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Upgrade of ATLAS Electron and Photon Triggers and Performance for LHC Run2

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Introduction

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Electron/Photon triggers essential for the LHC physics program

Standard Model Cross Section measurements

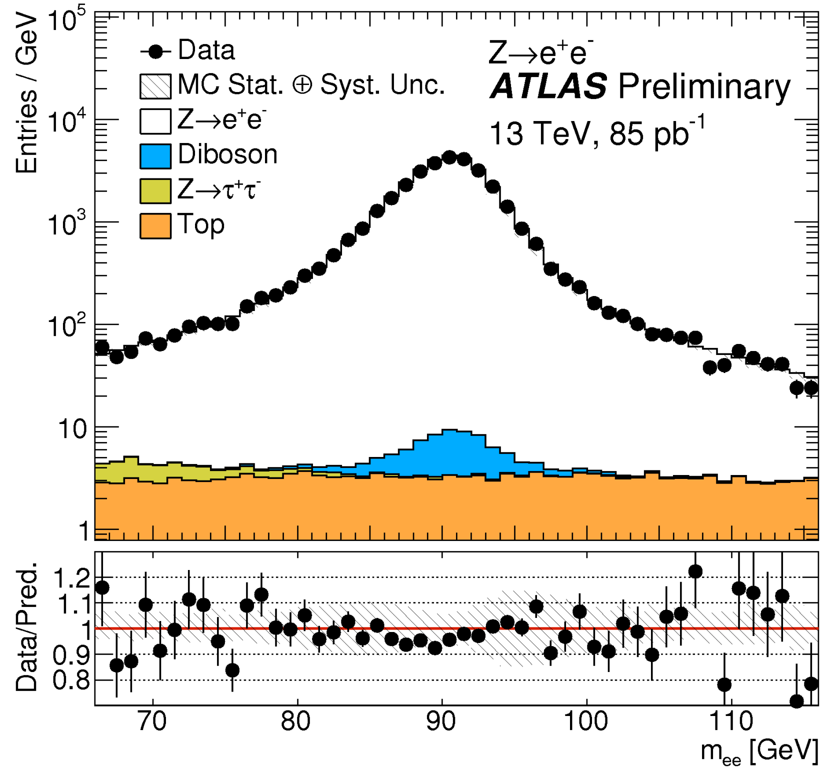
- W/Z (+jets); di-boson; inclusive photon; di-photon; tt production

Measurement of Higgs properties

- H➔γγ, ZZ, and WW final states
- H➔ττ (τ➔e), associated VH and ttH production and H➔bb when V, t decay leptonically

Searches span a broad range of p_T

- high-p_T Exotic searches to low-p_T compressed SUSY scenarios



Challenges for e/γ triggers

- Cross section of interesting physics is many orders below total cross section (3 Higgs / 10^{10} pp collisions)
- Maintain low thresholds with high signal efficiency while meeting constraints of the trigger system (rate)
- Reduction from 40 MHz crossing rate to 1 kHz output rate
- Flexible trigger menu for commissioning and physics needs
  - ➡ Prevent potential loss of data at startup
  - ➡ Provide a menu of triggers to cover all physics needs

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Trigger Challenges for Run2

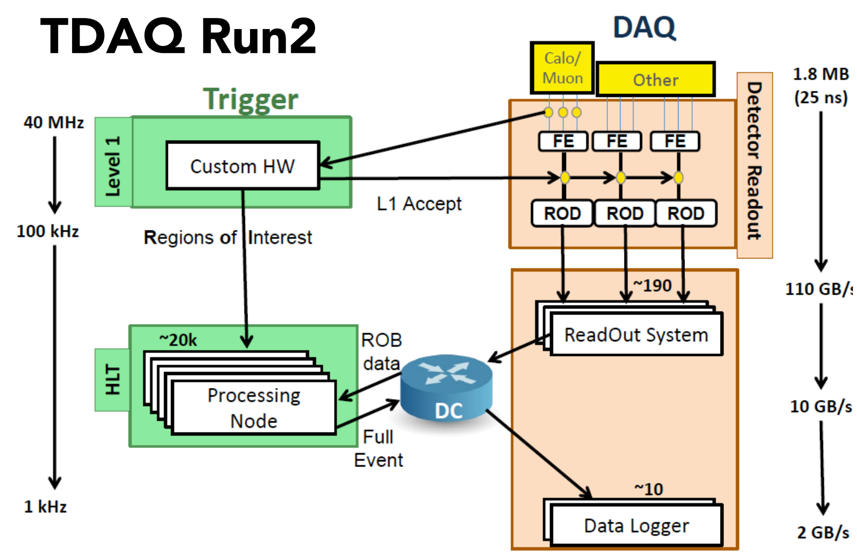
Run2 challenges

- Increase in centre of mass energy from 8 TeV to 13 TeV
- Peak luminosity 7×10^{33} to 1.7×10^{34} $cm^{-2}s^{-1}$
- Peak pileup increases from 40 interactions / event to 50 interactions /events
- Total integrated luminosity from 25 fb^{-1} to 100 fb^{-1}

