Projected ATLAS Electron and Photon Trigger Performance in Run 3

F. Monticelli*, for the ATLAS Collaboration

*IFLP/CONICET UNLP, Argentina

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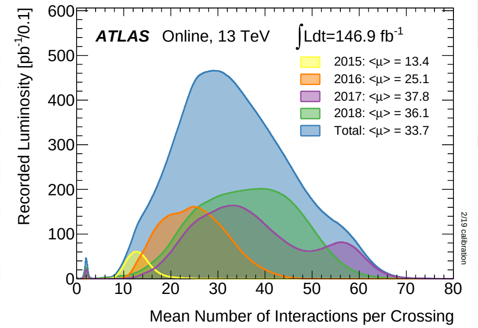
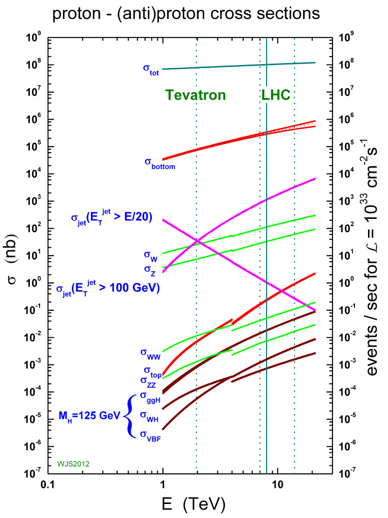
Why a Trigger system in ATLAS?

- 40 MHz Bunch Crossings (1 BC every 25 ns when LHC is full). ATLAS sees many collisions on each crossing (eg in 2018 $\sim$ 55 proton-proton scatterings at start of a run).
- Data size for a collision event in 2018 1.3 MBytes total data output rate with no trigger would be 52 TBytes/sec.
- All can't be stored: Limitations on storage and on CPU resources for data analysis downstream
- Trigger = online analysis of data; It must be efficient on interesting physics and still reject most of the non-interesting events!

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2



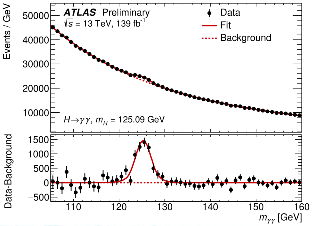


Electron and photon triggers

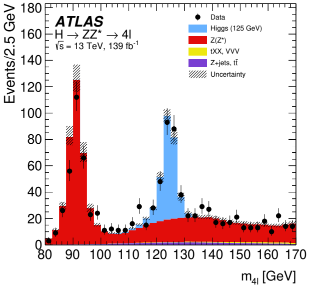
Electron/Photon triggers essential for the LHC physics programme

- Standard Model Cross Section measurements
  - W/Z (+jets); di-boson; inclusive photon; di-photon; $t\bar{t}$ production
    Eur. Phys. J. C 79 (2019) 535, Phys. Rev. D 100 (2019) 032007, JHEP 03 (2020) 054
- Measurement of Higgs properties
  - H$\rightarrow \gamma\gamma$, ZZ, WW final states
    Phys. Lett. B 786 (2018) 223, Phys. Lett. B 800 (2020) 135103, Phys. Lett. B 801 (2020) 135145
  - H$\rightarrow \tau\tau$ ($\tau \rightarrow e$), associated VH and ttH production and
    Phys. Lett. B 805 (2020) 135426, Phys. Rev. Lett. 125 (2020) 051801
  - H$\rightarrow b\bar{b}\rightarrow$ leptonic decay
    Phys. Lett. B 786 (2018) 59, Phys. Lett. B 801 (2020) 135145
- Searches span a broad range of p_T and multiplicity
  - high-p_{T} Exotic searches to low-p_{T} compressed SUSY scenarios
    JHEP 05 (2019) 142,Phys. Rev. D 100 (2019) 012006,Phys. Lett. B 764 (2017) 11, JHEP 05 (2019) 142

ATLAS-CONF-2019-029



arXiv:2004.03969 [hep-ex]



Challenges for the trigger system

- Trigger on interesting and very rare events ($\rightarrow$ 3 Higgs / 10^{10} pp collisions) and still drop most of possible background
- Maintain low thresholds, high efficiency with limited bandwidth (rate)
- Reduction from 40 MHz crossing rate to $\sim$ 1.5 kHz output rate
- What is not selected by the trigger $\rightarrow$ **LOST FOREVER!**

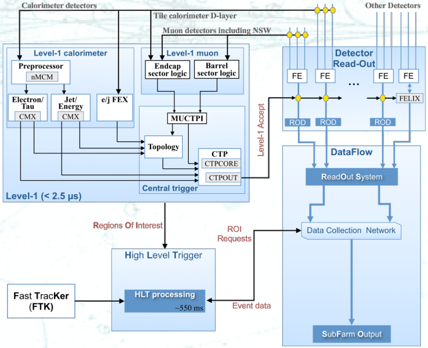
Challenges for Run-3

Harder conditions than in Run-2!

