The Upgrade of the ATLAS e/γ Triggers for Run-2 and their Performance

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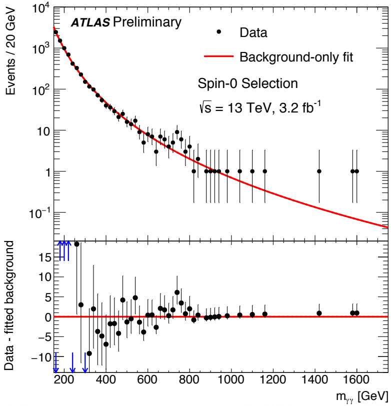
Introduction

Electron/Photon triggers essential for the LHC physics program

- Standard Model Cross Section measurements
  - W/Z (+jets); di-boson; inclusive photon; di-photon; $t\bar{t}$ production
- Measurement of Higgs properties
  - H$\rightarrow \gamma\gamma$, ZZ, WW final states
  - H$\rightarrow \tau\tau$ ($\tau \rightarrow e$), associated VH and ttH production and
  - H$\rightarrow b\bar{b} \rightarrow$ leptonic decay
- Searches span a broad range of p_T and multiplicity
  - high-p_T Exotic searches to low-p_T compressed SUSY scenarios



Challenges for the trigger system

- Trigger on very rare events ($\rightarrow$ 3 Higgs / 10^{10} pp collisions)
- Maintain low thresholds, high efficiency with limited bandwidth (rate)
- Reduction from 40 MHz crossing rate to $\sim$ 1.5 kHz output rate

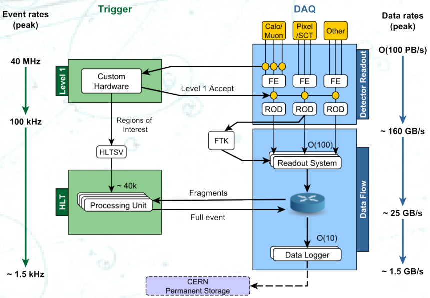
Challenges for Run-2

Harder conditions than in Run-1

- Increase in centre of mass energy from 8 TeV to 13 TeV
- Peak luminosity 7×10^{33} to $1.2 \times 10^{34} cm^{-2} s^{-1}$
- Peak pileup increases from 40 to 50 interactions /events
- Total integrated luminosity from 25 fb^{-1} to $\sim$ 100 fb^{-1}
- Increase input rate to Level-1 (L1) trigger by factor of 5

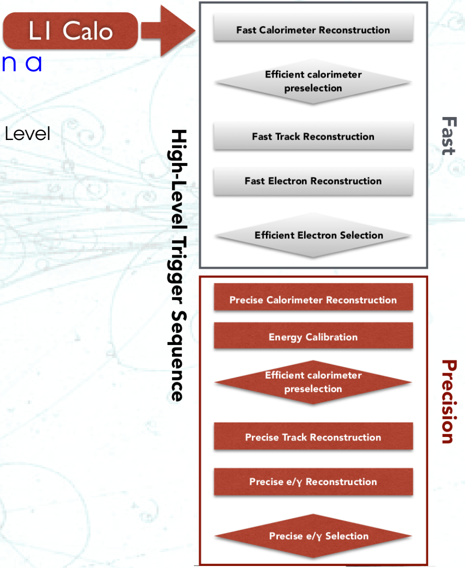
Trigger Upgrades for Run-2

- New TDAQ structure, single processing farm w/ increased throughput
- Common data preparation, share software and results from various algorithms
- L1 calorimeter granularity and relative isolation
- L1 Topological trigger system: input L1 Muon & L1 Calo
- Improvements in track reconstruction algorithm latency and performance
- Multivariate identification and calibration techniques
- Online pile-up corrections