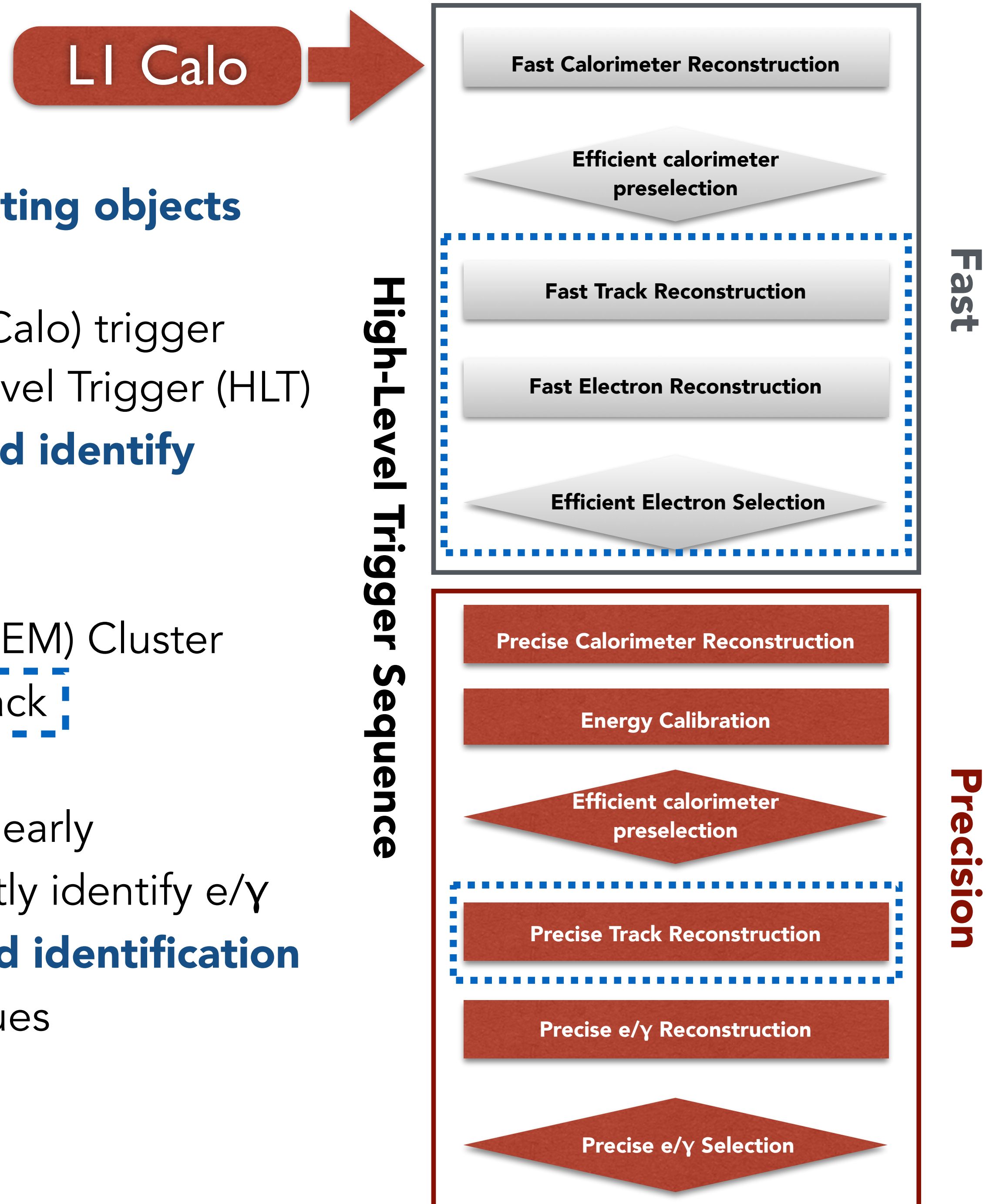
➡ Increase in Level-1 (L1) trigger rate by factor of 5

Trigger Upgrades for Run2

- New TDAQ structure uses 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 (see Q. Yang's talk)
- Multivariate identification and calibration techniques
- Online pile-up corrections



