di-lectron	17 (i)
Muon	26 (i)
Di-muon	22, 8 || 14, 14
Photon	140
Di-photon	20 (i), 20 (i)
Tau	160
Di-tau	35, 25
Jet (small-r)	420 (GSC)
Jet (large-R)	460
b-jet (40%)	225 (GSC)
Di-*b*-jet (60%)	175, 60 (GSC)
$E_{\mathrm{T}}^{\mathrm{miss}}$	110

2017 Trigger Menu[3] + TLA[4]

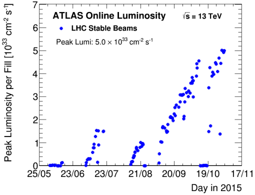
- Additional rate is allocated to calibration and monitoring streams
- Trigger level analysis: reduced event size, only HLT-jets, $\approx 0.5\%$ of a full event $\rightarrow$ record at a higher rate
- Allows significantly lower mass thresholds to be explored

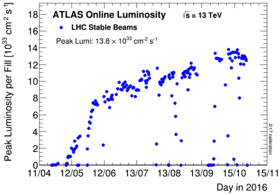


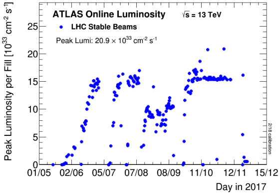




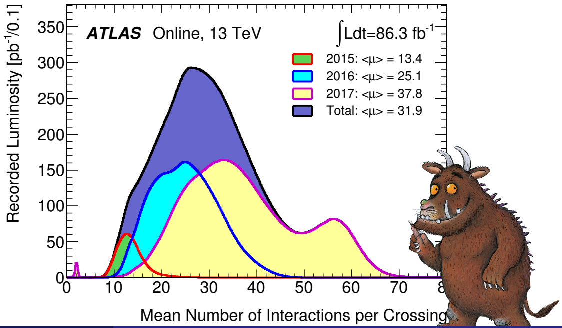
LHC Delivered in 2017[5]





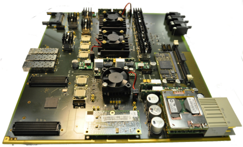


- The LHC has been steadily increasing the luminosity delivered to ATLAS since the start of Run 2
  - More luminosity means more data, obviously a good thing!
  - Consistent delivery from the LHC has pushed the data recorded by ATLAS in Run 2 beyond 100fb^{-1} in 2018
- Increased luminosity, brings more $p-p$ interactions in the same bunch crossing: Pileup!
  - Pileup interactions produce additional objects that can also fire triggers, rates increase, some exponentially!
  - HLT CPU usage scales by $\approx \mu^2$ at constant luminosity!

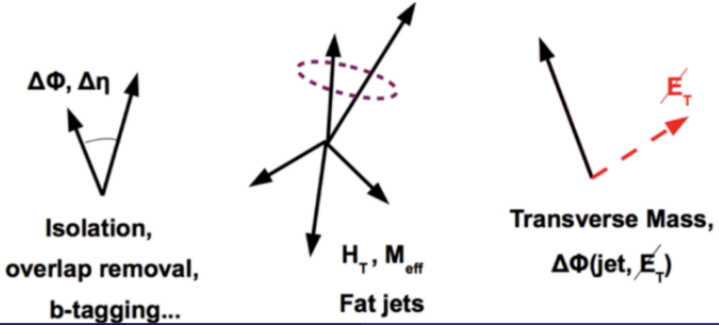


L1Topo - Introduction[6]

- Level-1 Topological trigger uses geometrical and kinematic information alongside energy thresholds to reduce Level-1 rate
    - Uses L1Calo and L1Muon trigger objects as input
    - Allows sophisticated selections to be made before the detector information is read out (100kHz limit)
    - Outputs up to 128 algorithm pass/fail decisions to the central trigger

