The ATLAS Trigger Algorithms Upgrade and Performance in Run-2

Catrin Bernius (SLAC)

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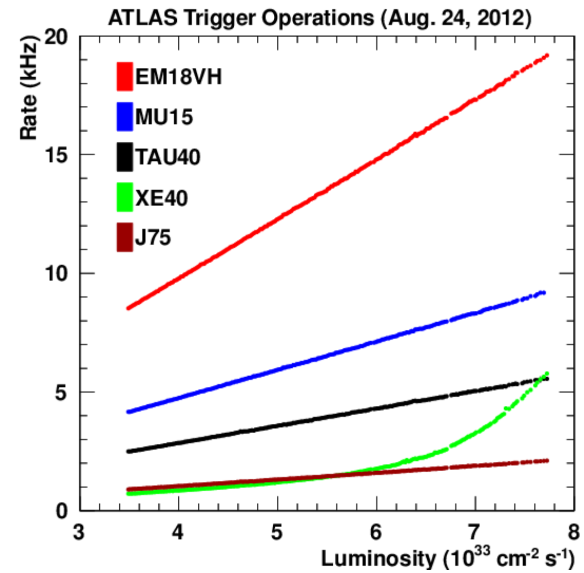
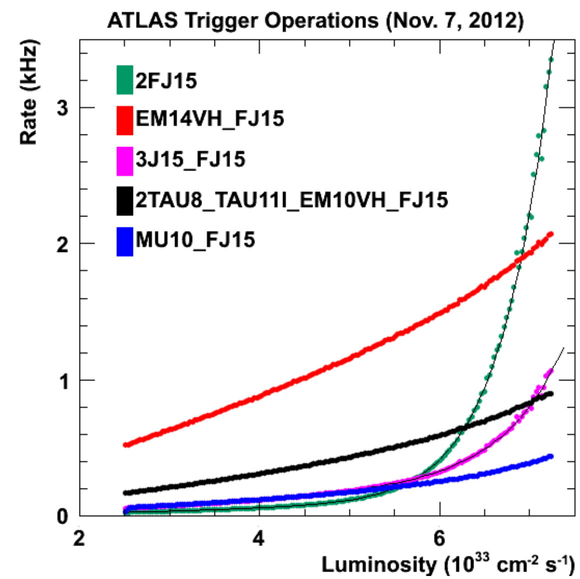
From Run-1 to Run-2

- The ATLAS trigger system operated successfully in Run-1 (2009-1012)
- In Run-2 (2015-2018), overall trigger rates have increased by a factor of ~5
  - A factor of ~2 due to the energy increase
  - A factor of 2-3 due to the luminosity increase

	√s [TeV]	Peak luminosity [cm^{-2}s^{-1}]	Peak pile-up
2012	8	~ 7 x 10^{33}	~ 35
2016	13	~1.4 x 10^{34}	~ 45

- Options to cope with the increase in trigger rates:
  - Increased trigger thresholds → potential loss of interesting physics
  - Increased trigger rejection power → improved hardware/ software
  - Increase output rate → challenge for offline computing