ATLAS Electron/Photon Trigger



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

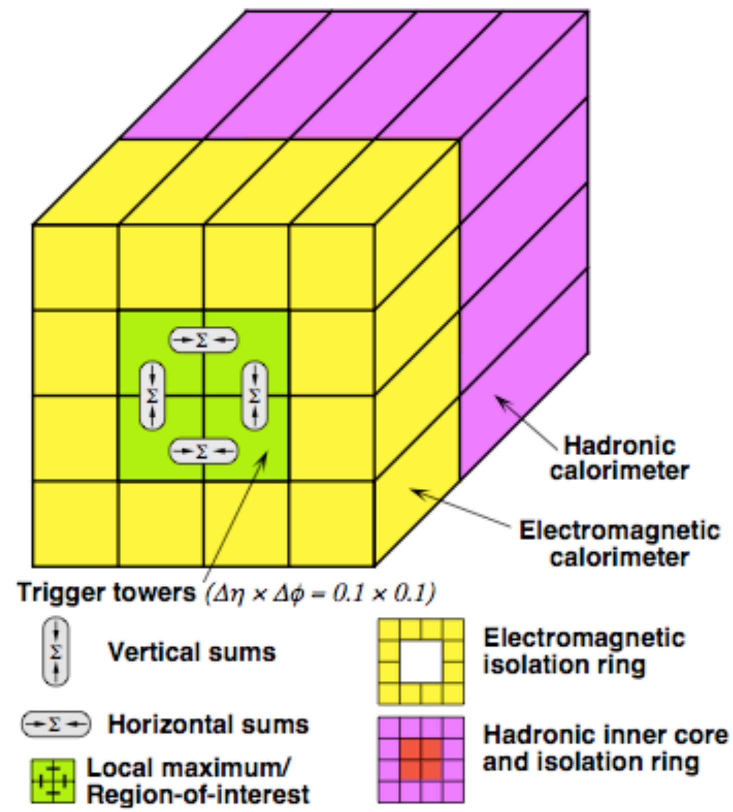
Level-1 Electromagnetic Trigger

Run-1

- η-dependent E_T thresholds with $\Delta E_T \sim 1$ GeV precision and Δη=0.4 granularity which follows the variation in η of the energy response to account for material effects
- Hadronic-core isolation for primary un-prescaled EM triggers with H ≤ 1 GeV (EM scale raw E_T)
- EM Isolation not used (but available) during Run1

Run-2

- Improved Signal Processing: **n**ew **M**ulti-**C**hip-**M**odule (nMCM)
  - Improved energy resolution (noise auto-correlation filtering)
  - Dynamical pedestal correction
- Clustering: **C**luster **P**rocessor **M**odule (CPM) firmware
  - E_T-dependent electromagnetic and/or 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 Δη=0.1 in granularity



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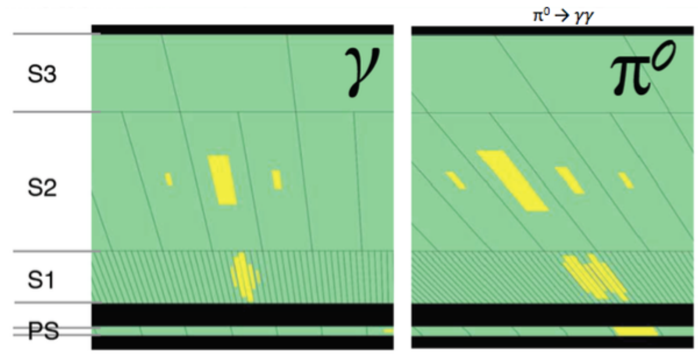
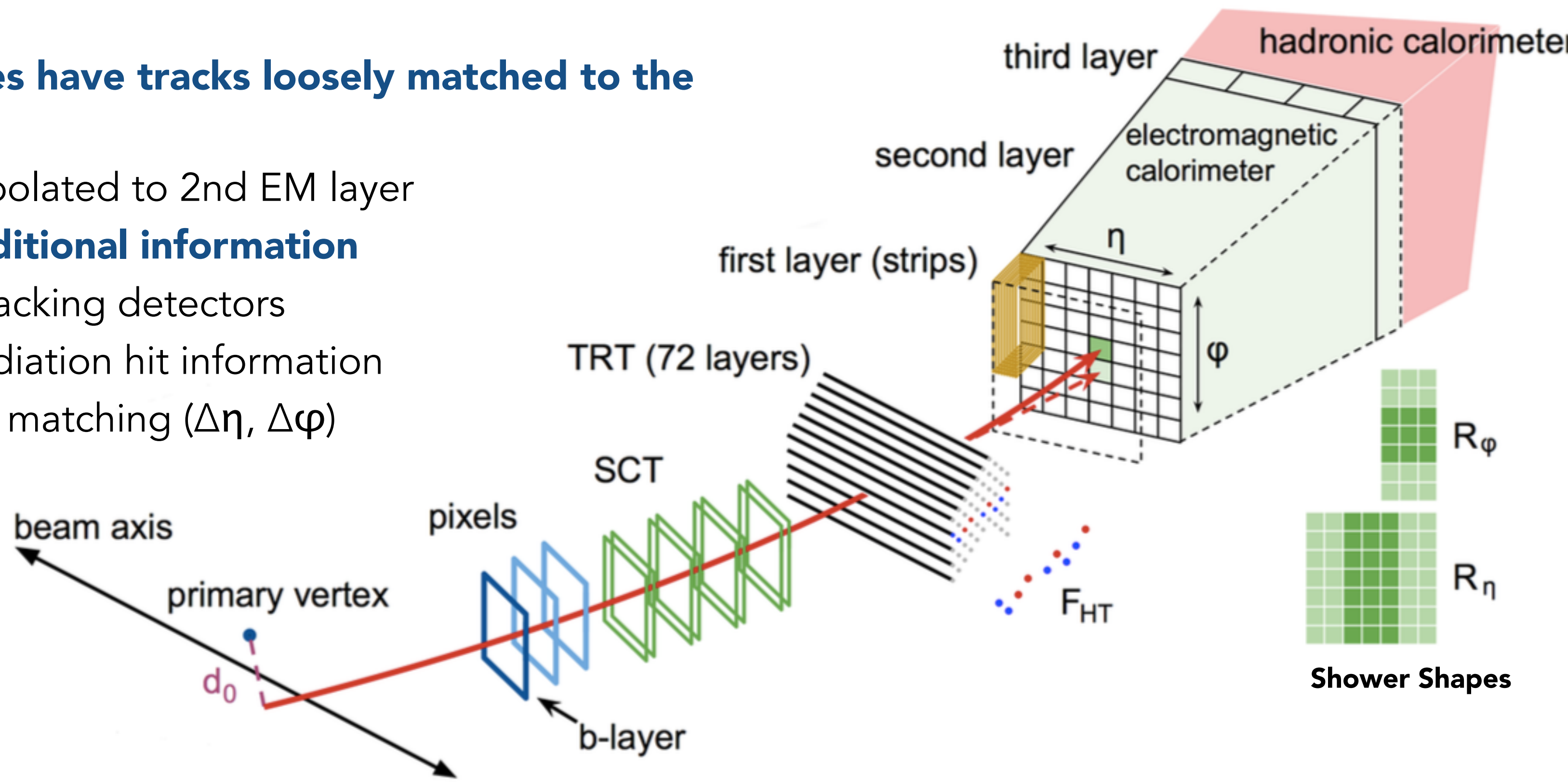
HLT e/γ Reconstruction