Triggering e/γ in ATLAS

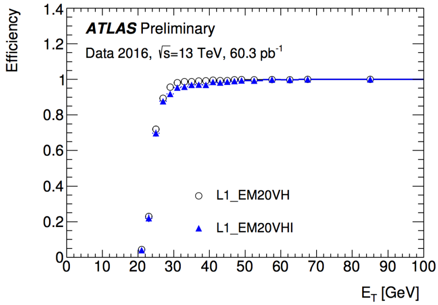
- E/γ trigger is based on reconstructing objects within a Region of Interest (RoI)
  - Level 1 Electromagnetic (L1 Calo) trigger seeds the RoI for the High Level Trigger (HLT)
- E/γ HLT algorithms reconstruct and identify
  - Clusters
  - Tracks
  - Photons — Electromagnetic (EM) Cluster
  - Electrons — EM Cluster + Track
- E/γ HLT algorithm flow
  - Fast algorithms rejects event early
  - Precise algorithms to efficiently identify e/γ
- E/γ Reconstruction, calibration and identification
  - Offline software and techniques



Level 1 EM trigger

Run-2

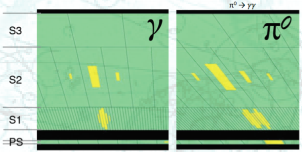
- Improved Signal Processing: new Multi-Chip-Module (nMCM)
  - Improved energy resolution (noise auto-correlation filtering)
  - Dynamical pedestal correction
- Clustering: Cluster Processor Module (CPM) firmware
  - E_T -dependent electromagnetic/hadronic isolation cuts with $\Delta E_T \sim 0.5$ GeV precision
- Counting: New extended Common Merger Module (CMX)
  - Doubles max number of E_T thresholds to 16
  - E_T thresholds can have $\Delta\eta$=0.1 in granularity



While during Run-1

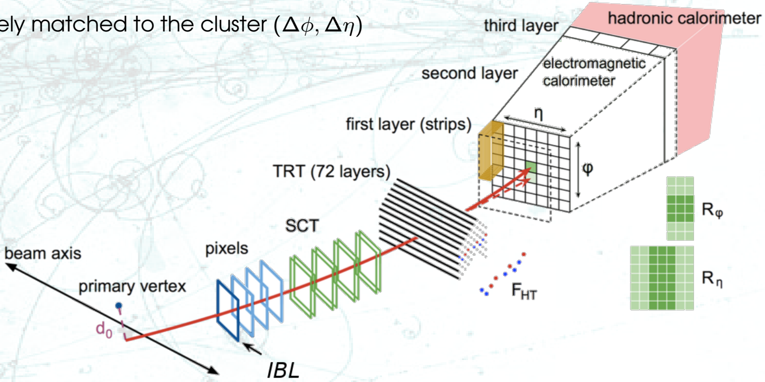
- η-dependent E_T thresholds $\rightarrow \Delta\eta$=0.4 granularity
- Fixed Isolation cut $\rightarrow$ Hadronic-core isolation H $\leq$ 1 GeV
- EM Isolation not used (but available) during Run-1

Electrons and photons at HLT



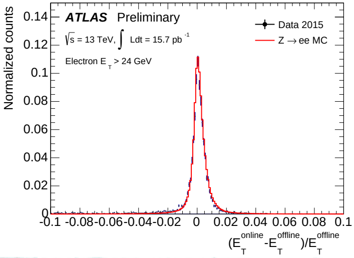
- Energy of an e/γ candidate built with cluster of cells in EM calorimeter
- Local maximum required for a cluster seed $\to$ sliding window algorithm
- Photons are reconstructed with only the cluster
- Common shower shape variables for e/γ calculated for identification