ATLAS Trigger Operation Public Results

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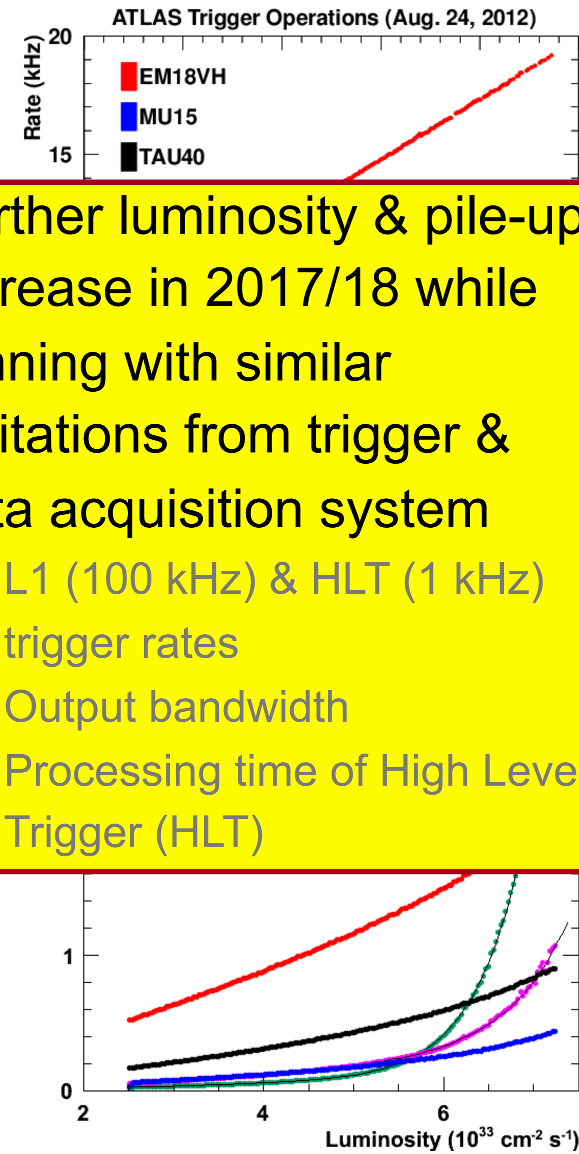
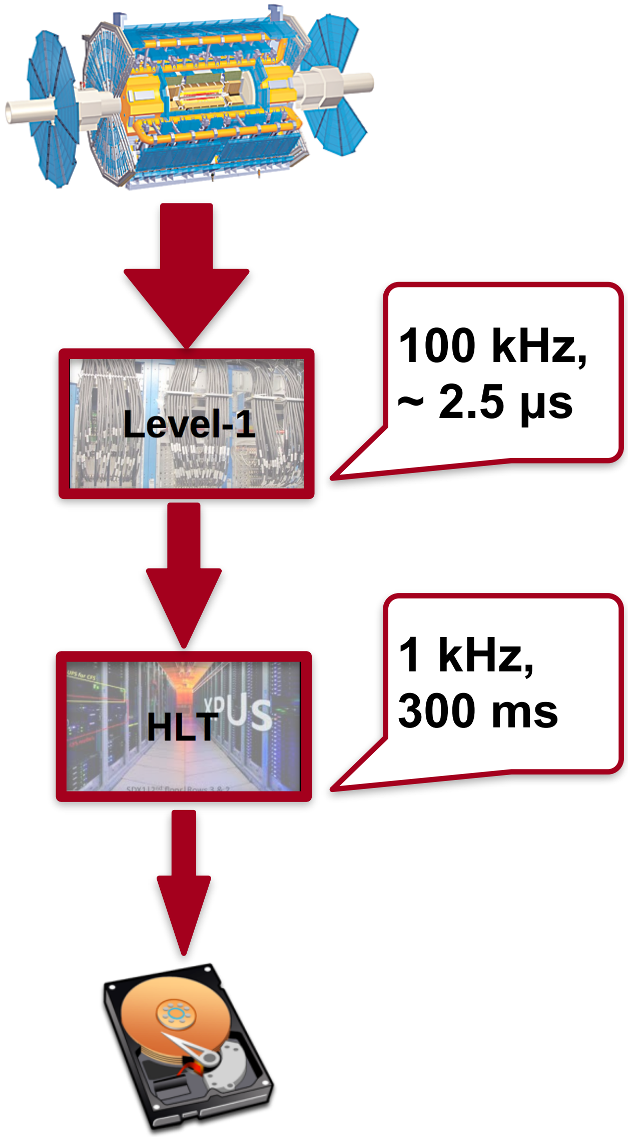


Further luminosity & pile-up increase in 2017/18 while running with similar limitations from trigger & data acquisition system
- L1 (100 kHz) & HLT (1 kHz) trigger rates
- Output bandwidth
- Processing time of High Level Trigger (HLT)

Overview of the ATLAS Trigger System



- **Level-1**
  - **Hardware-based**; Input from calorimeters & muon system
  - Rate and latency limit set by detector & trigger hardware
  - Dead-time applied if limits are exceeded
    - Preventive veto to stop the front-end buffers from overflowing
- **High Level Trigger (HLT):**
  - **Software-based;** Access to all detectors including tracking
  - Average processing time set by HLT farm size
  - 1 kHz **average** output rate set by computing model (bandwidth, disk space, Tier0 size, …)