- **Energy of an electron and photon candidate is built from the energy of a cluster of cells in the Electromagnetic (EM) calorimeter**
- **Minimal EM calorimeter grid with a local maximum (2.5 GeV) required for a cluster seed — 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 (Δη,Δφ)**
    - tracks extrapolated to 2nd EM layer
- **Electrons have additional information**
    - hits in the tracking detectors
    - transition radiation hit information
    - track-cluster matching (Δη, Δφ)



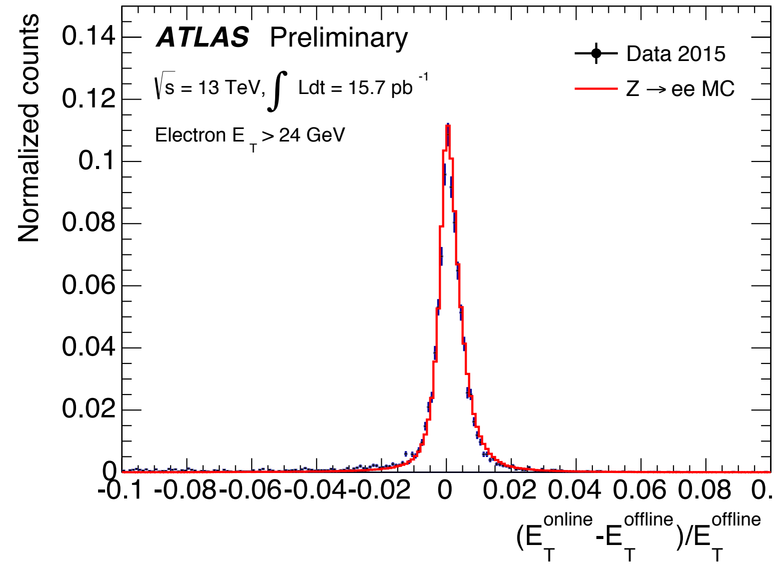


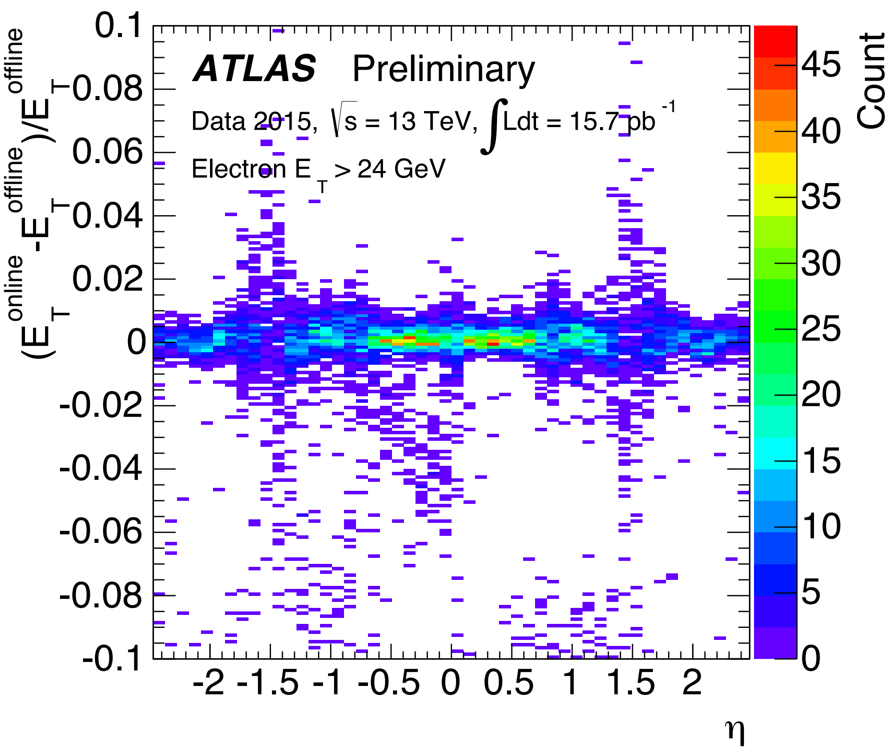
HLT e/γ Cluster Energy Calibration

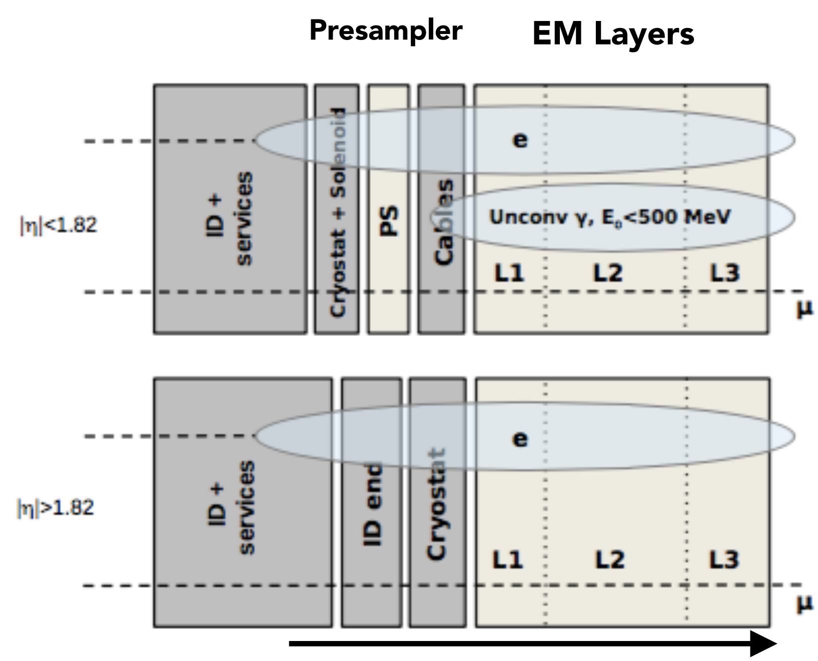
EM cluster properties (longitudinal development) are calibrated to the original energy of the electron and photon in Monte Carlo (MC) samples

MC samples are used to determine the e/γ response calibration where the constants are determined in a multivariate algorithm

➡ Separate calibration constants for electrons and photons due to different detector response

