The Upgrade of the ATLAS Electron and Photon Triggers towards LHC Run 2 and their Performance

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LISHEP
2nd–9th August, 2015
Manaus (Brazil)

Outline

- Introduction
  - **Energy reconstruction and trigger execution**
  - **Performance results from Run 1**
- Run 2 challenges and preparations
  - **Rate & Pileup**
  - **Level 1 and HLT upgrades**
- Electron and Photon Triggers
  - **Performance results with Run 2 data**

Introduction

The ATLAS Trigger System operated successfully in Run 1

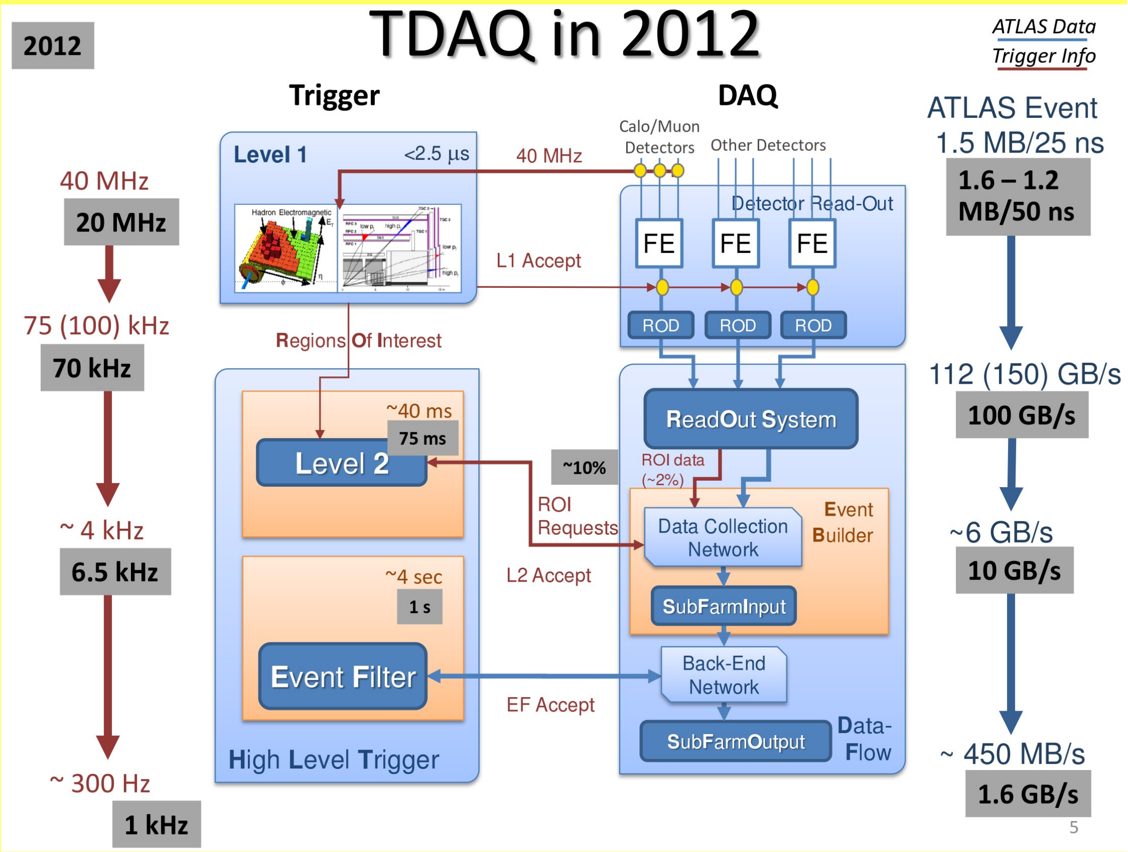
Selected interesting events online √s up to 8 TeV between 2009-2013 with high efficiency for a wide range of physics processes in ATLAS

Level 1 :

- **Fast custom-made hardware trigger**
- **Determines Regions-of-Interests (RoIs)**
- **Using calorimeter and muon signals**
- **Corse granularity data**
- **From 20 MHz input rate → 70 kHz rate**

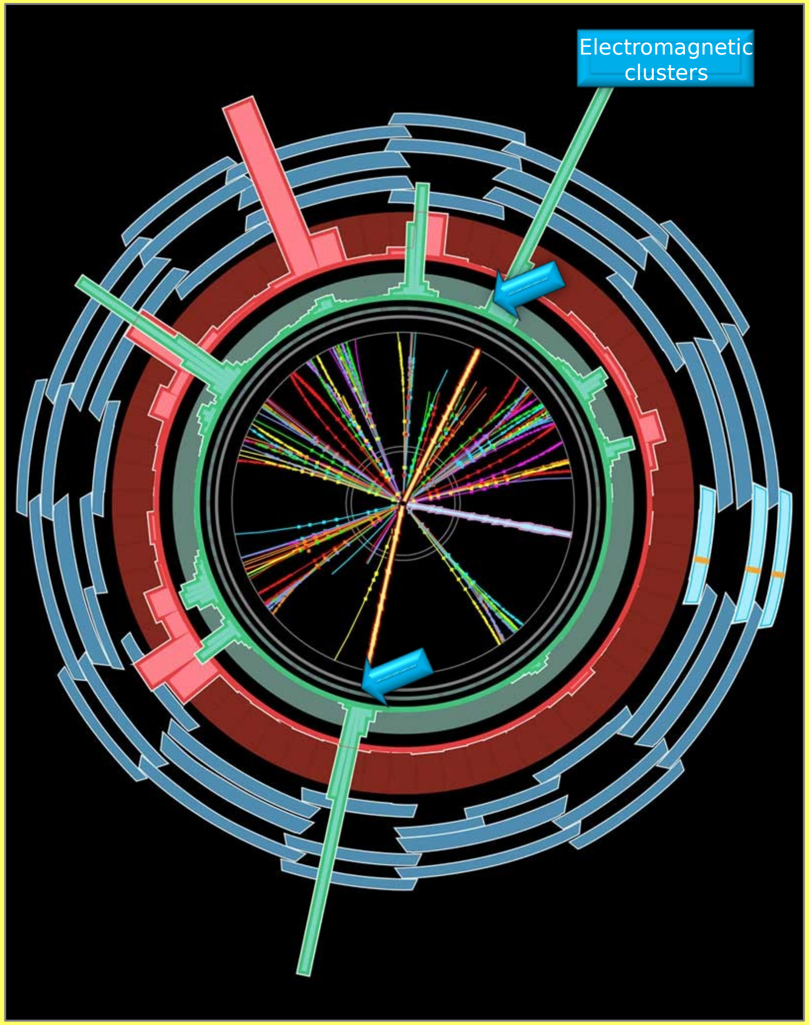
High Level Trigger :

- **Software based**
- **Two step design in Run 1**
- **L2: uses fast algorithms on input L1 RoIs**
- **EF: input from L2 and builds full events**
- **Selection uses offline reconstruction**
- **Designed output rate 300 Hz**
- **Average output rate ~500 Hz**
- **Peak output rate 1 kHz**



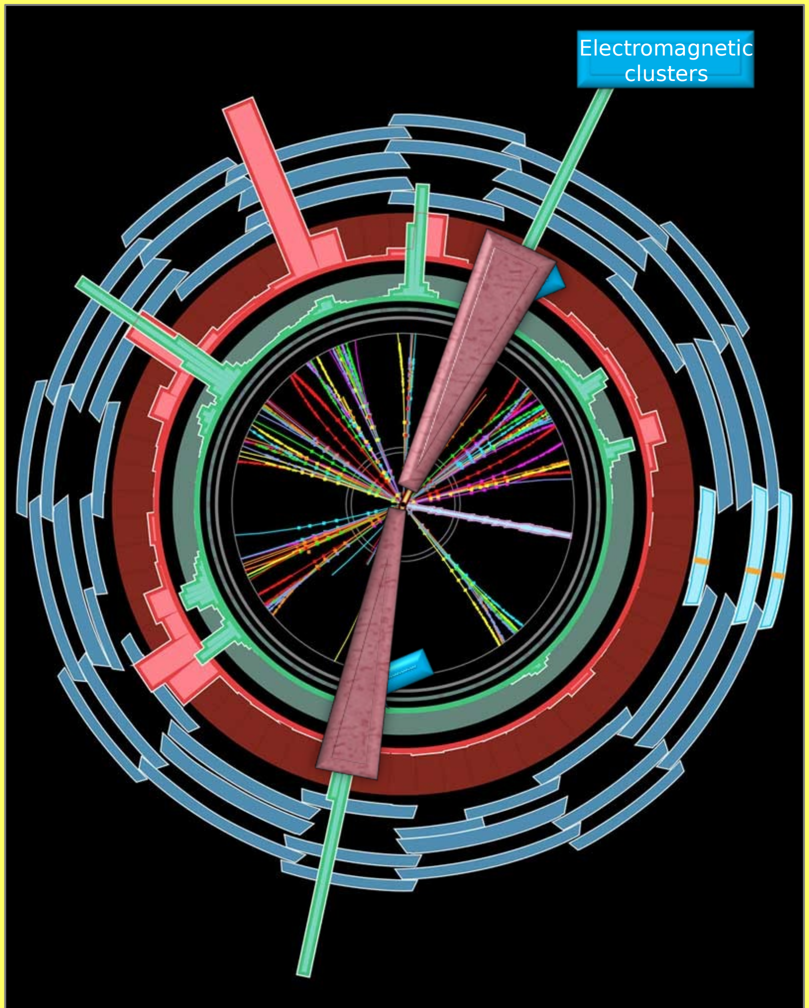
Trigger Execution in Run 1

EM RoI



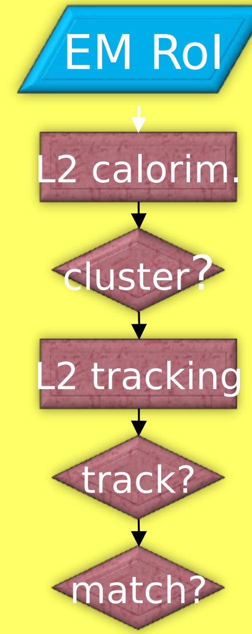
Level 1:
Region of Interest is found and position in EM calorimeter is passed to L2