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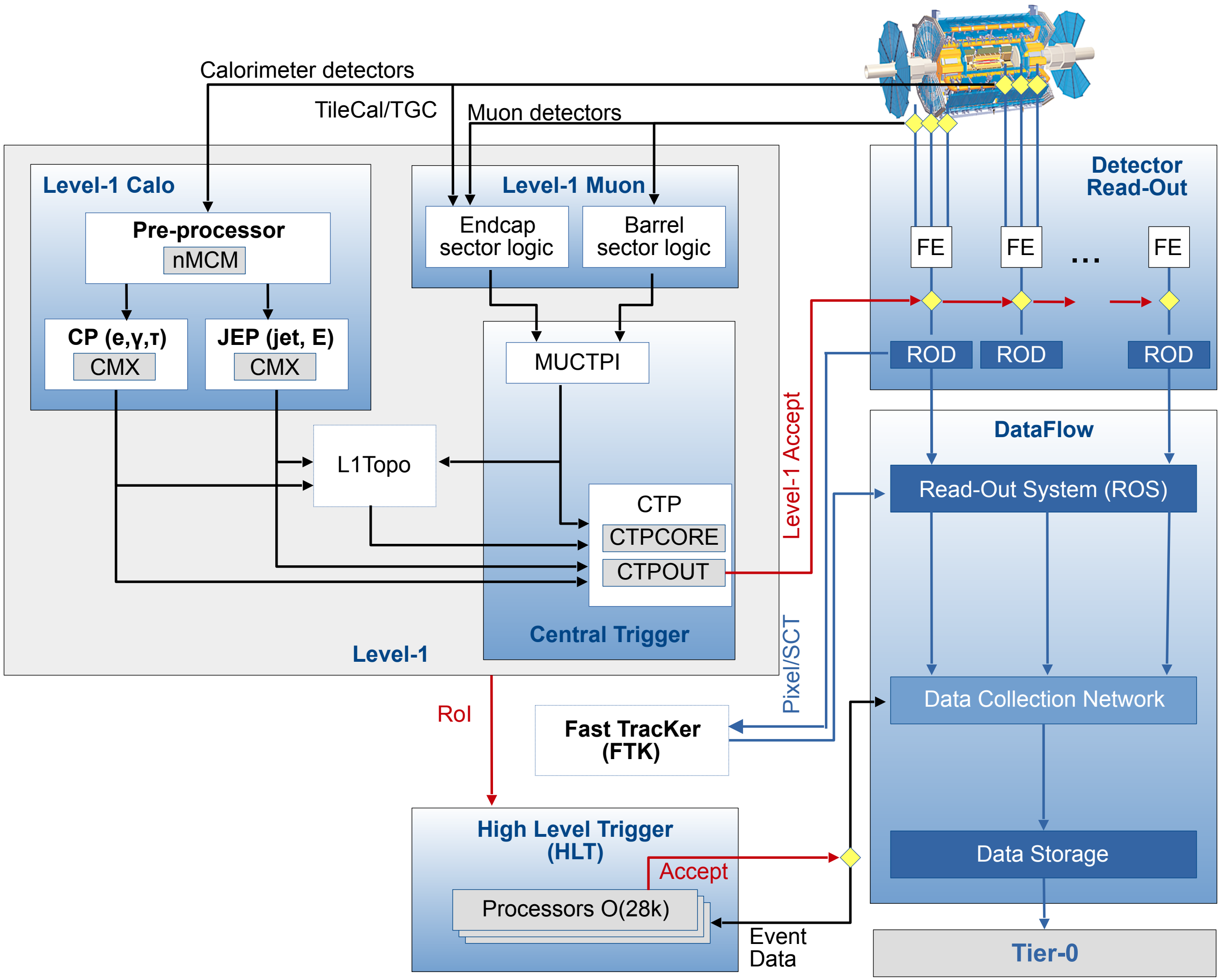
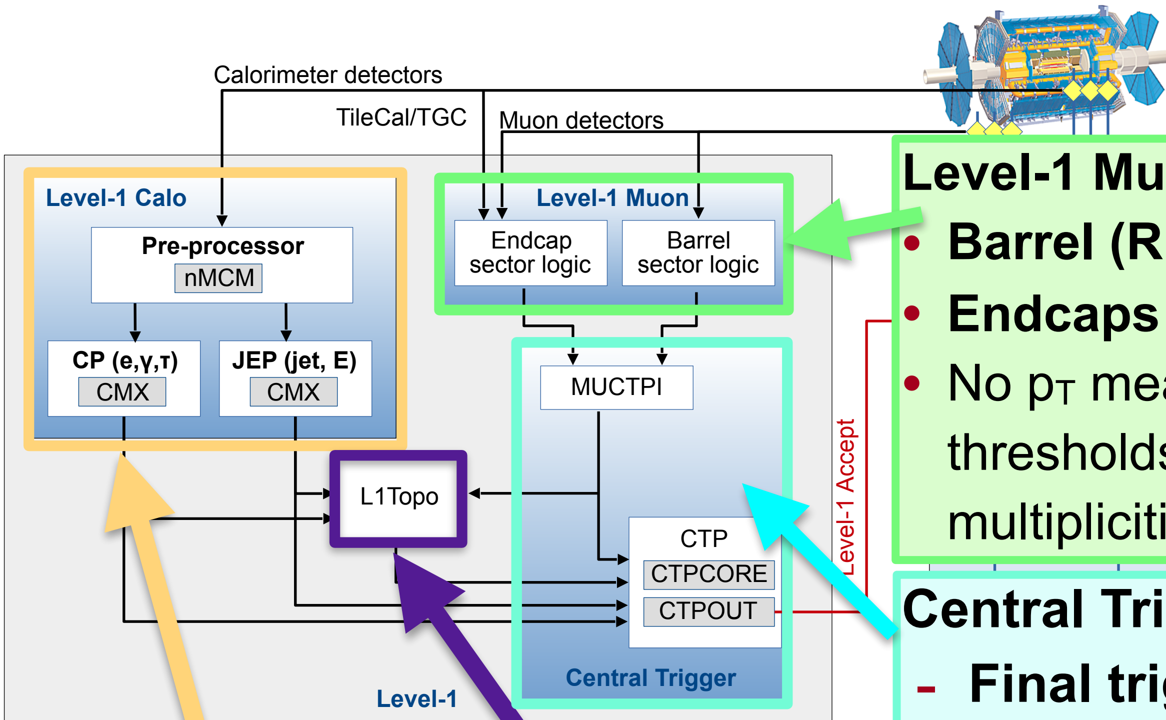