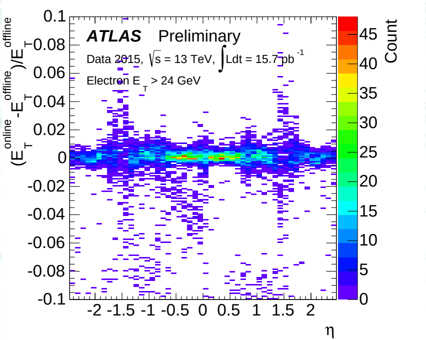
- Electron candidates have tracks loosely matched to the cluster ($\Delta\phi, \Delta\eta$)
- tracks extrapolated to 2nd EM layer
- Electrons have additional information
  - hits in the tracking detectors
  - transition radiation hit information
  - track-cluster matching ($\Delta\phi, \Delta\eta$)

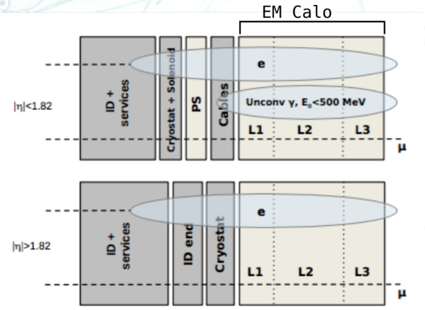


Energy Calibration at HLT

- EM cluster properties (longitudinal development) are calibrated to the original energy of the electron and photon in Monte Carlo (MC) samples
- MC samples are used to determine the e/γ response calibration where the constants are determined in a multivariate algorithm
- Good agreement between data and MC







Identifying e/γ

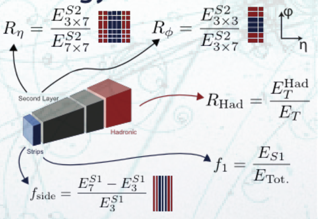
- Common set of shower shape variables used to identify electrons and photons
  - EM shower can be characterised by the longitudinal (depth) and lateral (width) shapes
  - e/γ use same variables, but different cut values

Variables and Position

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

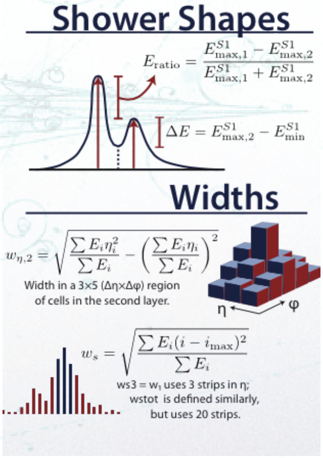
* Used in PhotonLoose.

Energy Ratios



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

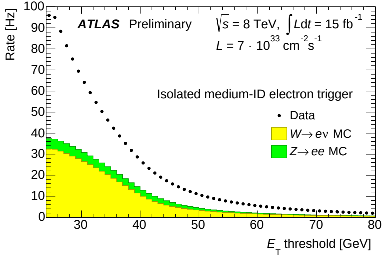
- Electron identification incorporates tracking information
  - Transition radiation hit information
  - Track quality & Track-cluster matching



Improved Electron ID for Run-2

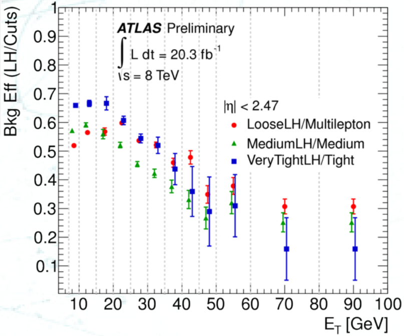
Rate depends **strongly** on Electron trigger threshold

- Physics potential suffers as threshold increases
- Run-2 improve purity and reduce background with tighter selections and multivariate techniques



Electron Likelihood (LH) Particle Identification

- Same as offline ID
- Relies on same variables as cut-based selection
- LH tuned to same signal efficiency as a cut-based selection
  - Factor 2 improvement in background rejection
  - Higher signal purity