- Increase in centre of mass energy from 13 TeV to 14 TeV
- Peak luminosity $2 \times 10^{34} cm^{-2} s^{-1}$ to $2.2 \times 10^{34} cm^{-2} s^{-1}$
- We will be *levelling* $\rightarrow$ peak luminosity for longer time (different, lumi profile)
- Total integrated luminosity from ∼150 fb^{-1} to ∼ 300 fb^{-1}

Trigger Upgrades for Run-3

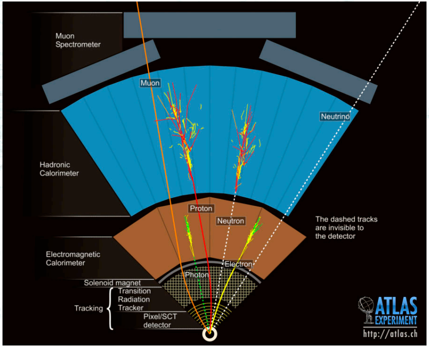
- Updated TDAQ structure
- L1 calorimeter granularity improved
- L1 identification of electron photons closer to offline than in Run-2
- Native multithreading framework to run algorithms at HLT
- Using at HLT same algorithms as offline at "precision" reconstruction



Triggering e/γ in ATLAS

- E/γ trigger is based on reconstructing objects within a Region of Interest (RoI)
  - Level 1 Electromagnetic (L1 Calo) trigger seeds the RoI for the High Level Trigger (HLT)

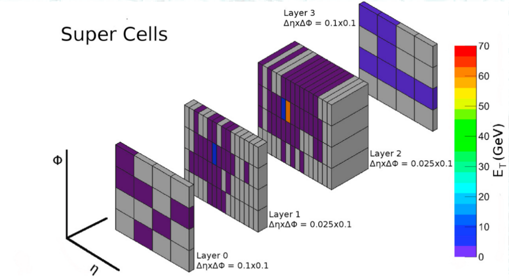
- E/γ HLT algorithms reconstruct and identify
  - Clusters
  - Tracks
  - Photons — Electromagnetic (EM) Cluster
  - Electrons — EM Cluster + Track

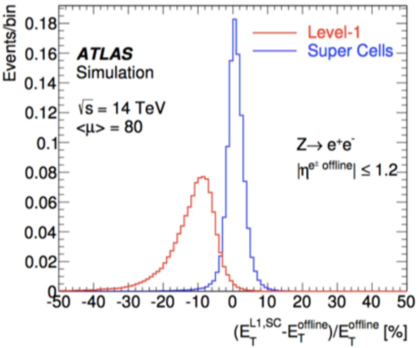


- E/γ HLT algorithm flow
  - Fast algorithms rejects background events early
  - Precise algorithms to efficiently identify e/γ

- E/γ Reconstruction, calibration and identification
  - Offline software and techniques

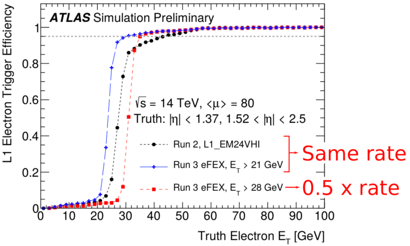
Level 1 EM trigger - Improvemens in Run-3





L1 Calo

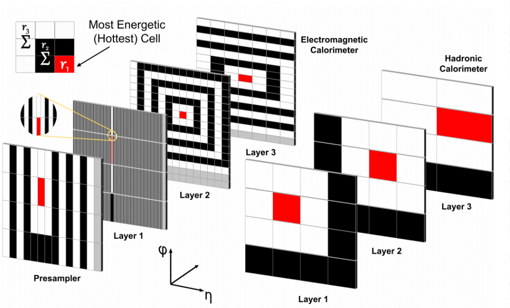
- The Run-3 LAr calorimeter's trigger digitised readout improved with finer granularity
- New suite of L1 hardware designed to take advantage of this
  - Finer granularity of the super cells allows to use shower shapes closer to offline and reduce the rate
  - Better resolution
  - Sharper trigger turn-on



NNs at fast reconstruction in HLT

The RINGER algorithm

- NN based algorithm to identify electrons at fast reconstruction since 2017. In Run-2 used for triggers with threshold above 15 GeV
- Use lateral shower development. Concentric ring energy sums in each calorimeter layer
- Transverse energy in each ring normalised to total transverse energy in the RoI
- Ring energies fed into multilayer perceptron (MLP) neural networks