The ATLAS Trigger System: Level-1



Level-1 Muon

- **Barrel (RPC, $|\eta| < 1.05$)**
- **Endcaps (TGC, $1.05 < |\eta| < 2.4$)**
- No p_T measurement, only thresholds passed (and multiplicities)

Central Trigger Processor (CTP)

- **Final trigger decision**

Level-1 Calo: For triggering on any EM object: Electrons, Photons, Jets, Taus, Global event quantities (ME_T)

L1Topo: Combines information from L1Calo and/or L1Muon into topological variables looking at absolute/relative location of trigger objects

→ *See Kate Whalen's talk on "Operation and Performance of the ATLAS* ***Level-1 Calorimeter and Level-1 Topological*** *Triggers in Run 2 at the LHC"*

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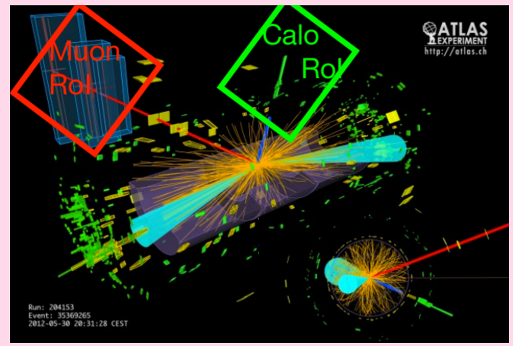
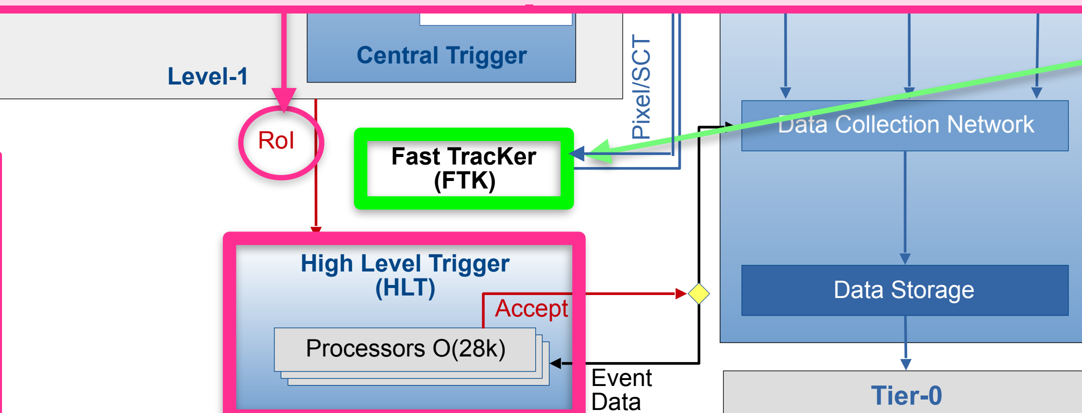
The ATLAS Trigger System: HLT

- High Level Trigger (HLT)
  - Input from Level-1 in form of a **Region-of-Interest (RoI)**
    - Geometrical region in η x Φ with information about type of object (EM, MU, TAU,…) and passed thresholds (p_T, E_T)
    - More CPU/time expensive reconstruction algorithms can be run in RoI, e.g. tracking
  - Decision about the final event accept is made

