The ATLAS Electron and Photon Trigger

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Outline

Introduction the Photon and Electron (e/γ) Trigger at ATLAS

- Brief tour of the most important aspects of the ATLAS detector for e/γ triggers
- Motivation and design
- Run 2 upgrades to the e/γ trigger system

Calibration and Identification

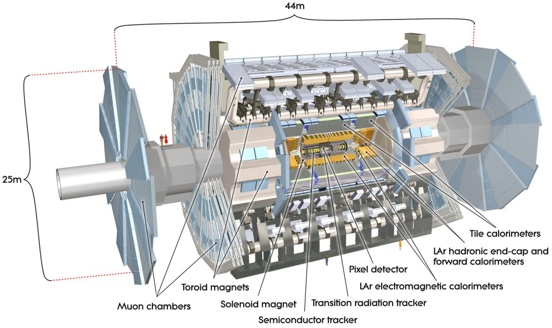
- Energy calibration and identification methods
- Recent improvements

e/γ Trigger Performance in 2016 and early 2017

- Performance with full 2016 dataset
- Early look at performance in 2017 data

Introduction to the ATLAS Electron and Photon Trigger

The ATLAS detector



Calorimeter

- Finely segmented calorimeter system
- Liquid Argon EM Calorimeter
- Liquid Argon Hadronic Calorimeter
- Tile Hadronic Calorimeter

Inner detector

- Pixel detector
- SemiConductor tracker
- Transition Radiation Tracker (TRT) provides electron / hadron separation by detection of transition radiation photons

Trigger system

- Reduces event rate to 1 kHz (around 20% allocated to e/γ) from beam crossing rate of 40 MHz
- Based on Region-of-Interest (ROI) concept
- Software based High-Level-Trigger is seeded by hardware based Level 1 (L1) trigger

e/γ **triggers are essential at ATLAS**

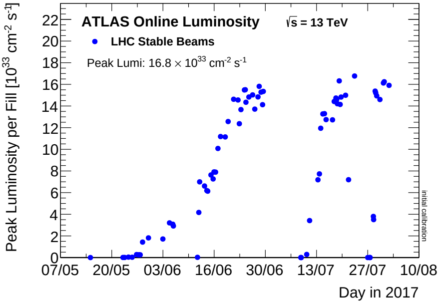
- SM measurements / backgrounds, diphoton, $W \to e\nu$, $Z \to ee$, ...

$$\sigma = \frac{N_{obs} - N_{background}}{\mathcal{L} \cdot \epsilon \cdot \mathrm{BR}}$$

- New physics, SUSY, $Z' \to ee$, $G_{KK} \to \gamma\gamma$, ...

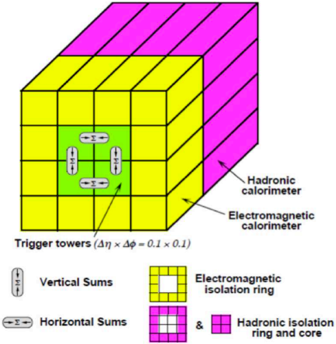
Higher than ever instantaneous luminosity

- Run 1 peak lumi: $7.73 \times 10^{33} \mathrm{cm}^2\mathrm{s}^{-1}$
- Run 2 peak lumi: $16.8 \times 10^{33} \mathrm{cm}^2\mathrm{s}^{-1} > 2\times$ larger!
- Want to keep as much physics as possible
- 25 ns bunch spacing $\to$ 40 MHz bunch crossing rate
- Only $\sim$ 1 kHz can be recorded
- Need to keep the rates under control



Level 1 (L1) Trigger

- e/γ L1 trigger decisions start from calorimeter input (L1Calo)
- Based on trigger towers in $\eta - \phi$ plane with granularity 0.1×0.1
- η-dependent E_{T} thesholds take into account energy loss in detector material
- Sliding-window algorithm (2×2 trigger towers) identifies local energy maxima for reconstruction of EM clusters
- Jet rejection using energy sum in hadronic isolation ring and core