Trigger Execution in Run 1

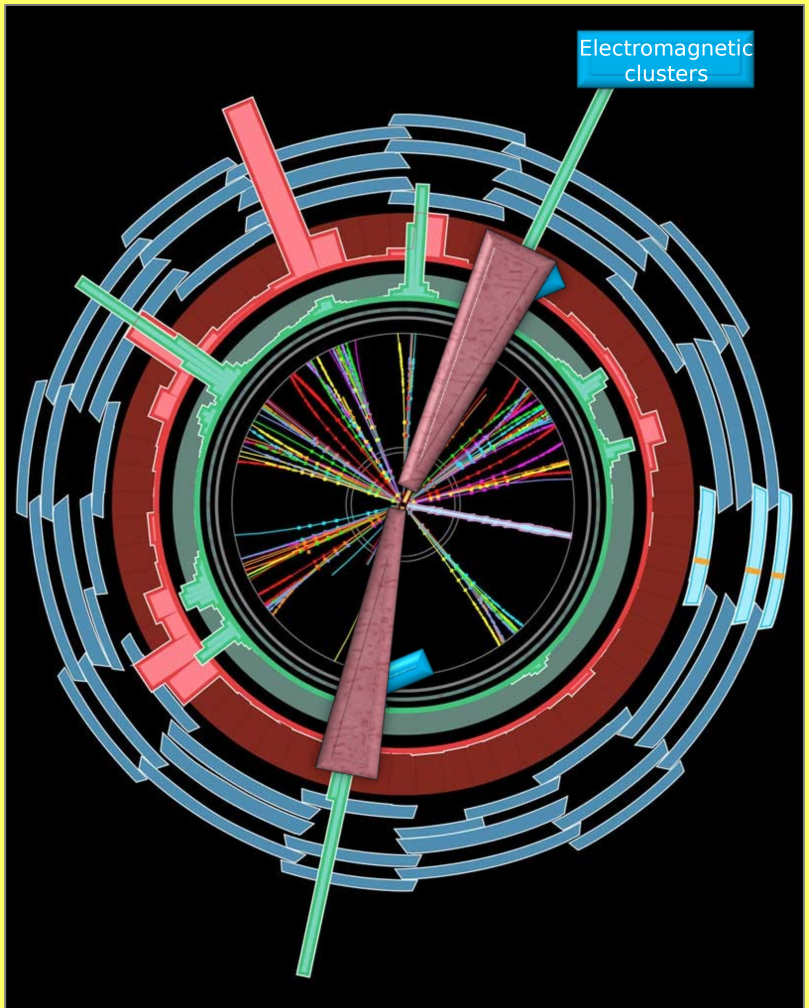


Level 1:
Region of Interest is found and position in EM calorimeter is passed to L2

Level 2 seeded by Level 1
- Fast reconstruction algorithms
- Reconstruction within RoI



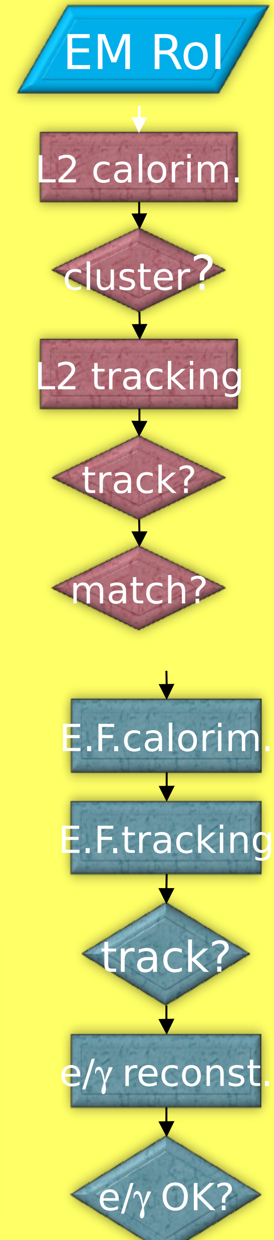
Trigger Execution in Run 1



Level 1:
Region of Interest is found and position in EM calorimeter is passed to L2

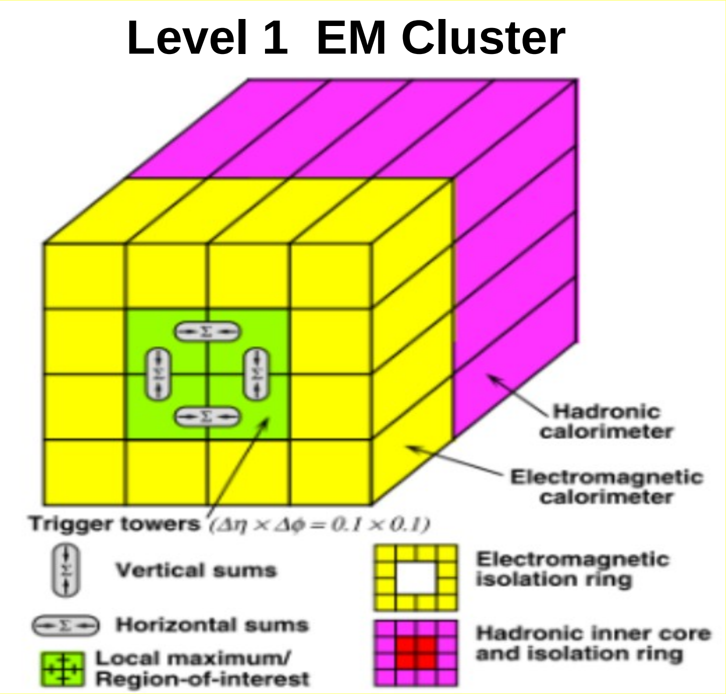
Level 2 seeded by Level 1
- Fast reconstruction algorithms
- Reconstruction within RoI

Ev. Filter seeded by Level 2
- Offline reconstruction algorithms
- Refined alignment and calibration



Trigger e/γ Reconstruction

- The Level 1 system finds electromagnetic (EM) clustered energy deposits which then seed the HLT reconstruction



- The reconstruction of electrons and photons in the region $|\eta| < 2.47$ starts from energy deposits (clusters) in the EM calorimeter.

- EM clusters:
  - Clusters are seeded by towers
  the EM calorimeter is divided into a grid of $N_\eta \times N_\varphi$
  - L1 towers of size $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1$
  - The energy of all cells in all longitudinal
  layers is summed into the tower energy.

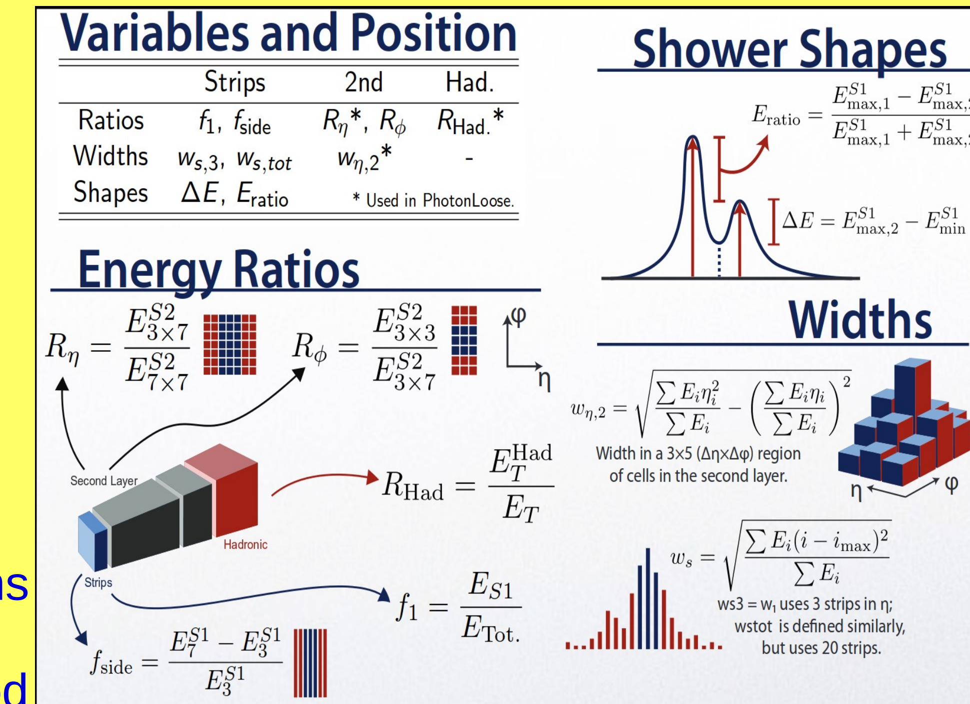
  - Clusters matched to a well-reconstructed ID track originating from a vertex found in the beam interaction region are classified as electrons