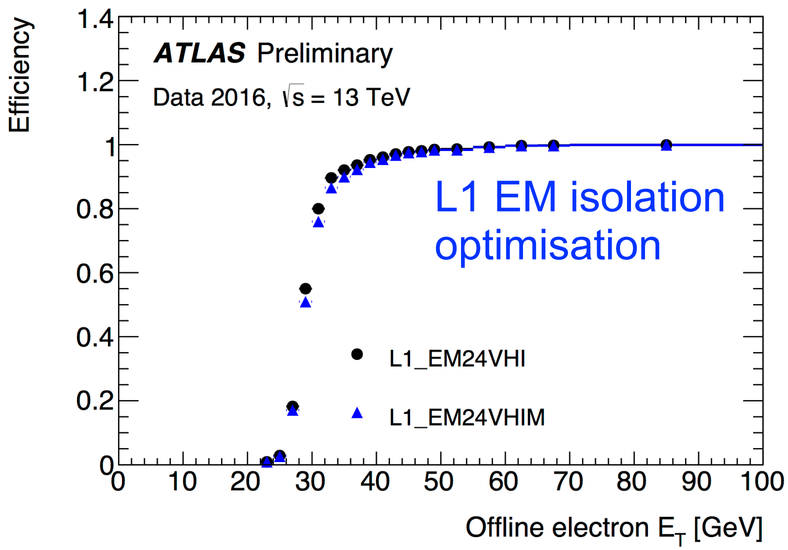


Fast TracKer (FTK)
- Currently being installed, under commissioning in 2017
- **Hardware-based full event track finding** using associate-memory chips (pattern matching)
- **Processes events at 100 kHz make fitted track available to HLT**
- **To replace/augment CPU-expensive software based tracking in the HLT**
- Key feature for **high-luminosity** running

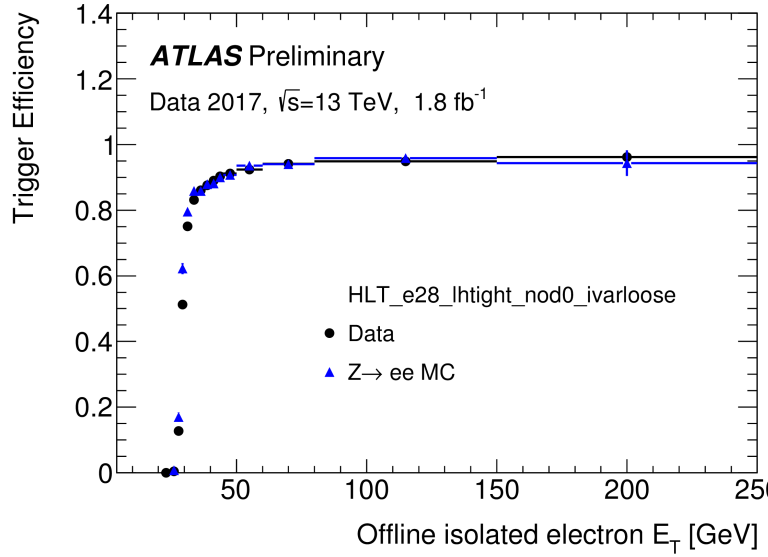


Electron & Photon Trigger Improvements

- Electron triggers:
  - **L1 EM isolation tightened to keep single electron trigger threshold low**
  - New data-driven smooth LH electron tunes using 2016 data
  - **Sharp turn-on curves and good agreement with MC comparison**
- Photon triggers:
  - Isolation at L1 and HLT for low-mass di-photon searches to keep thresholds low

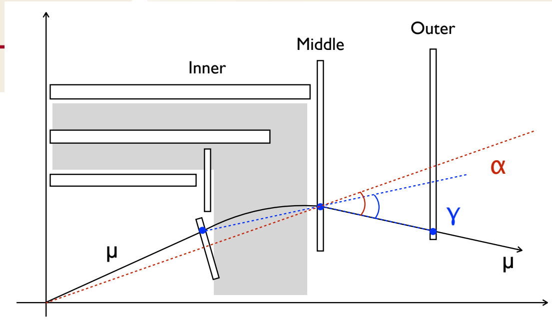


electron with pT > 28 GeV, tight lh identification criteria without using the d0 requirement and loose isolation