Run 2 Upgrades

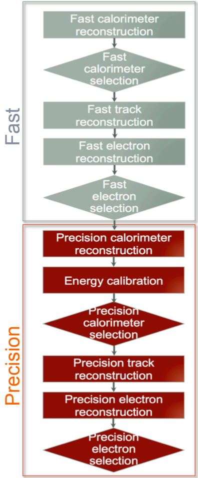
- New Multi Chip Module (nMCM) in Pre-Processor → improved energy resolution
- Firware upgrade of Cluster Processor Module (CPM): E_{T}-dependent EM / hadronic core isolation cuts with a precision of $\Delta E_{\mathrm{T}} \sim 0.5$ GeV.
- New Extended Common Merger Module (CMX) → doubles number of E_{T} thresholds

High Level Trigger (HLT)

- Full detector granularity used at HLT in ROIs
- Photons identified with EM cluster with no matching track requirement
- Electrons identified with EM clusters with matching charged track and minimum number of hits in inner Silicon tracking devices

Run 2 Upgrades

- Two-level HLT in Run 1 composed of Level 2 (L2) and Event Filter (EF)
- Now merged to run on a single computer farm
- Common data preparation for fast and precision online reconstruction
- Final online precision improved
- New electron and photon energy calibrations
- New electron identification based on Likelihood of relevant variables

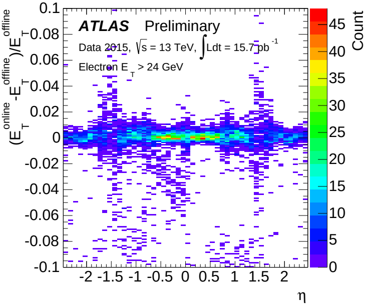


Based on MVA techniques

Calibration and Identification

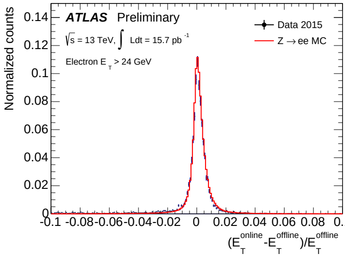
Cluster energy calibration

- Corrects for energy loss / leakage upstream and outside of calorimeter
- Simplified version of offline reconstruction
- BDT used to determine correction factors
- Separate calibrations for electrons and photons
- No separation between unconverted / converted photons → major source of difference wrt. offline reconstruction



Energy resolution

- Excellent resolution in most regions
- Suffers in the crack region ($1.37 < |\eta| < 1.52$) between the barrel and endcap EM calorimeter (as expected)



Common set of discriminating variables used for photon and electron ID

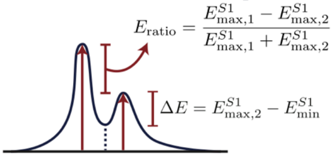
- **Likelihood-based** MVA method for electron ID
- **Cut-based** selection for photon ID

Variables and Position

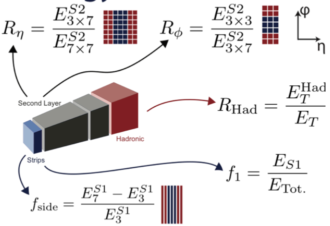
	Strips	2nd	Had.
Ratios	f_1, f_{side}	R_η*, R_ϕ	$R_{Had.}$*
Widths	$w_{s,3}$, $w_{s,tot}$	$w_{\eta,2}$*	-
Shapes	ΔE, E_{ratio}		

* Used in PhotonLoose.

Shower Shapes



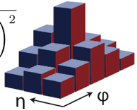
Energy Ratios



Widths

$$w_{\eta,2} = \sqrt{\frac{\sum E_i \eta_i^2}{\sum E_i} - \left(\frac{\sum E_i \eta_i}{\sum E_i}\right)^2}$$

Width in a 3×5 (Δη×Δφ) region of cells in the second layer.