  - Photon reconstruction and identification is only based on EM cluster information

e/γ Identification

Identification at the HLT:

- For central photons, identification relies on calorimeter cluster variables
- For electrons, track properties, track quality, Transition Radiation Tracker (TRT) fraction and track-cluster matching variables are also included



- Cutting on these variables in order to identify:
  - Electrons
  - Converted and unconverted photons

- Different working points translating to different levels of purity: loose, medium, tight
  cuts are optimized in 2D (E_T,η) bins

- For the main physics triggers in Run 1, loose and medium requirements were used in the trigger both for electrons and photons

- For 2012 electrons, possibility of using Likelihood (product of PDFs of discriminating variables from signal and background samples), used offline only
  - This is the main strategy for Run 2 (more on this later)

- Forward electrons (2.5 < |η| < 4.9) do not use tracking, we use cluster moments instead

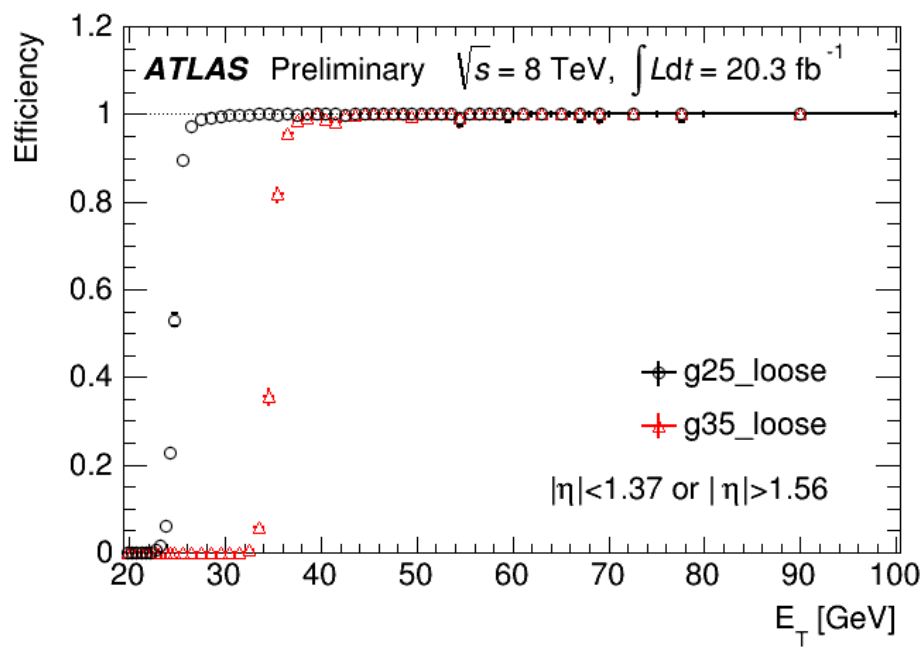
Run 1 Trigger Efficiencies

Single photon trigger efficiencies in Run 1

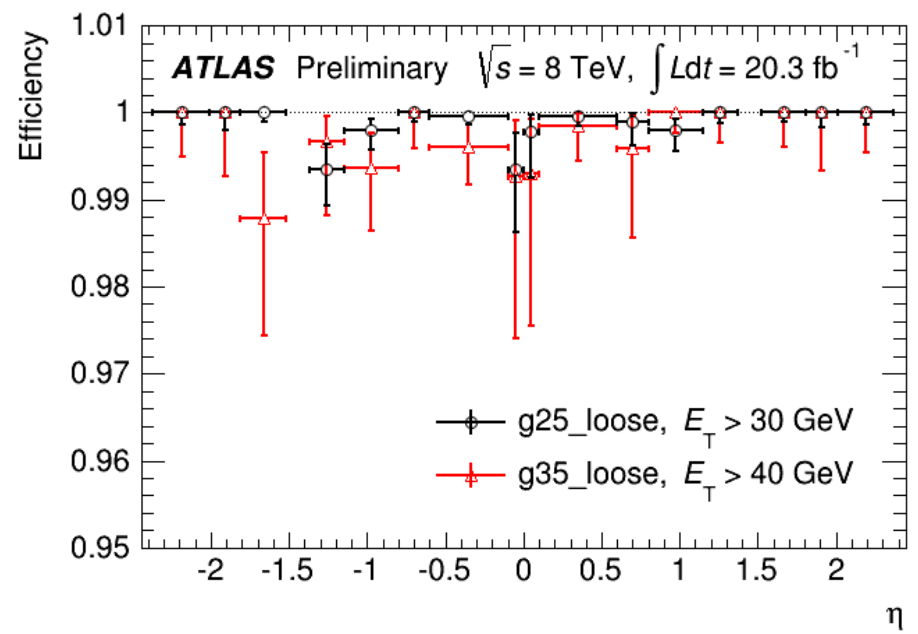
Efficiency of photon triggers requiring:

- Transverse energy (E_T) greater than 25 GeV and 35 GeV
- Loose photon identification criteria w.r.t. photons reconstructed offline passing the tight identification criteria
- Measurements are performed using a clean sample of radiative Z decays ($Z \to l^+l^-\gamma$)

E_T of eff. as a function of offline E_T



Pseudorapidity

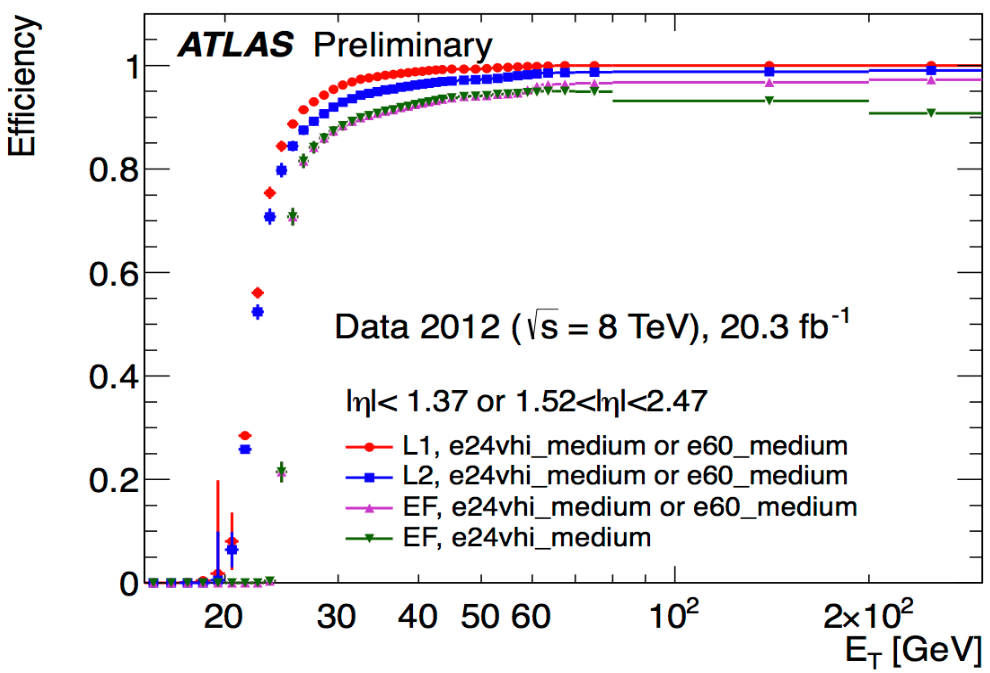


Run 1 Trigger Efficiencies

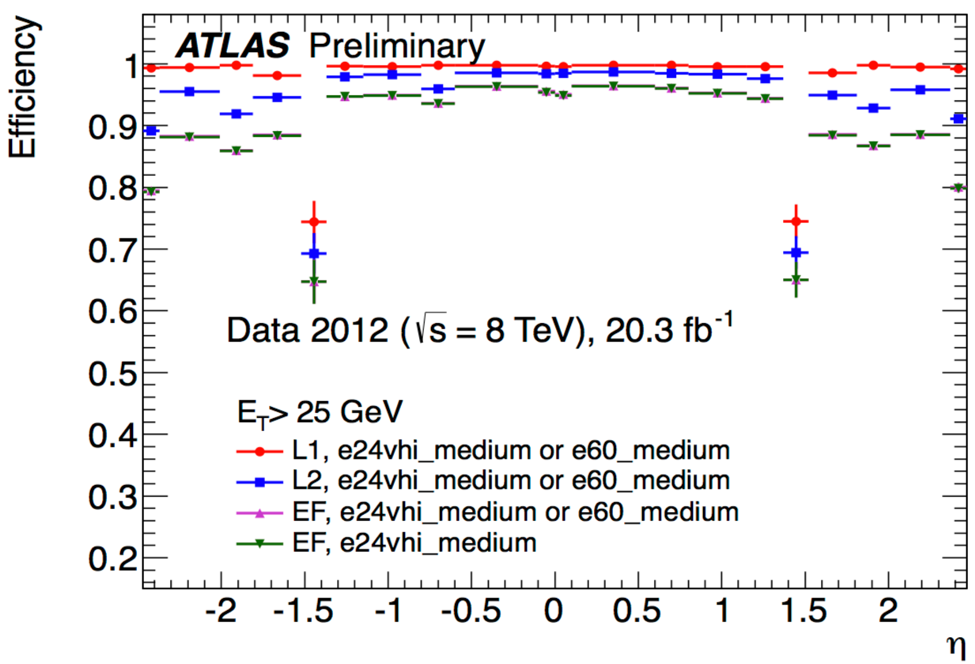
Single electron efficiencies at different trigger Levels (L1,L2,EF)