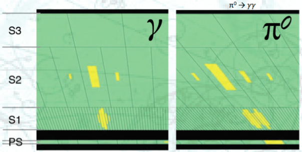


- Ringer increases fast calorimeter step reconstruction time, but reduces input candidates to the tracking
- Significantly reduced CPU demand
- In Run-2 50% CPU reduction at the HLT for the lowest p_{T} un prescaled single electron trigger

Run-3

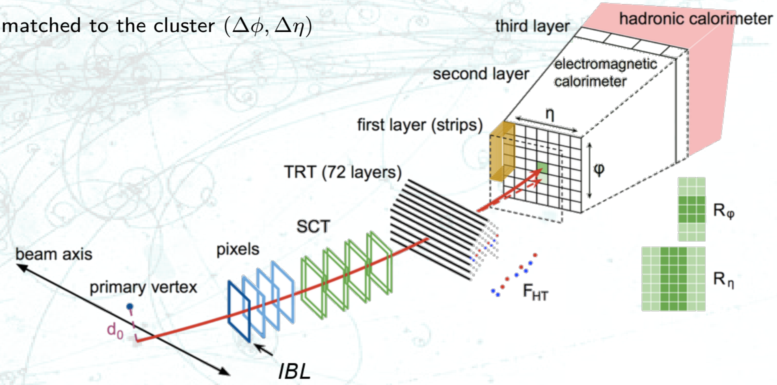
- To be used for all electron triggers (gaining on CPU improvement)
- Evaluating its use in photon triggers too $\rightarrow$ expected to gain early rejection on photon chains

Electrons and photons at HLT



- Energy of an e/γ candidate built with cluster of cells in EM calorimeter
- Photons are reconstructed with only the cluster
- Common shower shape variables for e/γ calculated for identification

- Electron candidates have tracks loosely matched to the cluster $(\Delta\phi, \Delta\eta)$
- tracks extrapolated to 2nd EM layer
- Electrons have additional information
  - hits in the tracking detectors
  - transition radiation hit information
  - track-cluster matching $(\Delta\phi, \Delta\eta)$



Identifying e/γ

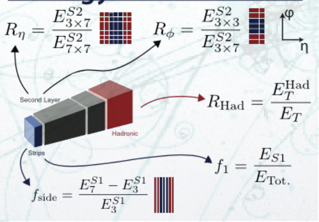
- Common set of shower shape variables used to identify electrons and photons
  - EM shower can be characterised by the longitudinal (depth) and lateral (width) shapes
  - e/γ use same variables, but in different ways

Variables and Position

	Strips	2nd	Had.
Ratios	f_1, f_{side}	R_η*, R_ϕ	$R_{Had.}$*
Widths	$w_{s,3}$, $w_{s,tot}$	$w_{\eta,2}$*	-
Shapes	ΔE, E_{ratio}		

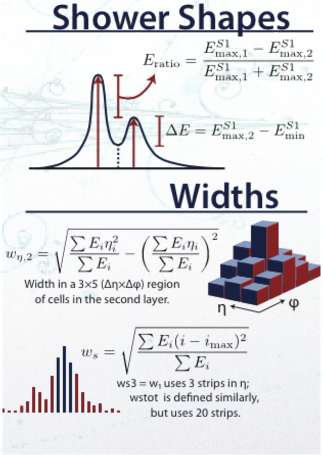
* Used in PhotonLoose

Energy Ratios



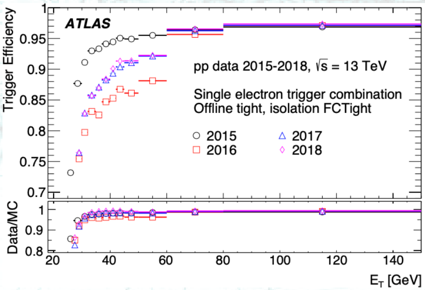
- Identification of photons and electrons
  - Using Cut-Based identification for photons and Likelihood identification for electrons
  - Optimised in bins of E_T and η
  - Several levels of discrimination with higher efficiency but lower purity (loose, medium, tight)

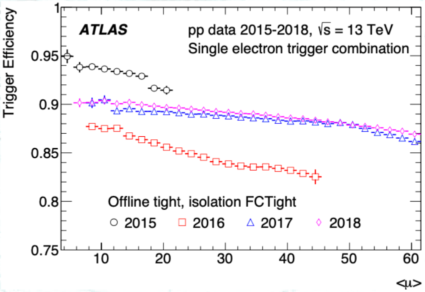
- Electron identification incorporates tracking information
  - Transition radiation hit information
  - Track quality & Track-cluster matching