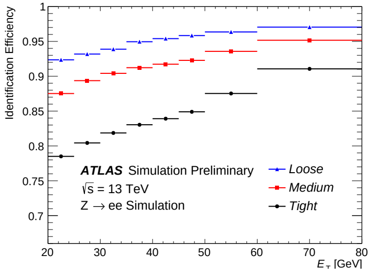


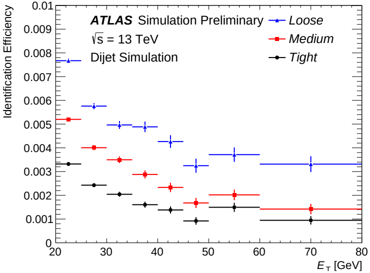
Electron ID

- Likelihood (LH) based ID
  - MVA technique to construct signal / background PDFs from electron discriminating variables
  - Combined into discriminant $d_{\mathcal{L}}$

$$d_{\mathcal{L}} = \frac{\mathcal{L}_S}{\mathcal{L}_S - \mathcal{L}_B}, \quad \mathcal{L}_{S(B)}(\vec{x}) = \prod_{i=1}^{n} P_{S(B),i}(x_i)$$

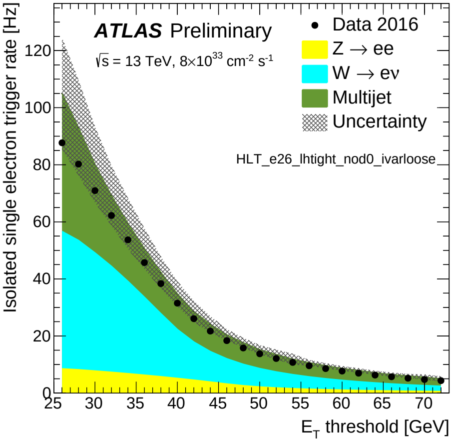
  - 20% lower rate for same efficiency as cut-based selection used in Run 1
  - LH default for electrons at HLT in Run 2
- Three ID operating points (OPs) defined for electron ID
  - Referred to as *loose*, *medium*, *tight*
  - Each uses the same variables to define the LH discriminant
  - Different selection on the LH discriminant for each OP
  - Sample selected by each OP are subsets of one another





Trigger rates depend heavily on E_T threshold

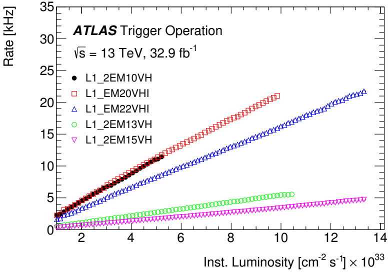
- Single electron dominated by $W \to e\nu$
- Sample purity is affected by trigger threshold
- In Run 2 HLT threshold kept at Run 1 level (24 GeV for single electron trigger) for as long as possible
- Tightening the ID level at HLT can significantly reduce the rate eg. *lhmedium* → *lhtight* gives around 45% rate reduction

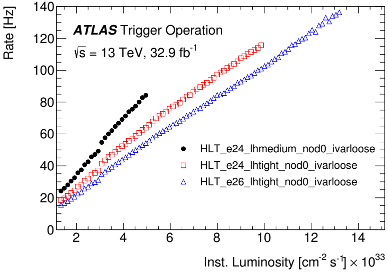


Run 2 Trigger Progression

Rates are dependent on instantaneous luminosity / pileup conditions

- Linear correlation (as expected)
- As these increase, it becomes necessary to tighten trigger selections to manage rates
- L1 progression:
  - Non-isolated → isolated
  - E_T threshold 18 → 22 → 24 GeV
- HLT progression:
  - Isolated, likelihood (LH) based electrons default in Run 2
  - E_T threshold 24 → 26 → 28
  - *medium* → *tight*
- Without improvement, tighter selections can harm the physics goals of the experiment