- Measurements are performed using a Tag & Probe method using $Z(e^+e^-)$ events
- The trigger e24vhi_medium requires an electron candidate with E_T>24 GeV
- Medium identification requirements and isolation based on tracks near the electron tracks in the inner detector
- The trigger is complemented with a higher threshold non-isolated electron trigger e60_medium

E_T of eff. as a function of offline E_T



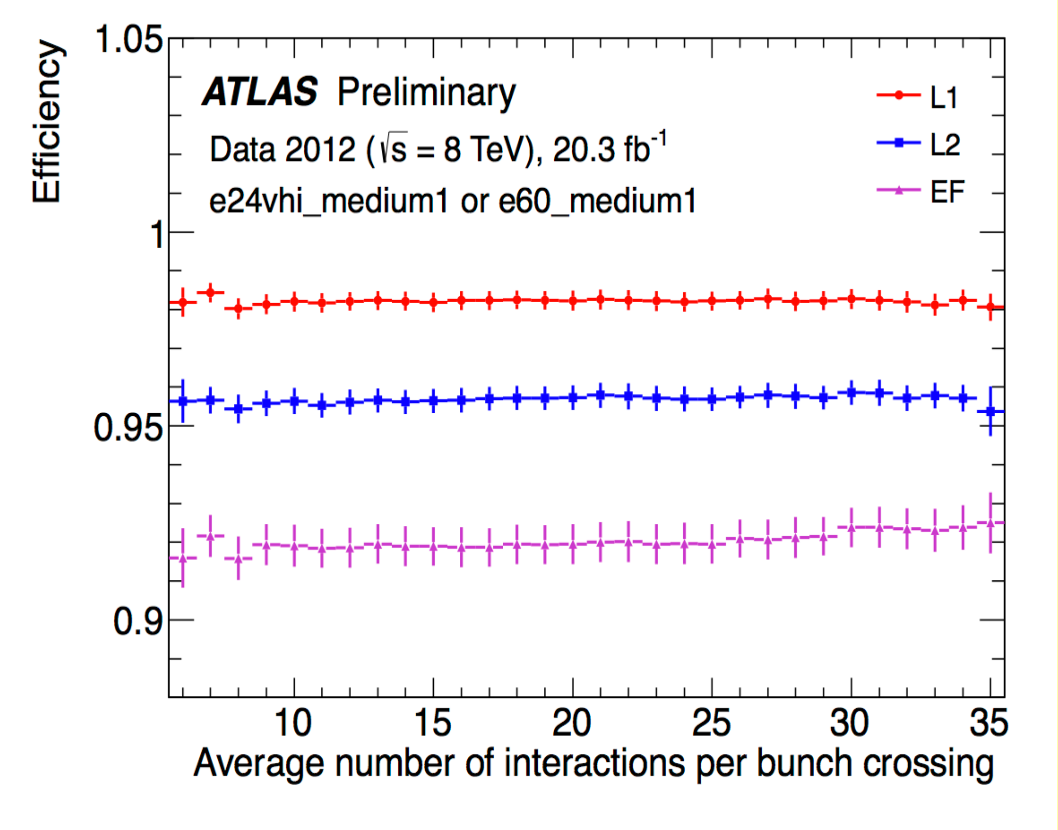
Pseudorapidity



Run 1 Trigger Efficiencies

Single electron efficiencies

- Measurements are performed using a Tag & Probe method using $Z(e^+e^-)$ events
- The trigger e24vhi_medium requires an electron candidate with E_T>24 GeV
- The trigger selection in 2012 was robust against pileup effects at all trigger levels (L1,L2,EF)



Trigger Challenges and Preparations for Run 2

Run 2 Challenges

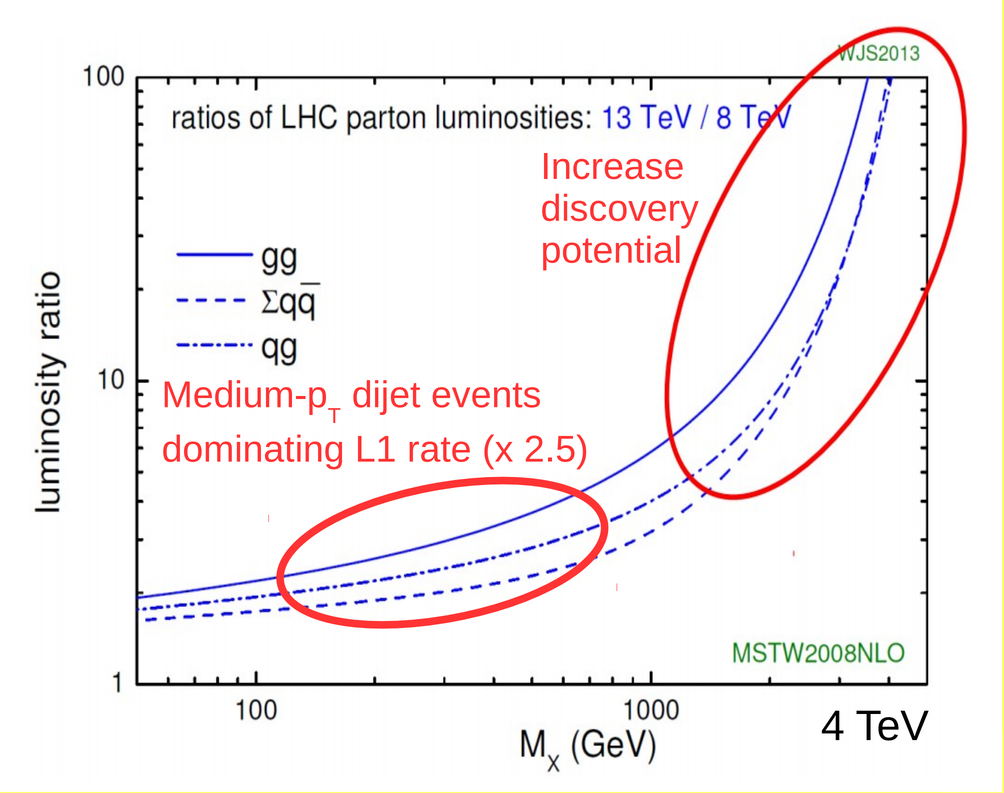
Energy increase (13 TeV) and higher luminosity brings new challenges

Run 2:

- 10 times increase in cross section for heavy objects (@ 2 TeV)
- Keeping electrons and photons is crucial
  - Need to keep (rare) Higgs events and events containing Z, W bosons
- Possibility of discoveries from day 1

To achieve this :

- Important for the trigger to be ready from day 1
- Rapid commissioning of trigger strategy
- New Level 1 and HLT hardware readout



Rate and pileup:

Level 1 max. rate was a limiting factor in Run 1

- Level 1 rate 2-3 higher than in Run 1
- Luminosity increase of 2 w.r.t. Run 1
  - **~5 times higher trigger rate**
  - **Needs new trigger strategy**
  - **<μ> ~43** @ 1.6×10^{34} $cm^{-2}s^{-1}$ (25ns)
  - **Level 1 upgrade needed**
  - **Still a limiting factor in Run 2**

Run 2 Preparations

Critical for Run 2 : Talk by Florian B. Friday (The ATLAS Trigger: Ready for Run 2)

Better suppression & mitigation of pileup effects

Code improvements & offline selection

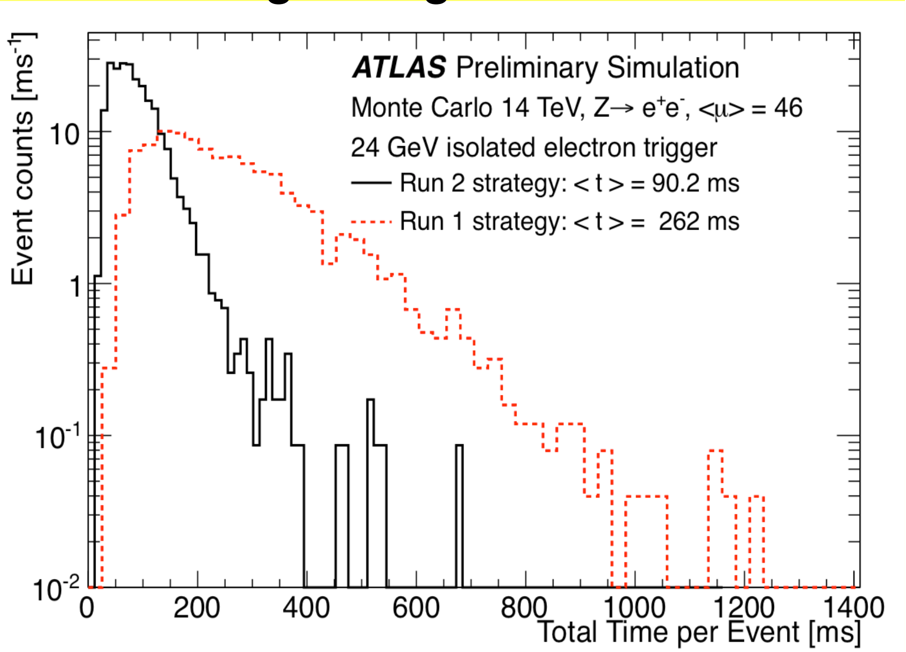
Level 1 Calo upgrade: Improve energy resolution and reduce pileup effects