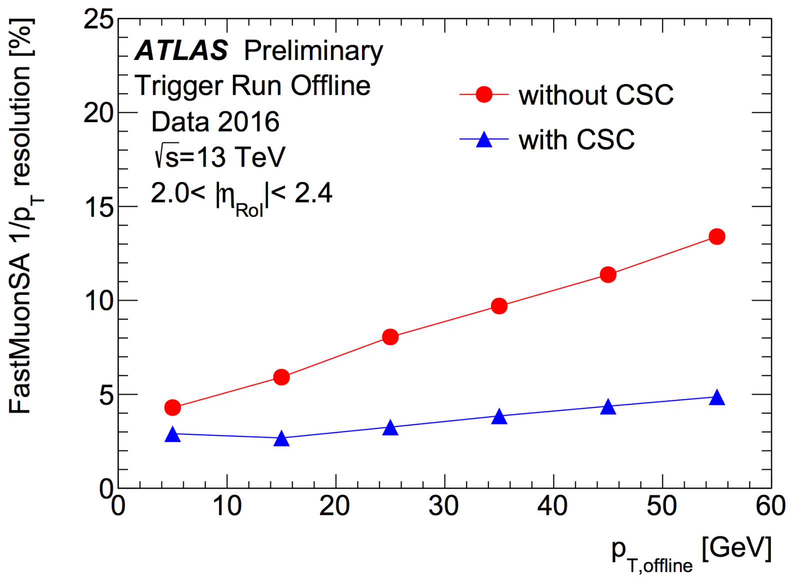
Tau & Muon Trigger Improvements

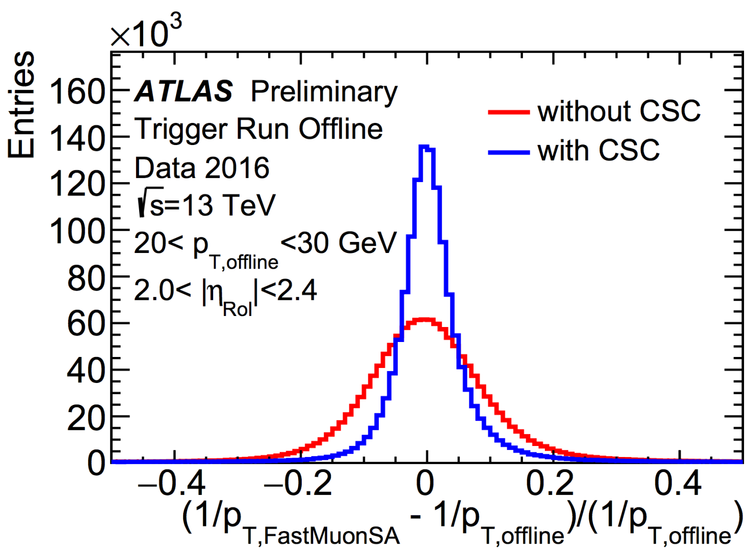
- Tau triggers (hadronic):
  - L1Topo used by default for di-tau and lepton+tau triggers
  - Various improvements and changes to online tau energy scale corrections, online tau identification (BDT) to reflect offline changes, high-pT (> 400 GeV) selection for higher efficiencies



$$p_T - \text{Residual} = \frac{1/p_{T,\text{CSC}} - 1/p_{T,\text{offline}}}{1/p_{T,\text{offline}}}$$

- Muon triggers:
  - **p_T determination using the Cathode Strip Chambers (CSC)** to improve the resolution in the forward region (2.0 < |η| < 2.4)