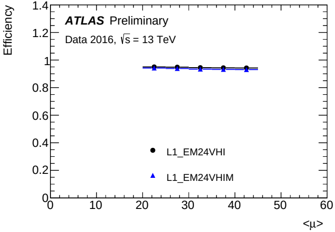


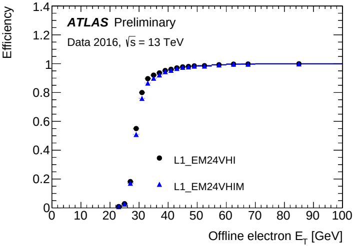


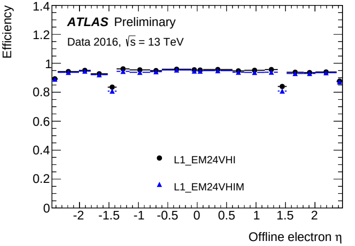
New Medium L1 working point

- New in 2017
- V indicates pseudorapidity dependent E_T theshold
- H indicates upper cut on hadronic energy behind em cluster
- I(M) indicates isolation requirement
- Significant rate reduction for small efficiency reduction

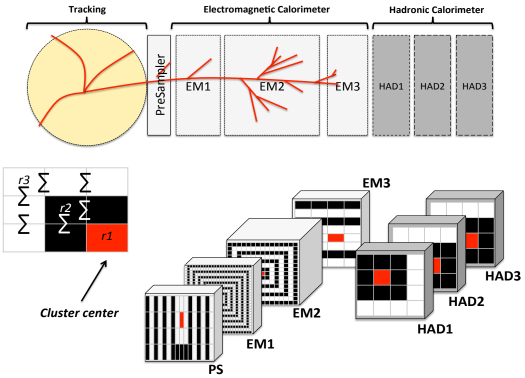
Level-1 E_T	Efficiency loss	Rate reduction
22 GeV	1.3%	14.6%
24 GeV	1.0%	10.8%







Ringer Upgrade



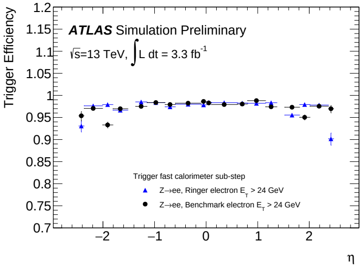
Total number of Rings per layer (covering 0.4 x 0.4 region in η x φ)						
PS	EM1	EM2	EM3	HAD1	HAD2	HAD3
8	64	8	8	4	4	4

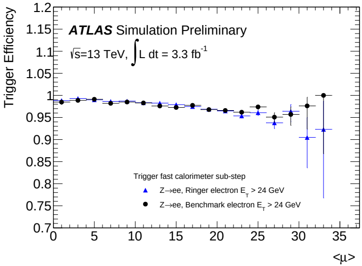
Upgrade to fast calorimeter preselection step

- Alternative approach to cut-based methods
- Neural network classifier performs particle ID targeting high efficiency of the complete trigger chain with significant reduction on the number of calls to tracking (usually much heavier in terms of computing)
- Explores conic geometry, building rings in layers of the calorimeter
- Sum of energy in a ring over sum of energy in all rings provides a vector of discriminating variables (generalise shower shapes)

Upgrade to fast calorimeter preselection step

- Achieves ×2 better background rejection with efficiency almost unchanged
- Plots refer to 2016 tunes, smoother efficiency in 2017
- Ringer algorithm now the default in electron triggers