- Noise autocorrelation filtering
- Dynamic pedestal correction

Two HLT levels (L2, EF) merged into one for Run 2

- **Improved timing of algorithms in trigger**
  - Tracking, Calo clustering, muon reconstruction
  - More flexibility in trigger strategies

Tracking timing Run 1 vs Run 2



Electron and photon triggers

- **Use offline reconstruction and calibration**
  - Offline clustering for jets, taus, e and γ
  - Improved resolution, steeper turn-on curves
- **Use of Likelihood identification (electrons)**

Likelihood discriminant :

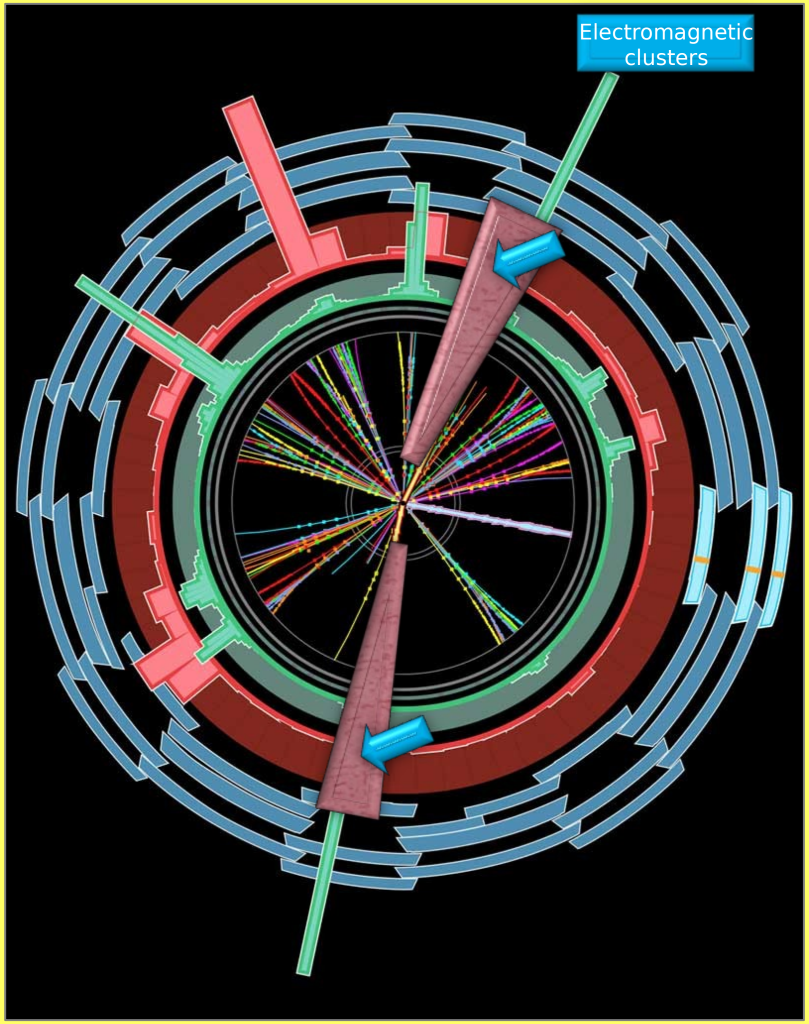
$$d_{\mathcal{L}} = \frac{\mathcal{L}_S}{\mathcal{L}_S + \mathcal{L}_B}, \qquad \mathcal{L}_S(\vec{x}) = \prod_{i=1}^{n} P_{s,i}(x_i)$$

- product of PDFs of discriminating variables from signal and background samples (backup)

New HLT Hardware: New readout boards

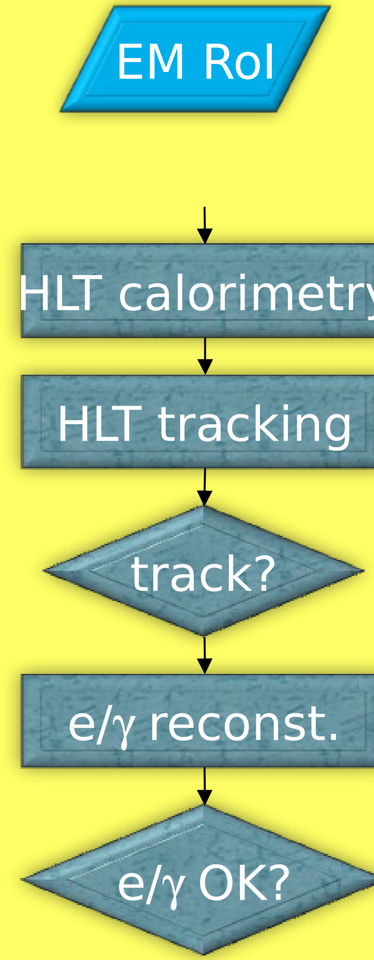
- Selection based on full detector information at a higher rate w.r.t. Run 1

Trigger Execution in Run 2



Level 1:
Region of Interest is found and position in EM calorimeter is passed to HLT

HLT seeded by Level 1
- Runs Fast analyses on ROIs and later using full detector information, **all in the same process** allowing more flexibility
- Refined alignment
- **calibration same as offline**
- **Likelihood based identification**



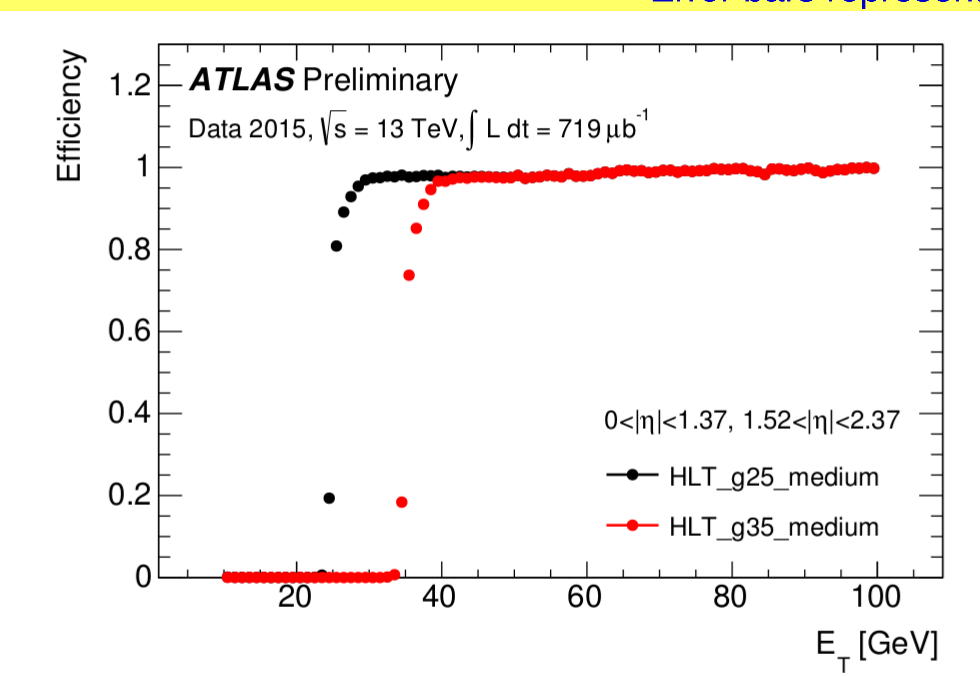
Electron and Photon Trigger Performance in Run 2

Run 2 Trigger efficiencies

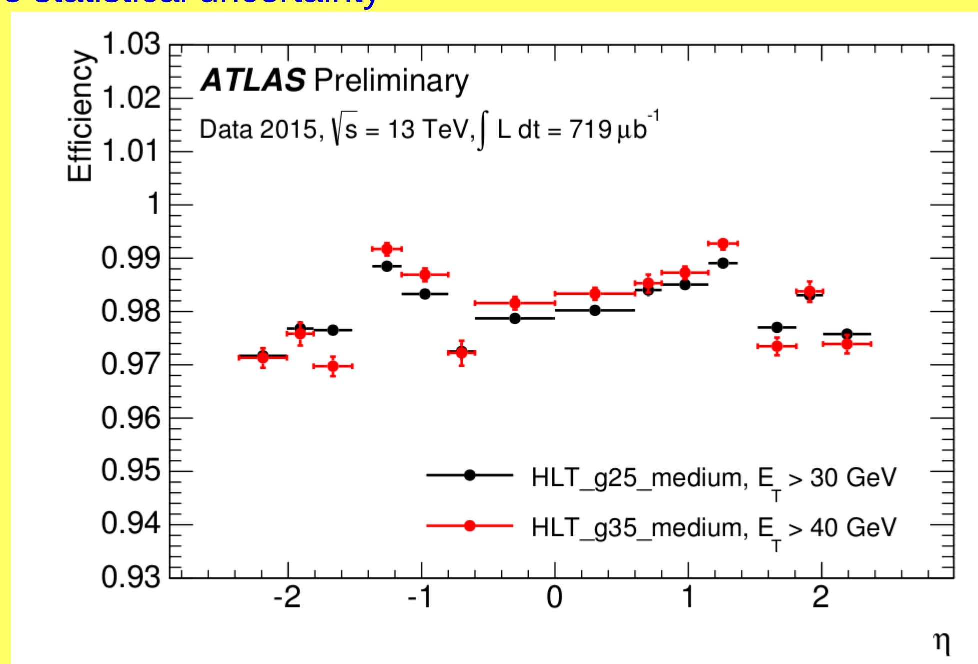
Single photon trigger efficiencies in Run 2