Electron Trigger Performance in data

- Trigger performance is evaluated using tag and probe method using Z$\rightarrow e^+e^-$ events
  - Tag lowest un-prescaled single-electron trigger
  - Probe used to measure the trigger efficiency, opposite charge to tag
- single electron trigger combination: un-prescaled single-electron triggers with lowest thresholds
- Efficiency is measured with respect to offline electron
- Latest results using all Run-2 data
- Eur. Phys. J. C 80 (2020) 47



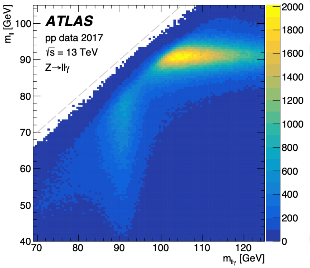


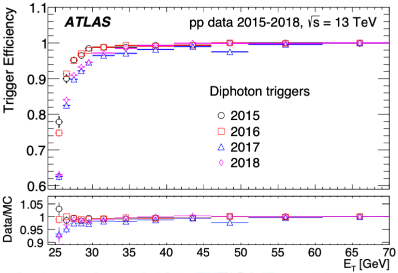
Photon Trigger Performance in data

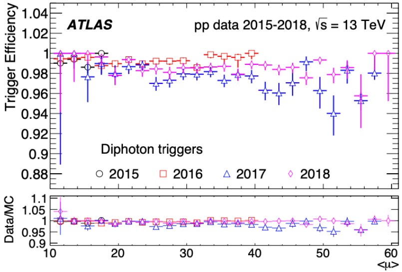
- Trigger efficiency measured using Z radiative decay Z→ $\ell^+\ell^-\gamma$
- Tag and probe method:

  Tag: Events triggered by primary electron or muon triggers

  Probe: Tight Photon satisfying mass of $\ell^+\ell^-\gamma$ is within Z mass
- Eur. Phys. J. C 80 (2020) 47

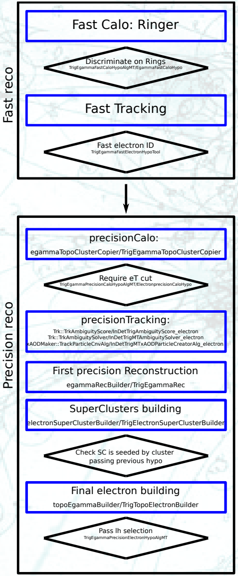






Improvements for Run-3

Electron triggers in Run 3



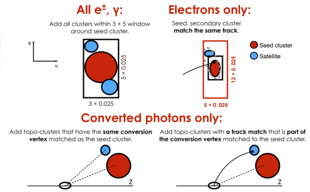
Many improvements being implemented at the HLT for electrons and Photons

Using offline algorithms

- Precision reconstruction of Electron and Photon triggers implemented using offline algorithms for Run-3 (instead of Trigger-Specific)

Improved Calorimeter reconstruction

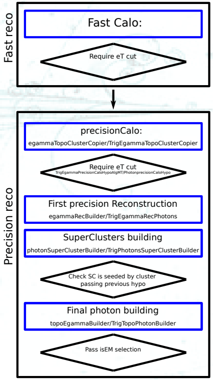
- While using offline algorithms, electrons and photons at HLT are built using SuperClusters as offline while in Run-2 trigger used a sliding-window algorithm
- Energy resolution to improve at HLT making sharper turn ons



Improved Tracking

- Implement Gaussian Sum Filter algorithm on tracks refitting for electrons
- Recover from Bremsstrahlung
- Used offline (since 2012!!!), while not used at HLT in Run-2
- electron p_{T} resolution at HLT to improve w.r.t. Run-2

Photon triggers in Run-3



Conclusions

Electron and photon triggers

- Electron and Photon triggers are key for a vast fraction of ATLAS physics programme
- Trigger is the first step of any physics analysis → Trigger **must** be efficient on signal and still reject most of the background

Challenges for Run-3

- Harsher operation conditions for the Trigger with respect to Run-2
- Increased instantaneous luminosity makes pileup larger and more difficult for the Trigger to distinguish signal from background
- Increase of CME will increase production of QCD background

Performance and improvemens for Run-3

- During Run-1 and Run-2 Electron and Photon triggers performed with very high efficiency keeping overall rates within the storage limitations
- Move towards MultiThread algorithms at HLT will improve the system and make the CPU usage more efficient
- Use of offline algorithms at HLT makes the trigger selection closer to offline → improving efficiency
- Use of SuperClusters at HLT for Electron and Photon triggers will improve the Energy resolution of the Trigger
- Use of NN based Ringer for low p_{T} electron triggers and photon triggers will improve early background rejection and CPU usage at HLT