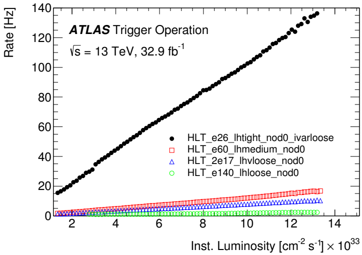


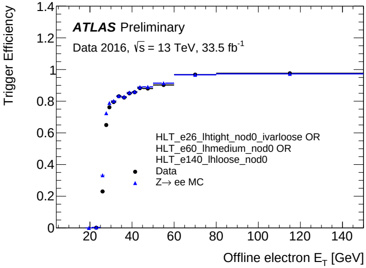
e/γ Trigger Performance in 2016 and 2017

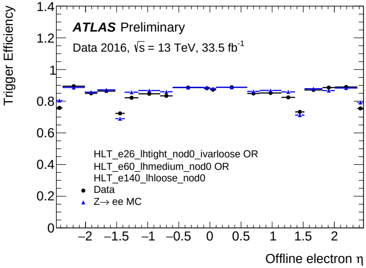
Electron Trigger Performance

Electron trigger performance for full 2016 dataset

- Efficiency measured using *Tag and Probe* method with $Z \to ee$
- At high E_T track isolation losses become important
- Lowest unprescaled electron trigger ORed with non-isolated high-threshold triggers
- Excellent data / MC agreement



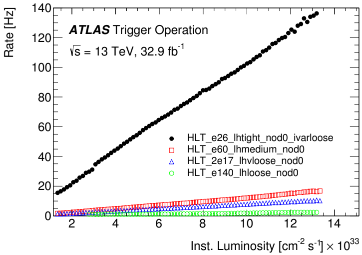


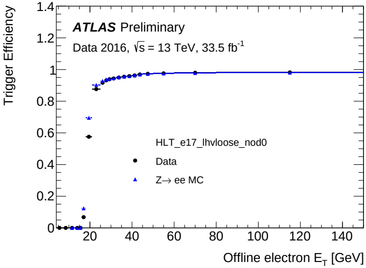


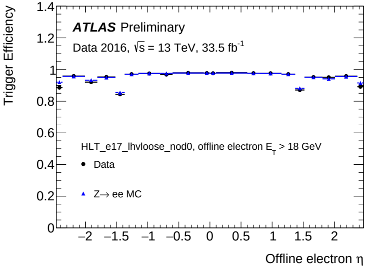
Electron Trigger Performance

Electron trigger performance for full 2016 dataset

- *lhvloose* trigger used for di-electron triggers
- Efficiency measured for single leg e17_lhvloose_nod0
- Excellent data / MC agreement

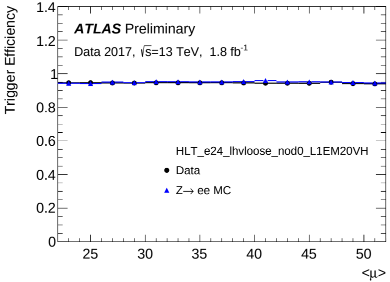


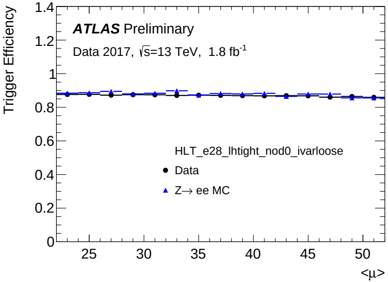




A first look at 2017 data

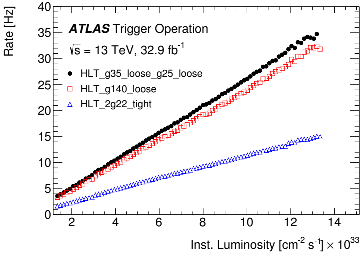
- Good trigger performance, excellent data / MC agreement
- Robust against pileup
- Tighter identification more pileup dependent (as expected)