- The efficiency is measured on events recorded with no selection applied at the HLT
- Transverse energy (E_T) greater than 25 GeV (black circles) and 35 GeV (red circles)
- No background subtraction is applied
- High efficiency with a fast turn on curve is observed,
- Expect similar performance as in Run 1, but in harsher environment

Error bars represent the statistical uncertainty



Offline photon transverse energy

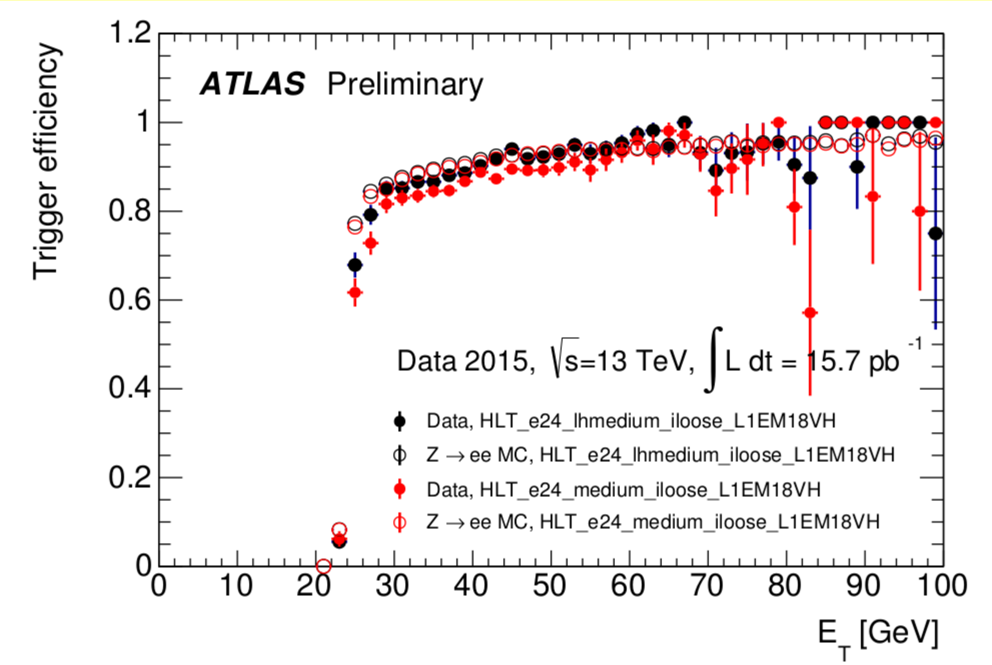


Pseudorapidity

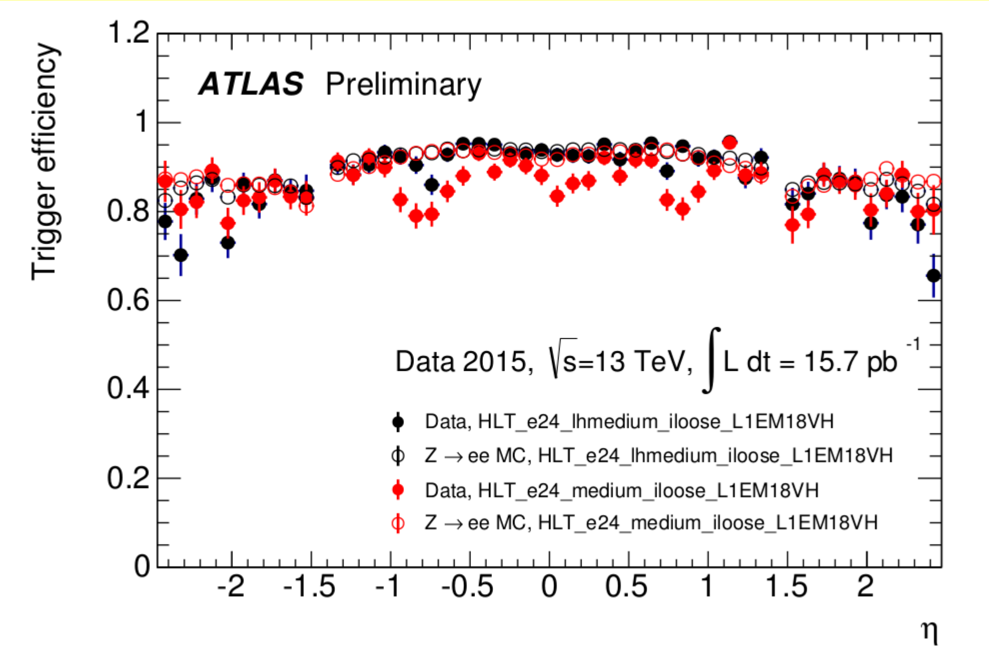
Run 2 Trigger efficiencies

Single electron trigger efficiencies at 13 TeV

- Measurements are performed using a Tag and Probe method using $Z(e^+e^-)$ events
- The likelihood trigger lhe24vhi_medium requires a trigger electron object with E_T>24 GeV
- High efficiency with a fast turn on curve is observed



Offline electron transverse energy



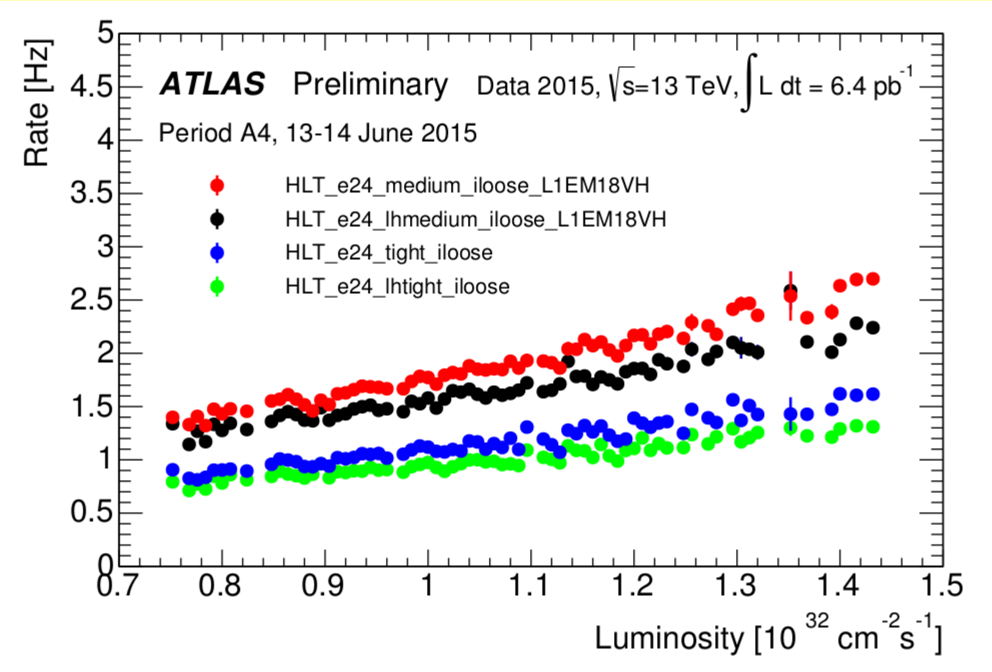
Pseudorapidity

Run 2 Trigger Rates

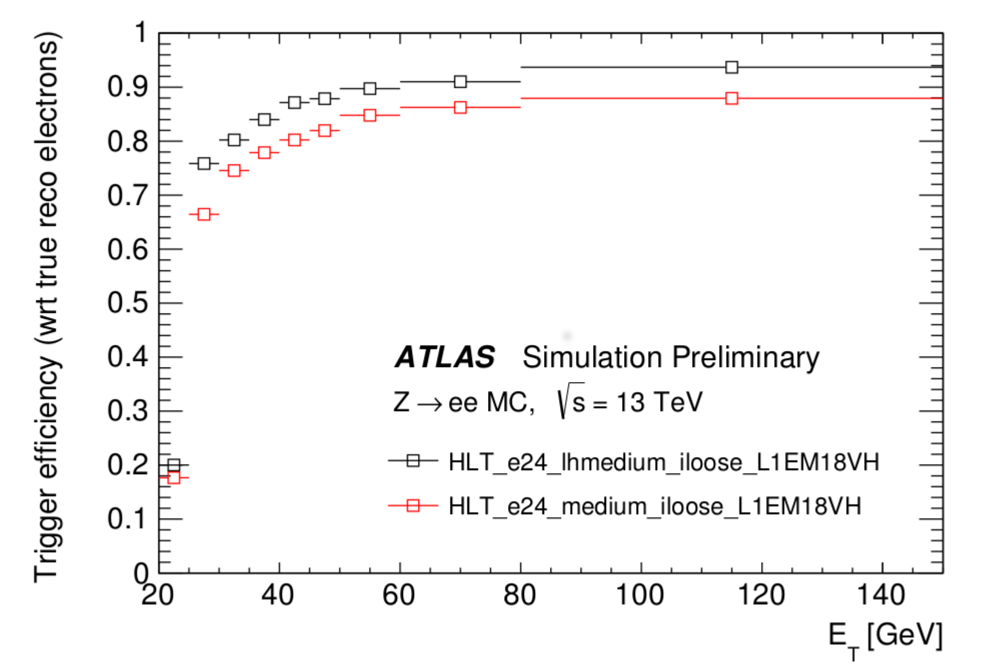
Run 2 data single electron triggers

- Commissioning phase of trigger menu for Run 2
- Commissioning of electron triggers
- The new likelihood based triggers (e24_lh) outperforming the Run 1 cut based triggers