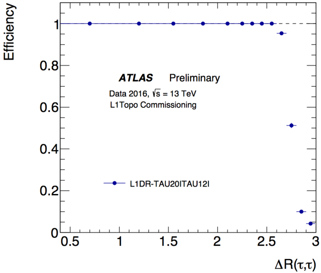


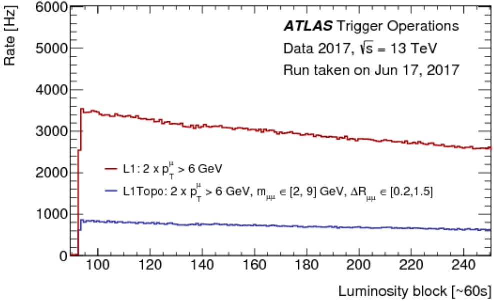
- Significant rate reductions achieved, and efficiencies recovered in the face of the extreme pileup conditions

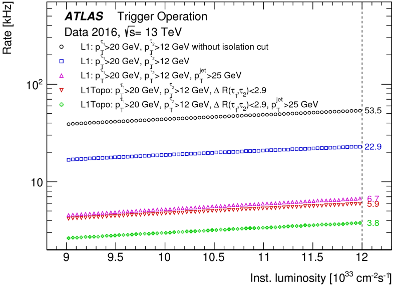


L1Topo for low-p_T di-lepton triggers [7]

- Making topological requirements allows use to make significant rate savings whilst maintaining efficiency
  - Reduce L1 rate by orders of magnitude
  - Maintain offline efficiency in needed region
- Around a 4× rate reduction in di-muon chains by requiring $0.2 < \Delta R_{\mu\mu} < 1.5$
- Large rate savings also in $H \to \tau\tau$ chains by requiring $\Delta R_{\tau\tau} < 2.9$

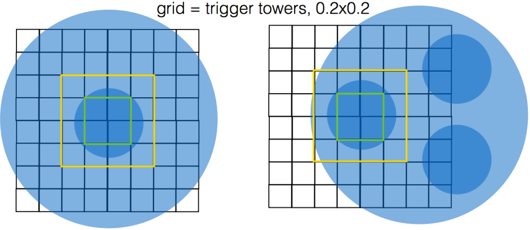






L1Topo for large-R jet triggers[8]

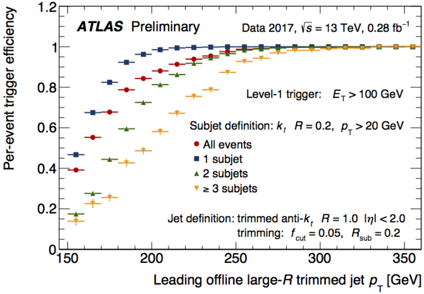
- Jets containing multiple hard sub-jets (t, $W/Z/H$ initiated) lose efficiency when using nominal sliding window algorithm
  - Sliding window only picks up part of the hard structure
  - Therefore jet can fail p_{T} threshold
- Can recover these inefficiencies by running a simple cone algorithm in the L1Topo system

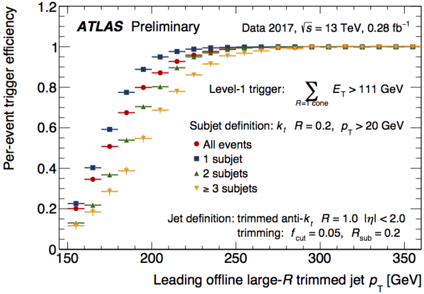


grid = trigger towers, 0.2x0.2

One R=0.3 subjet

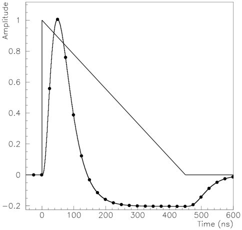
Three R=0.3 subjets



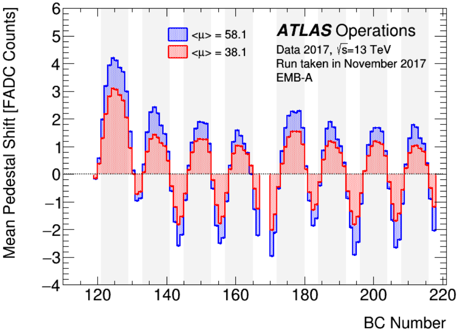


L1Calo [9]