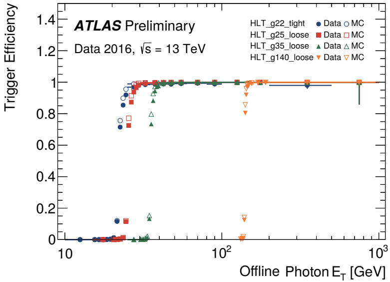


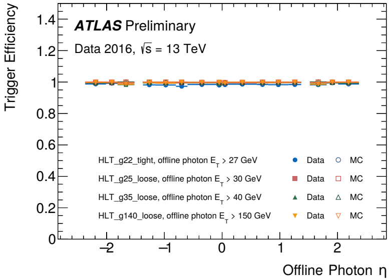


Photon trigger efficiency for full 2016 dataset

- Measured using *Bootstrap* method using L1 trigger
- Fully efficient at 5 GeV above threshold
- Lowest threshold triggers:
  - Single photon - g140_loose
  - Multi photon - g35_loose_g25_loose







A first look at 2017 data

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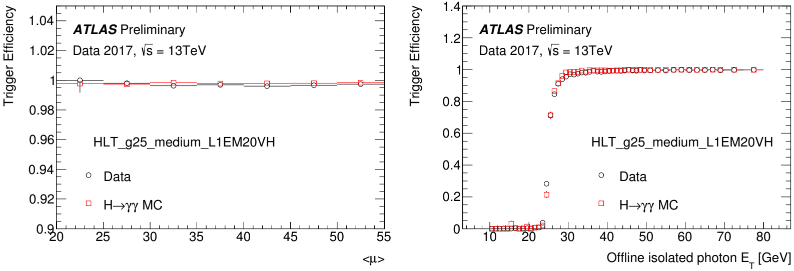
- Robust against pileup



Conclusions

Improved L1

- Run 2 upgrades improve resolution and granularity
- New working point gives significant rate reduction

Improved HLT

- Run 2 likelihood IDs improve cut-based ID used in Run 1
- Further improvements from ringer algorithm at L2 (fast calorimeter step)

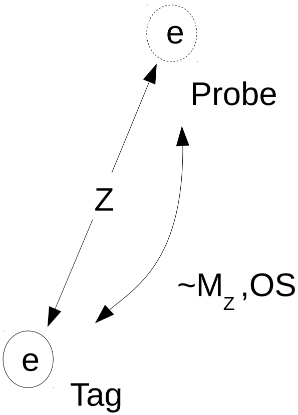
Electron and photon triggers performing well in Run 2

- Consistent performance for 2015-2017 data taking

Backup

Need a clean, unbiased sample of electrons for efficiency measurement

- Use $Z \to ee$ / $J/\psi \to ee$ / $W \to e\nu$ characteristic decays
- Apply strict selection criteria to one of the decay electrons, the *tag*
- For W T&P, trigger in E_{T}^{miss}
- The second decay electron, the *probe* is identified with the tag by m_{ee} within the mass window
- Probe electrons are used for the efficiency measurement