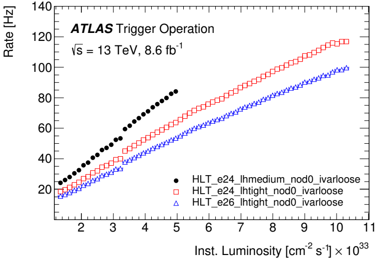


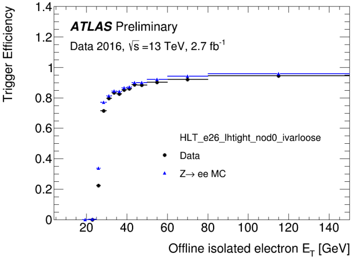
$$d\mathcal{L} = \frac{\mathcal{L}_S}{\mathcal{L}_S + \mathcal{L}_B}, \mathcal{L}(\vec{x}) = \prod_{i=1}^{n} P_{s,i}(x_i)$$

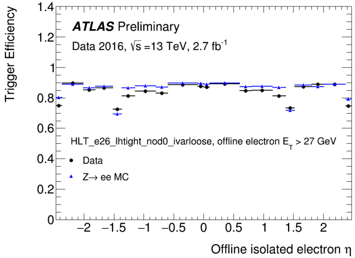
Electron Trigger Performance

Likelihood electron selection out-performs cut-based selection in Run-2

- LH selection efficiency 4-6% higher than cut-based selection with respect to same offline
- Likelihood trigger out-performs cut-based when measured with respect to any offline identification
  - 20% rate reduction and 90% efficient in barrel region for medium selection → unprescaled in 2015
  - Tight selection 45% rate reduction with 7% efficiency loss
- Excellent Data-MC agreement



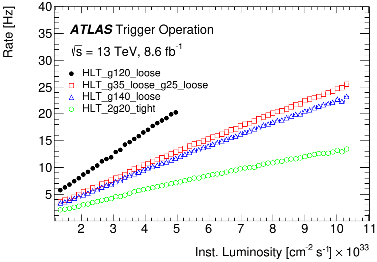


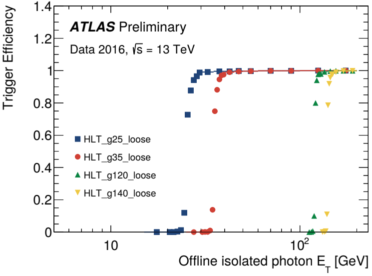


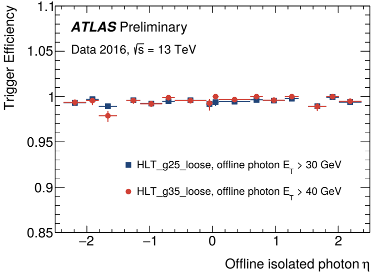
Photon Trigger Performance

Photon performance of Run-2 similar to Run-1

- Photon ID uses cut-base selection as in Run-1 $\rightarrow$ reoptimized for Run-2 higher $\sqrt{s}$ and instantaneous luminosity
- Incorporated *medium* Id working point at trigger level, in addition to *loose* and *tight*
  - Medium includes lateral Energy ratio in first layer to discriminae γ from $\pi^0 \rightarrow \gamma\gamma$
- Lowest threshold unprescaled triggers up to $L = 1.2 \times 10^{34} cm^{-2} s^{-1}$:
  - `g35_medium_g25_medium`
  - `g140_loose`







Conclusions

Successful commissioning of Run-2 e/γ triggers upgrade

- New features at L1
  - Finer granularity in η for threshold variation
  - Double number of L1 thresholds
  - Relative isolation
- Improved HLT structure (single HLT trigger level)
- New HLT tracking in Run-2
- New likelihood-based electron triggers (as in offline)

Constantly evaluating and monitoring e/γ trigger performances

- Electron and photon triggers perform similar to Run-1:

  High efficiency and high fake rejection

HLT developments under study

- Offline electron reconstruction refits tracks to account for bremsstrahlung
- Converted photons reconstructed offline which provides additional information for calibration
- Calorimetric isolation based on topological clusters also a possibility for further rate reduction