- LAr calorimeter pulses in ATLAS span more than 20 bunch–crossings
    - Leads to an increase in rate at the start of the bunch train
    - Caused by interplay of pulse shape with in-/out-of time pileup
- The new Multichip Module allows the per bunch crossing pedestal corrections to be applied
    - Average over ≈ 6s (65536 LHC orbits)

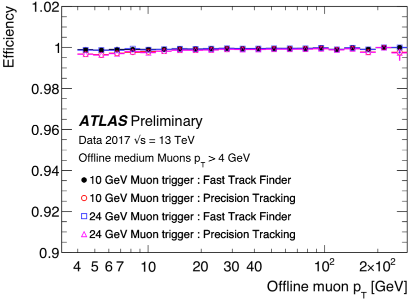


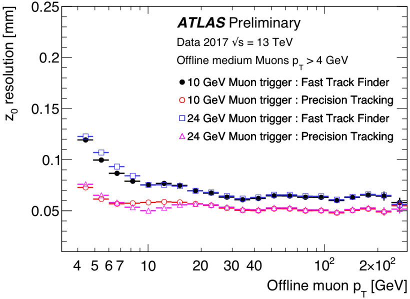
- Significantly reduces the level-1 rates of E_T^{miss} and jet triggers
    - Partially corrects for average pileup, dynamically for the current conditions
- The dynamic nature of the correction allowed ATLAS to smoothly adapt the change in bunch structure due to the Gruffalo
    - Allowed smooth running while the noise thresholds were optimised for modules of the calorimeter



HLT tracking 2017[10]

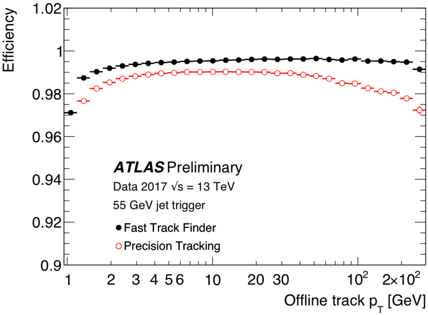
- Track reconstruction is the most CPU intensive operation performed in the trigger: But, needed by most of the HLT triggers!
- The ATLAS HLT runs two tracking versions, both (normally) only in regions of interest,
  - Fast Track Finder (FTF): Runs quicker tracking, in narrow regions: Cheaper in CPU
  - Precision Tracking: More detailed tracking, refines result from FTF
- Trigger chains can, depending on their needs, choose,
  - To run a first pass with the FTF to reduce the rate with lower cost
  - If needed run precision tracking in events selected by cuts on the first level of tracking
- For example,
  - Muon chains run a first loose pass, which is then refined to tighten the z_0 resolution

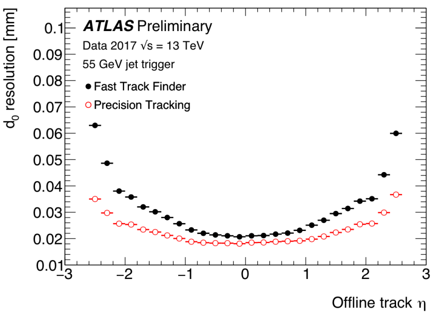




HLT tracking 2017[10]