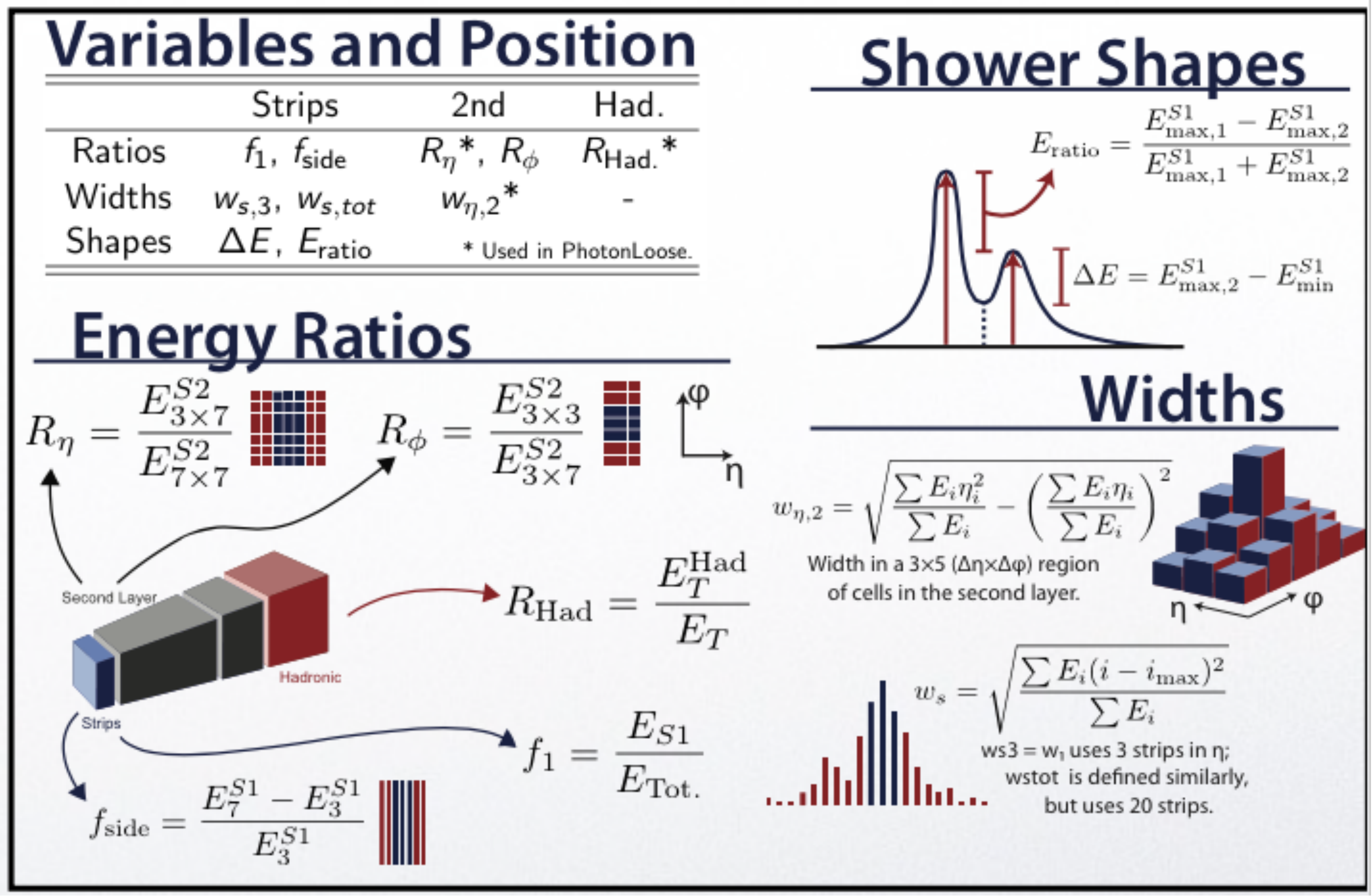






hep-ex 1407.5063 **Longitudinal shower development**

HLT e/γ Identification



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

Identification of photons and electrons

- Optimised in bins of E_T and η with different optimisation techniques
- 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

HLT Electron Trigger Strategy for Run2

Electron trigger rate depends steeply on the E_T threshold

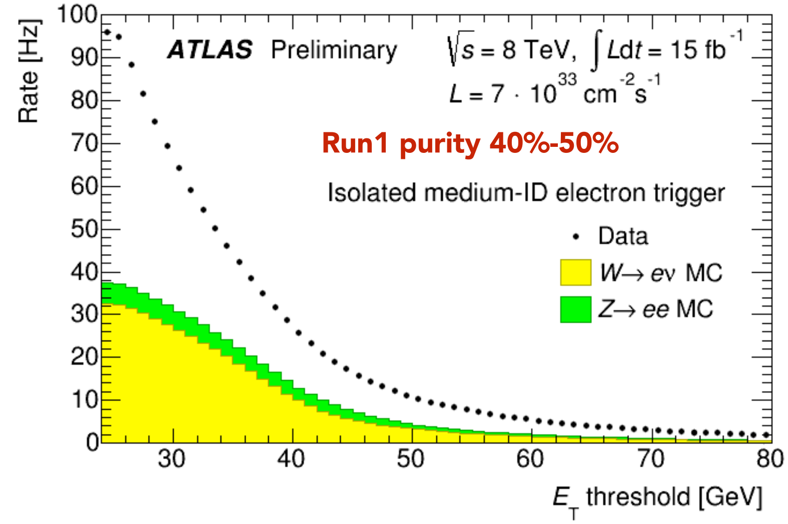
- Physics potential suffers as threshold increases
  - ➡**Run2 improve purity and reduce background with tighter selections and multivariate techniques**