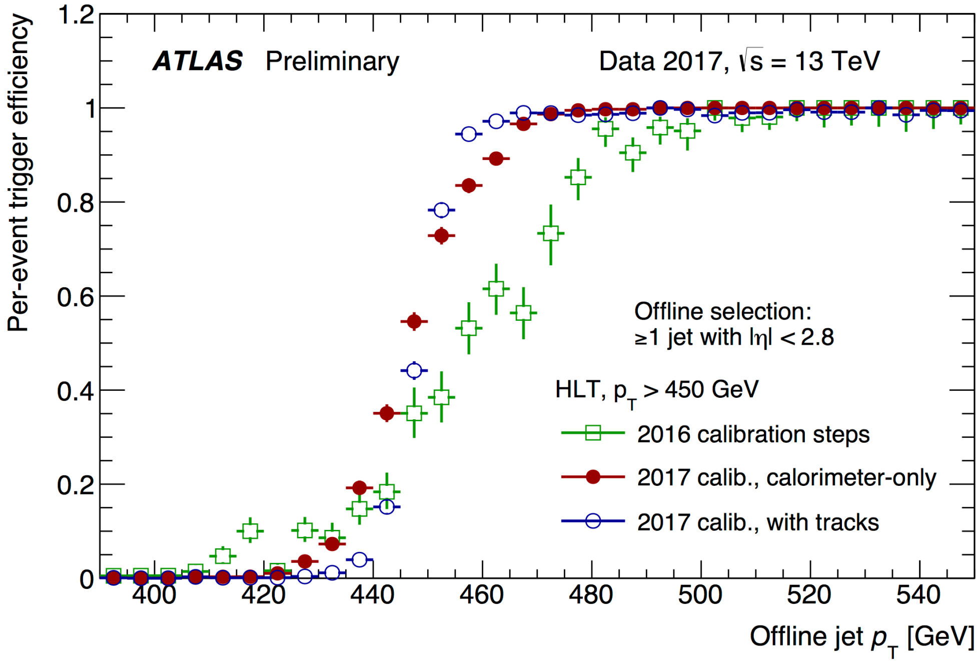




Jets - Global Sequential Calibration in Small-R Jets

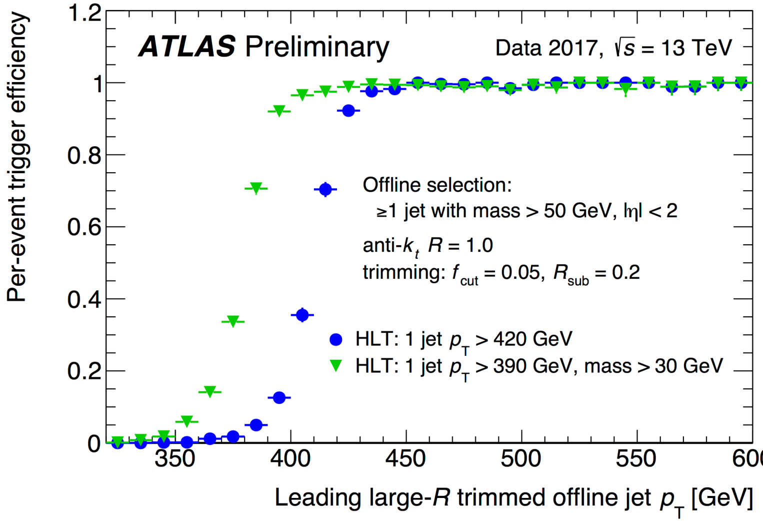
- Jet trigger turn-on curves driven by relative HLT/offline jet resolutions
  - If online resolution closer to the offline → sharper turn-on curve
  - Sharper turn-on curve → less wasted rate below the plateau in the turn-on curve

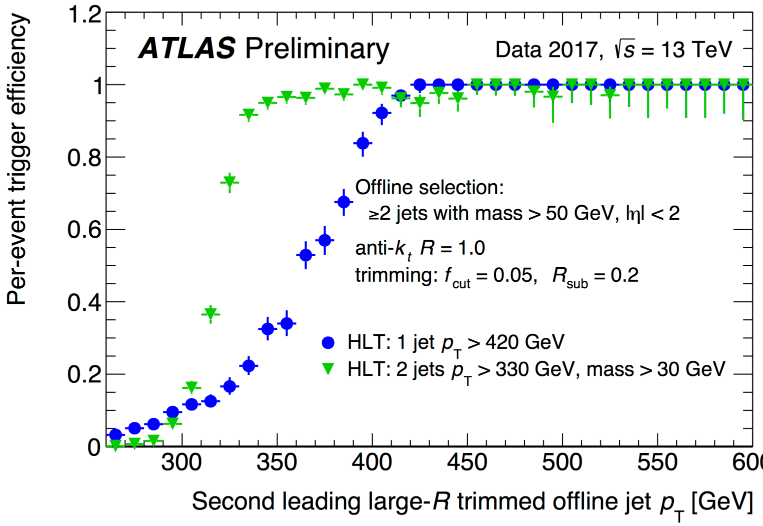
- Small R-jet trigger (R = 0.4):
  - Global Sequential Calibration (GSC) calibration for majority of jet triggers
    - Applies additional Jet Energy Scale (JES) corrections using tracking and jet shape information
    - Reduces the flavor dependence of the response and **improves the jet energy resolution**