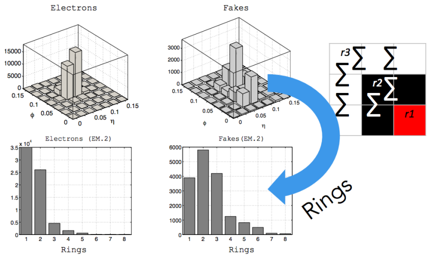
- Similarly, *b*-jets run a loose first pass tracking, which is then refined in the second precision pass
  - All tracking is run within regions of interest defined by the selected jets
  - First pass FTF tracks are produced unconstrained in the *z* direction
  - High-p_T ($>$ 5 GeV) tracks from this pass are used to find the PV
  - Precision tracks, defined using a PV constraint from the FTF stage,
  - Used to define the primary/secondary vertices, needed to run the *b*-tagging algorithms
  - Tracks selected down to 1 GeV!
  - Tracks become harder to reconstruct as they straighten at high p_T

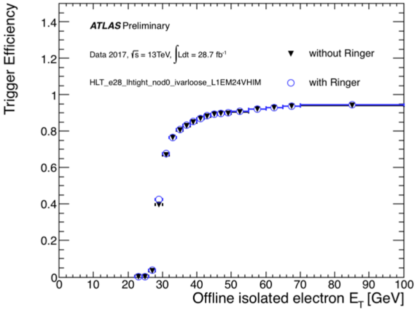




Electron/Photon trigger 2017[11]

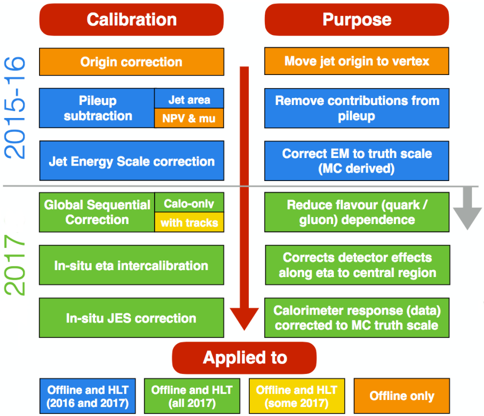
- Running (CPU expensive) tracking on fake electrons is wasted CPU
- Electron triggers run fast tracking first, followed by a second precision reconstruction
- The Ringer algorithm was introduced in 2017 to electron triggers to improve the calorimeter reconstruction in the fast first pass
    - Form ring shaped calorimeter inputs, the "rings", electrons narrower than fakes
    - Feed into an ensemble of neural networks to select electrons
    - Pass on purer set of "electrons" to run tracking on
- Chain latency reduced from 200 ms→100 ms
- Maintained efficiency of original chain!





Jet trigger 2017 improvements[12]

- Jet triggers significantly updated the online calibration in 2017, bringing it in line with the offline calibration (part of a trigger wide harmonisation effort)
  - Added in calorimeter and tracking information for jet shape/properties
  - Tracking is expensive online ∴ use tracks already found for *b*-jet triggers!

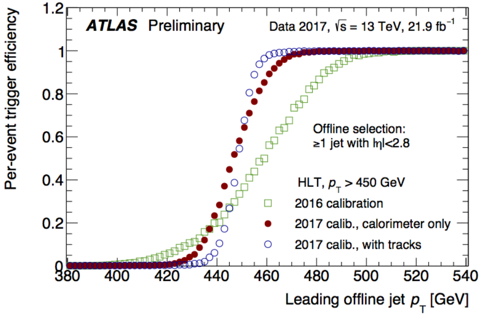


Calibration	Purpose
Origin correction	Move jet origin to vertex
Pileup subtraction: Jet area NPV & mu	Remove contributions from pileup
Jet Energy Scale correction	Correct EM to truth scale (MC derived)
Global Sequential Correction: Calo-only with tracks	Reduce flavour (quark / gluon) dependence
In-situ eta intercalibration	Corrects detector effects along eta to central region
In-situ JES correction	Calorimeter response (data) corrected to MC truth scale