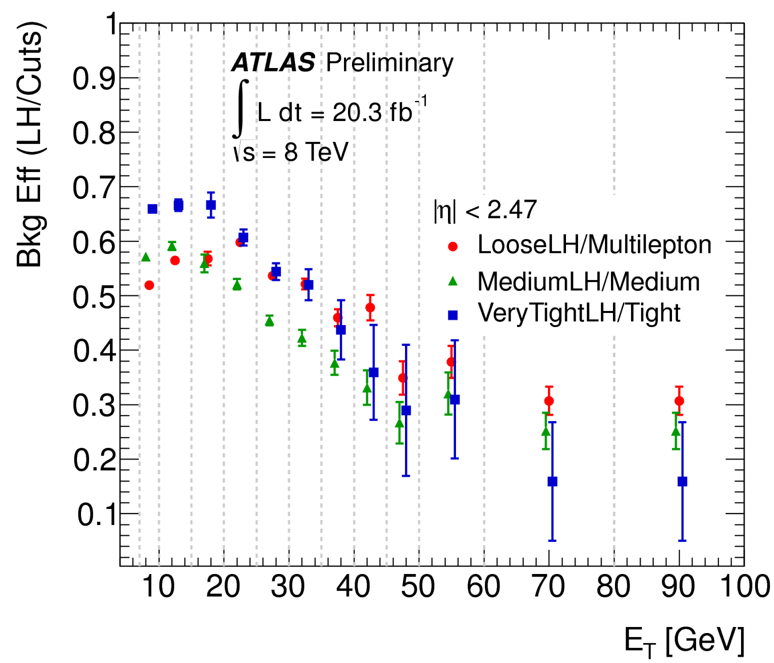
Electron Likelihood (LH) Particle Identification

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

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

	Variable name	
Calo Variables	R_{Had}	Taken out for high ET
	f_3	←
	R_η	
	R_ϕ	
	$W_{\eta 2}$	
	E_{ratio}	
	f_1	
Track-cluster matching	$\Delta\eta_1$	
	$\Delta\phi_{\text{Res}}$	
Track Variables	d_0	Replacing f_{HT}
	d_0 significance	
	TRT PID	←
	$\Delta p/p$ (except online)	
Additional Cuts	nSiHits ≥ 7	
	nPixHits ≥ 2 (1 for VeryLoose)	
	Blayer (except Loose, VeryLoose)	





Factor 2 improvement in background rejection

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Electron Trigger Menu Strategy

Lowest single electron trigger evolution as function of luminosity