Electron Discriminating Variables

Type	Description	Name
Hadronic leakage	Ratio of E_T in the first layer of the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| < 0.8$ or $\|\eta\| > 1.37$)	R_had1
	Ratio of E_T in the hadronic calorimeter to E_T of the EM cluster (used over the range $0.8 < \|\eta\| < 1.37$)	R_had
Back layer of EM calorimeter	Ratio of the energy in the back layer to the total energy in the EM accordion calorimeter. This variable is only used below 100 GeV because it is known to be inefficient at high energies.	f_3
Middle layer of EM calorimeter	Lateral shower width, $\sqrt{(\Sigma E_i \eta_i^2)/(\Sigma E_i) - ((\Sigma E_i \eta_i)/(\Sigma E_i))^2}$, where E_i is the energy and η_i is the pseudorapidity of cell i and the sum is calculated within a window of 3×5 cells	$w_{\eta 2}$
	Ratio of the energy in 3×3 cells over the energy in 3×7 cells centered at the electron cluster position	R_ϕ
	Ratio of the energy in 3×7 cells over the energy in 7×7 cells centered at the electron cluster position	R_η
Strip layer of EM calorimeter	Shower width, $\sqrt{(\Sigma E_i (i - i_\mathrm{max})^2)/(\Sigma E_i)}$, where i runs over all strips in a window of $\Delta\eta \times \Delta\phi \approx 0.0625 \times 0.2$, corresponding typically to 20 strips in η, and i_max is the index of the highest-energy strip	w_stot
	Ratio of the energy difference between the largest and second largest energy deposits in the cluster over the sum of these energies	E_ratio
	Ratio of the energy in the strip layer to the total energy in the EM accordion calorimeter	f_1
Track conditions	Number of hits in the innermost pixel layer; discriminates against photon conversions	n_Blayer
	Number of hits in the pixel detector	n_Pixel
	Number of total hits in the pixel and SCT detectors	n_Si
	Transverse impact parameter with respect to the beam-line	d_0
	Significance of transverse impact parameter defined as the ratio of d_0 and its uncertainty	d_0/σ_{d_0}
	Momentum lost by the track between the perigee and the last measurement point divided by the original momentum	$\Delta p/p$
TRT	Likelihood probability based on transition radiation in the TRT	eProbabilityHT
Track-cluster matching	$\Delta\eta$ between the cluster position in the strip layer and the extrapolated track	$\Delta\eta_1$
	$\Delta\phi$ between the cluster position in the middle layer and the track extrapolated from the perigee	$\Delta\phi_2$
	Defined as $\Delta\phi_2$, but the track momentum is rescaled to the cluster energy before extrapolating the track from the perigee to the middle layer of the calorimeter	$\Delta\phi_\mathrm{res}$
	Ratio of the cluster energy to the track momentum	E/p

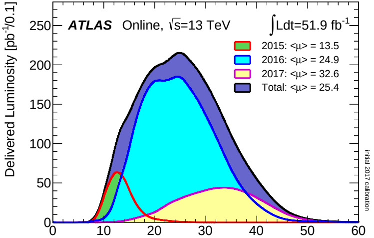
Photon Discriminating Variables

Category	Description	Name	Loose	Tight
Acceptance	$\|\eta\| < 2.37$, $1.37 < \|\eta\| < 1.52$ excluded	–		✓
Hadronic leakage	Ratio of E_T in the first sampling of the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| < 0.8$ and $\|\eta\| > 1.37$)	R_{had_1}	✓	✓
	Ratio of E_T in all the hadronic calorimeter to E_T of the EM cluster (used over the range $0.8 < \|\eta\| < 1.37$)	R_{had}	✓	✓
EM Middle layer	Ratio in η of cell energies in 3×7 versus 7×7 cells	R_η	✓	✓
	Lateral width of the shower	w_2	✓	✓
	Ratio in ϕ of cell energies in 3×3 and 3×7 cells	R_ϕ		✓
EM Strip layer	Shower width for three strips around maximum strip	$w_{s\,3}$		✓
	Total lateral shower width	$w_{s\,\text{tot}}$		✓
	Fraction of energy outside core of three central strips but within seven strips	F_{side}		✓
	Difference between the energy associated with the second maximum in the strip layer, and the energy reconstructed in the strip with the minimal value found between the first and second maxima	ΔE		✓
	Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies	E_{ratio}		✓

Electron Identification

Pileup Dependence

- Shower shape variables are dependent on level of pileup in the event
  - Increased instantaneous luminosity + higher $\sqrt{s} \rightarrow$ greatest pileup for 2017 data taking
  - Cut on discriminant is loosened as a function of the number of primary vertices to maintain efficiency at high pileup



Isolation

- Isolation requirement provides further discrimination against electrons originating from converted photons and hadronic activity
- *Track* isolation used at HLT
- Definied as p_T sum of non electron associated tracks in a cone surrounding the electron candidate