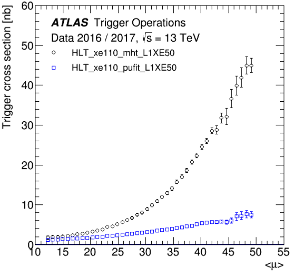
Applied to

- Offline and HLT (2016 and 2017)
- Offline and HLT (all 2017)
- Offline and HLT (some 2017)
- Offline only

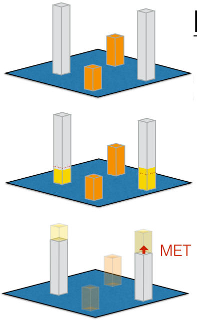
- Improving the online calibration sharpens the turn-on curve significantly!
- Less wasted rate ∴ can run triggers at a lower threshold for same rate cost



E_T^{miss}: New pileup fitting algorithm[13]

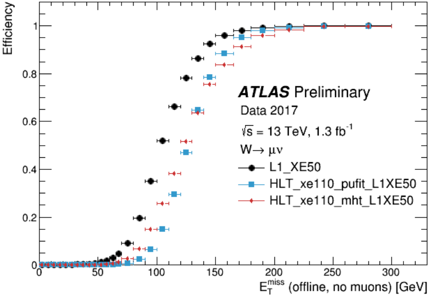


- ATLAS' 2016 E_T^{miss} algorithm showed exceptionally undesirable pileup behaviour
- pufit algorithm was introduced in 2016 & refined in 2017
  - Fixed undesirable behaviour and improved resolution
  - Sharpened the turn on curve
  - As a result drastically reduced CPU usage/rate



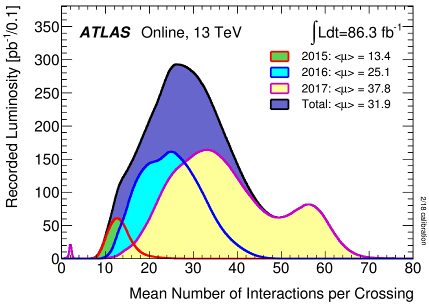
pufit in a nutshell

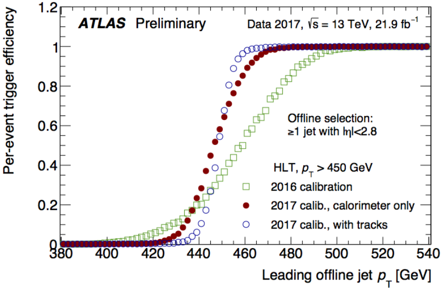
- Categorise calorimeter towers into pileup/signal like, based on tower E_T
- Fit the pileup contribution in signal towers, and remove
- Calculate the E_T^{miss} from remaining signal



Conclusions

- Despite an extremely challenging set of data taking conditions in 2017, the ATLAS trigger provided stable output throughout the year
- Improvements were made to the performance of the L1 and HLT systems
- Cost savings were made to various signatures
  - Introduced level-1 rate saving improvements
  - L1Topo moves sophisticated selections to before the detector readout, freeing up L1 rate
  - Saved L1 rate allows us to keep low p_{T} selections thresholds at higher luminosity
  - HLT algorithm improvements directly save CPU
  - Saved CPU allows more harmonisation of offline→online algorithms
- Improvements in the trigger CPU and rate have direct effects on the physics reach of the trigger





BACKUP

b-jets[14]

- *b*-jet triggers interleave with jet triggers and HLT tracking
  - They are the source the the FTF tracks needed to apply the GSC to jets, therefore they gain the same p_T threshold benefits
  - They then run precision tracking to allow *b*-tagging to occur

- A suite of *b*-tagging working points are run online
  - Efficiency w.r.t. offline working points needs to be carefully monitored and calibrated
- Stability of the various online working points with respect to pileup shows impressive robustness versus the intense pileup conditions seen in 2017