Peak Instantaneous Luminosity [$10^{34}cm^{-2}s^{-1}$]	HLT E_T Threshold [GeV]	HLT Identification	L1 E_T Threshold	L1 Isolation
< 0.8 [Run1]	24	medium1	18V	H
< 0.3	24	lhmedium	18V	H
< 0.5	24	lhmedium	20V	H
< 1.0	24	lhtight	20V	HI
< 1.5	26	lhtight	22V	HI

medium1: Run1 cut-based medium selection

lhmedium (lhtight): Run2 likelihood medium (tight) selection

V: Level-1 E_T threshold variation as function of η

H: Level-1 Hadronic core isolation

I: Level-1 Electromagnetic ring isolation

Keep Run1 trigger threshold as long as possible in Run2 with tighter selections at L1 (EM ring isolation)

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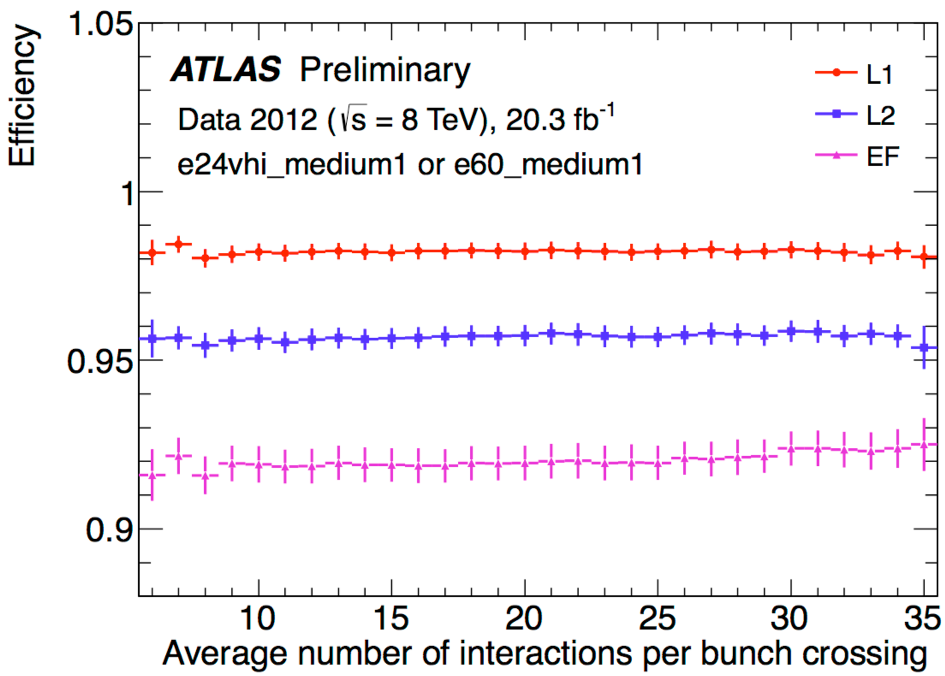
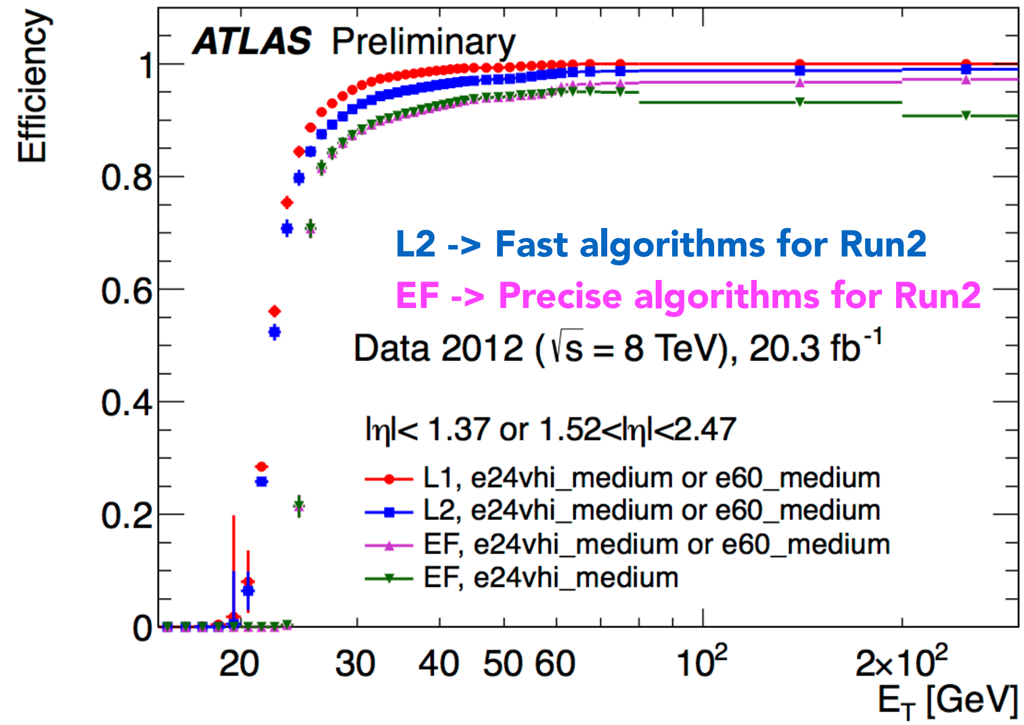
Run1 Electron Performance