Rate vs Inst. Luminosity



Efficiency w.r.t true reco electrons



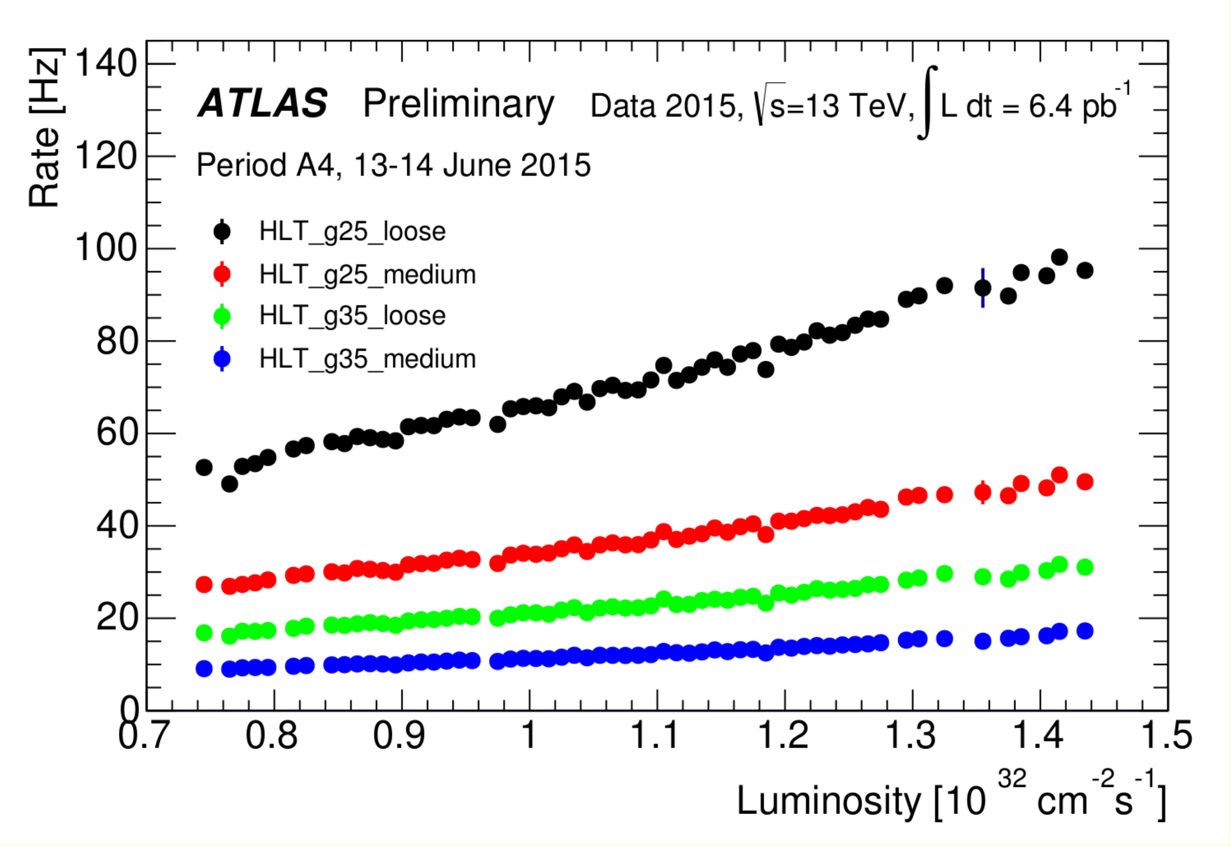
Offline electron transverse energy

Run 2 Trigger Rates

13 TeV data photon triggers

- Commissioning phase of trigger menu for Run 2

Rate vs Inst. luminosity



Summary

- Atlas Trigger underwent significant changes in order to face Run 2 challenges

- Atlas trigger commissioning is in full swing, so far very successful

- The early Run 2 data taking period has shown no major problems for electron and photon triggers and in general for the whole Atlas trigger system

- Excellent performance of electron and photon triggers in Run 2

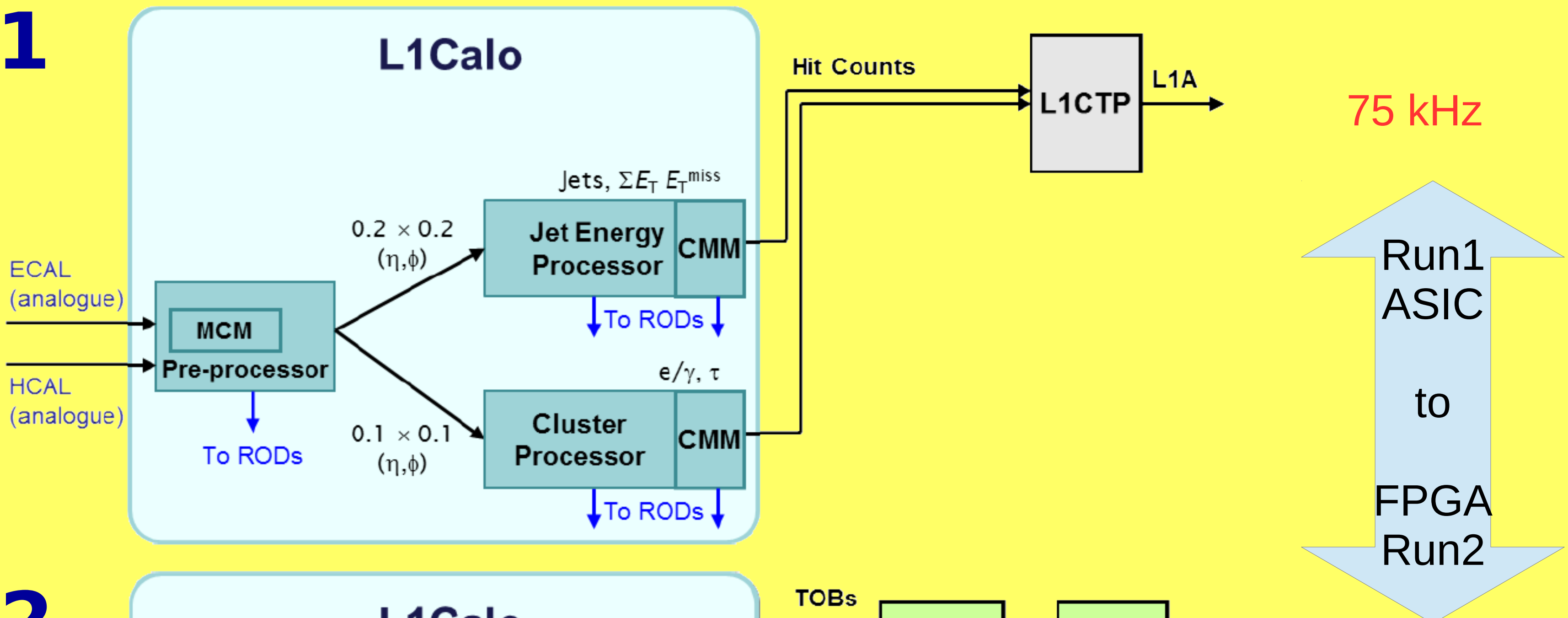
- Excellent trigger selection vital to maximise physics reach, in particular single electron and photon triggers are crucial for our physics programme

- Still a great deal of work is waiting ahead to be able to fully exploit the physics LHC will provide us in the months/years ahead