Jets - Trimming & Mass Cuts in Large-R Jets

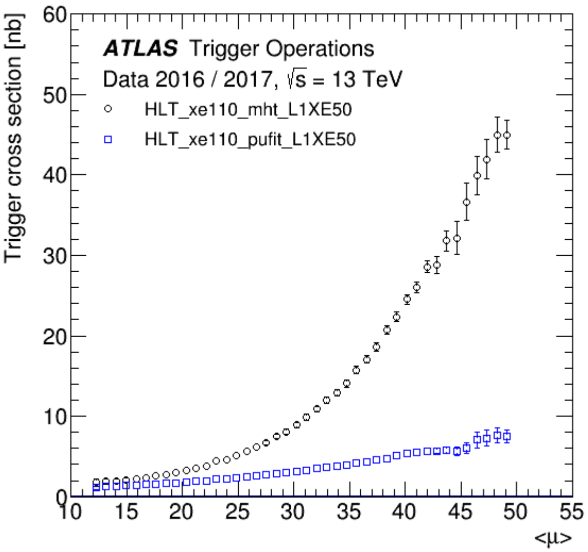
- Large-R jet trigger (R = 1.0):
  - Jets are wider → more susceptible to pile-up
  - Make use of offline grooming techniques to reduce the effects of pile-up
    - **Trimming**:
      - ★ Re-cluster jet constituents with R = 0.2 to form sub-jets
      - ★ Remove sub-jets if $p_T^{sub}/p_T^{jet} < 4\%$
    - Slightly altered from offline (5% → 4%) to recover lost efficiency
    - Produces stable mass/p_T vs pile-up
    - As mass distribution is stable, can apply mass cuts and discriminate QCD vs W/Z/H/t
  - **Reduced pile-up dependence, improved resolution**
  - Brings online closer to offline → **sharper turn-on curve**

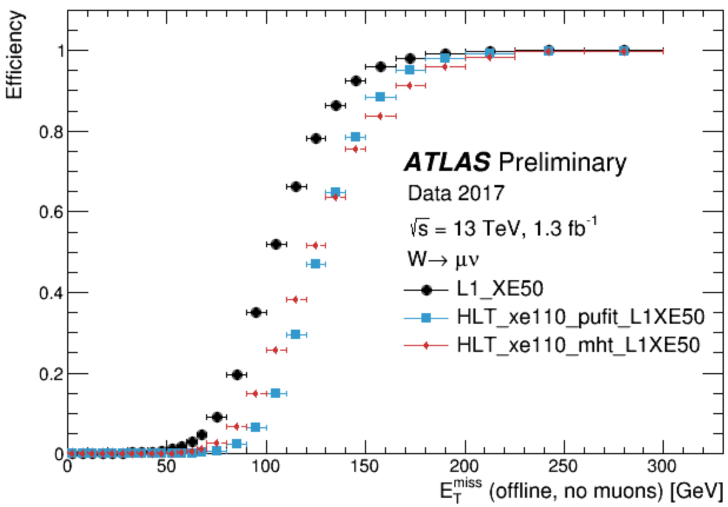


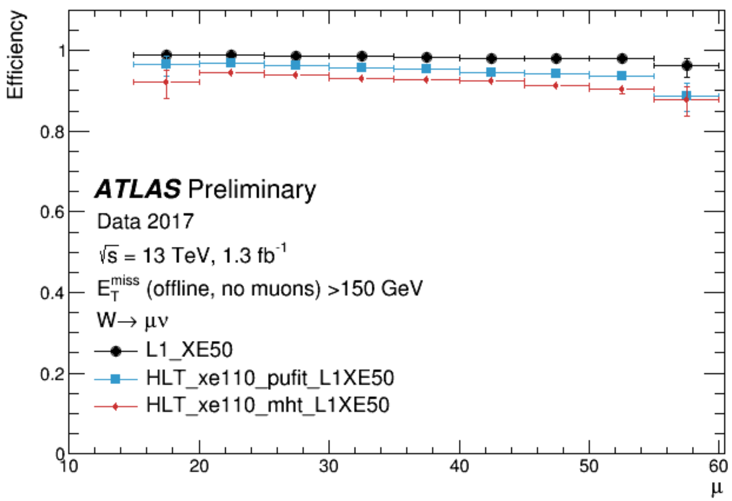


Missing Transverse Energy (ME_T)

- Pile-up mitigation is the main challenge for E_T^{miss} triggers
  - In 2016: used *mht* algorithm which is based on negative p_T sum of all jets reconstructed by the anti-k_T jet finding algorithm
  - New algorithm in 2017: **PUFit** which calculates E_T^{miss} as the negative pT sum of all calorimeter topological clusters corrected for pile-up, pile-up estimated event-by-event and subtracted
    - **Excellent performance in high pile-up regimes**







Conclusion

- Many improvements in algorithm performance and robustness across all signature groups to deal with increasing rates due to luminosity and pile-up increase
  - Only highlighted a few of them here!
- FTK currently being installed and commissioned in 2017 → further hardware improvement to the TDAQ System
- Run-1 and ongoing Run-2 have shown that ATLAS trigger system & strategy for event selection is very robust and able to adapt to the changing LHC conditions
  - Dedicated list of triggers (trigger menu) with various backups in place
    - *See Heather Russell's talk on "The ATLAS Trigger Menu design for higher luminosities in Run 2"*
- Ready for the remaining two years of Run-2 Operations with increased luminosities and pile-up!