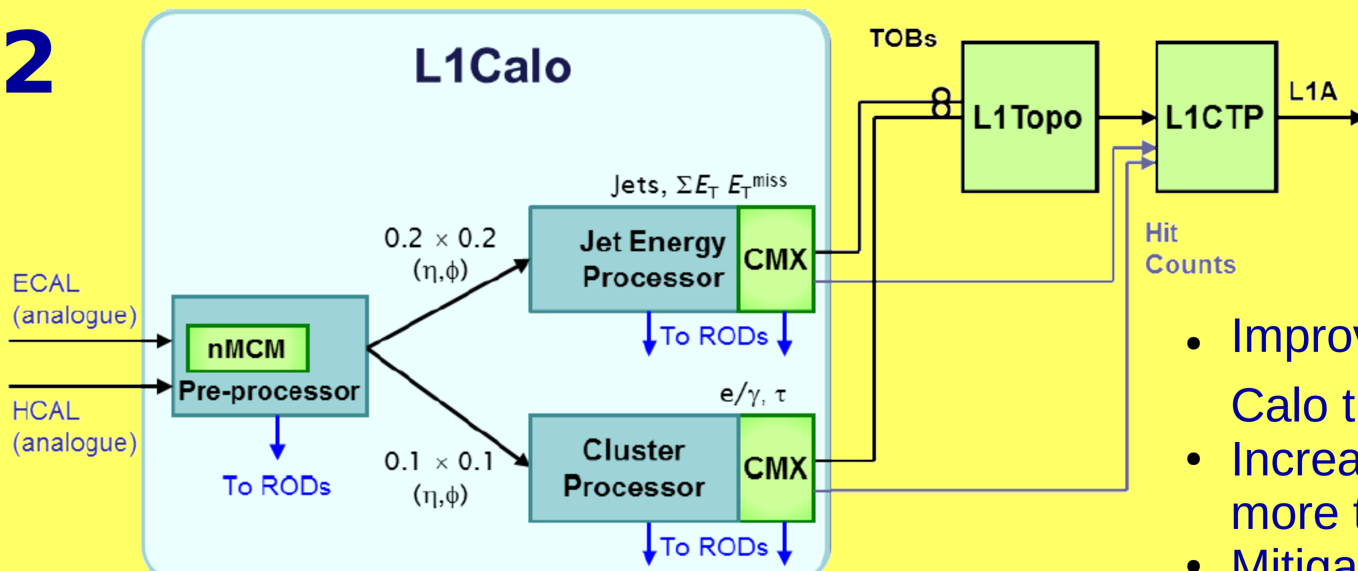
Backup

L1 Calo Upgrade

Run1



Run2



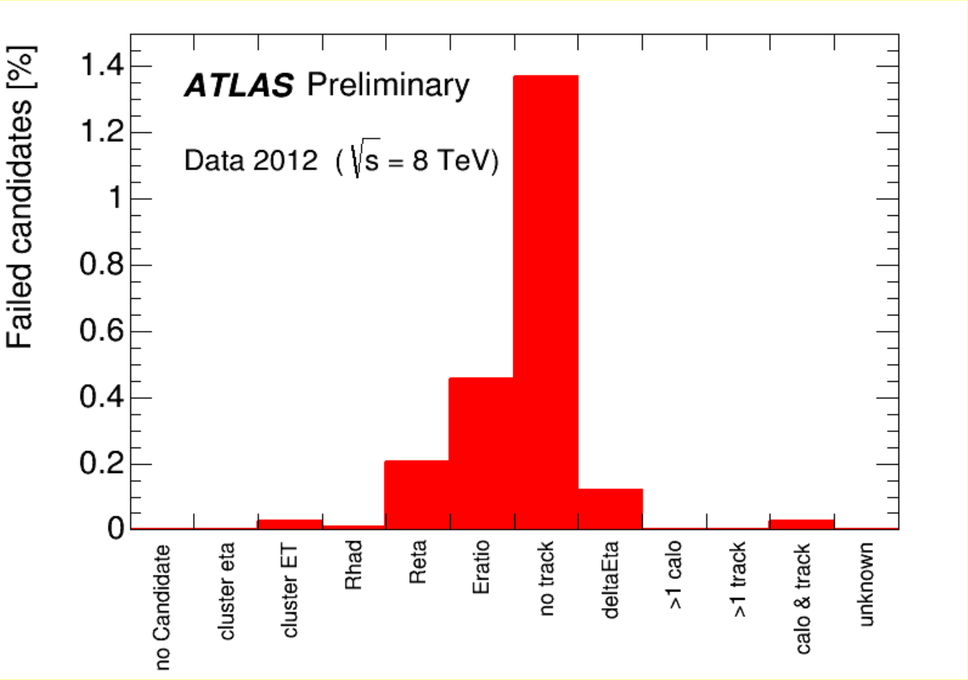
100 kHz

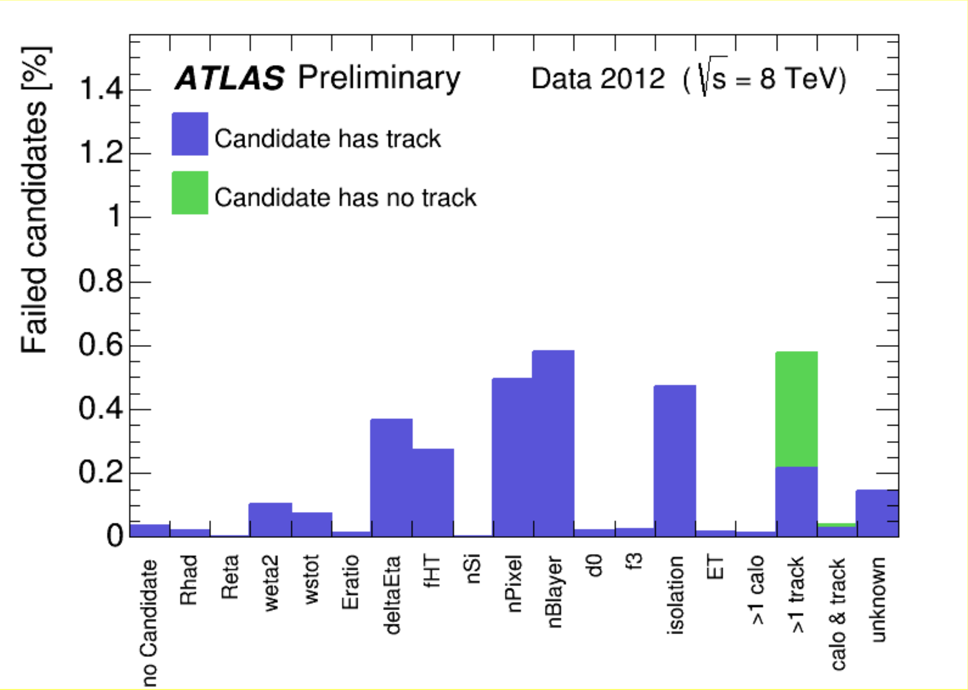
- Improved E_T resolution for Calo trigger towers.
- Increased flexibility, allows more trigger thresholds
- Mitigate pileup effects

Run 1 Trigger Inefficiencies

Single electron trigger inefficiencies w.r.t offline selections

Track inefficiencies are highest as simpler track reconstruction algorithms are run at L2, due timing constraints.





Identification Variables

- **All variables used for electron Identification in the central region (|η|<2.5)**
- **Unconverted photon ID variables are the Calorimeter one in this group.**

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 $\lvert\eta\rvert < 0.8$ and $\lvert\eta\rvert > 1.37$)	R_{Had1}
	Ratio of E_T in the hadronic calorimeter to E_T of the EM cluster (used over the range $\lvert\eta\rvert > 0.8$ and $\lvert\eta\rvert < 1.37$)	R_{Had}
Third layer of EM calorimeter	Ratio of the energy in the third layer to the total energy	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, $\sqrt{(\Sigma E_i (i - i_{\max})^2)(\Sigma E_i)}$, 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	f_1
	Shower width for three strips around strip with maximum energy deposit	w_{s3}
	Energy outside core of three central strips but within seven strips divided by energy within the three central 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
Track quality	Number of hits in the B-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	d_0
	Significance of transverse impact parameter defined as the ratio of d_0 and its uncertainty	σ_{d_0}
	Momentum lost by the track between the perigee and the last measurement point divided by original momentum	$\Delta p/p$
TRT	Total number of hits in the TRT	n_{TRT}
	Ratio of the number of high-threshold hits to the total number of hits in the TRT	F_{HT}
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 extrapolated track	$\Delta\phi_2$
	Defined as $\Delta\phi_2$, but the track momentum is rescaled to the cluster energy before extrapolating the track to the middle layer of the calorimeter	$\Delta\phi_{\mathrm{Res}}$
	Ratio of the cluster energy to the track momentum	E/p
Conversions	Veto electron candidates matched to reconstructed photon conversions	!isConv

Forward Electron Identification

- **Variables used when no tracking is available (forward electron Identification)**
- **Region 2.5<|η|<4.9**

Category	Description	Variable
Acceptance	$2.5 < \|\eta\| < 4.9$	
Shower depth	Distance of the shower barycentre from the calorimeter front face measured along the shower axis	λ_{centre}
Maximum cell energy	Fraction of cluster energy in the most energetic cell	f_{max}
Longitudinal second moment	Second moment of the distance of each cell to the shower centre in the longitudinal direction (λ_i)	$\langle\lambda^2\rangle$
Transverse second moment	Second moment of the distance of each cell to the shower centre in the transverse direction (r_i)	$\langle r^2\rangle$
Normalised lateral moment	w_2 and w_{max} are second moments of r_i for different weights per cell	$\frac{w_2}{w_2+w_{\text{max}}}$
Normalised longitudinal moment	l_2 and l_{max} are the second moments of λ_i for different weights per cell	$\frac{l_2}{l_2+l_{\text{max}}}$