- **Largest impact at L1 is the energy resolution**
  - Hadronic isolation has negligible impact up to E_T ~ 300 GeV
  - ➡ **Run2 includes EM ring isolation at L1**
- **HLT inefficiencies from Fast and Precise identification**
  - Fast ID: 5% loss at 30 GeV and 1% loss at 100 GeV
  - Precise ID: 10% loss at 30 GeV 5% loss at 45 GeV
- **At high-E_T track isolation impacts performance**
  - 6% inefficiency recovered at high-pt with non-isolated trigger for p_T > 60 GeV
  - ➡ **Same strategy in Run2**
- **Pileup robust selection at all trigger levels**
  - ➡ **Run2 incorporates pileup corrections in likelihood**



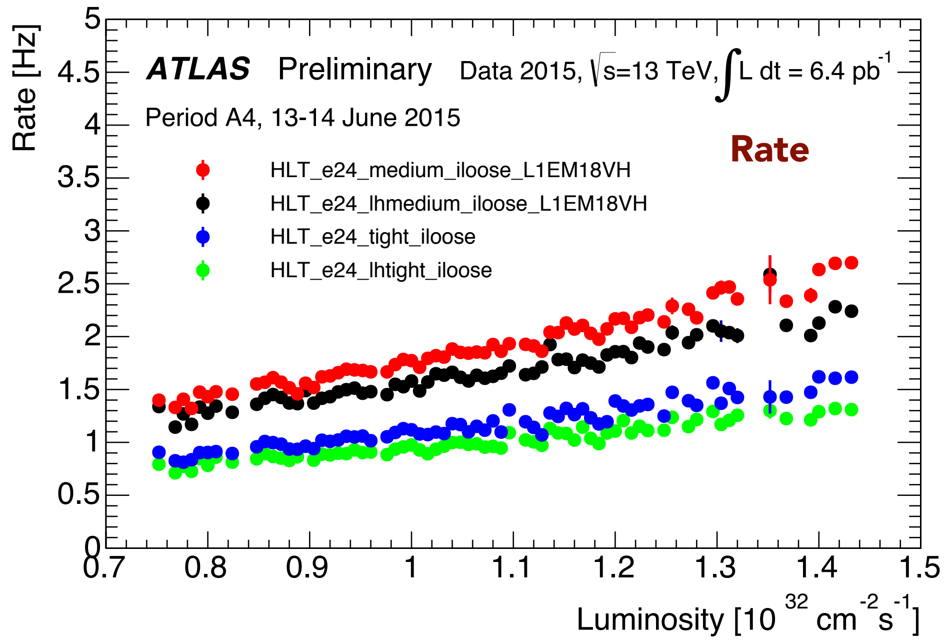


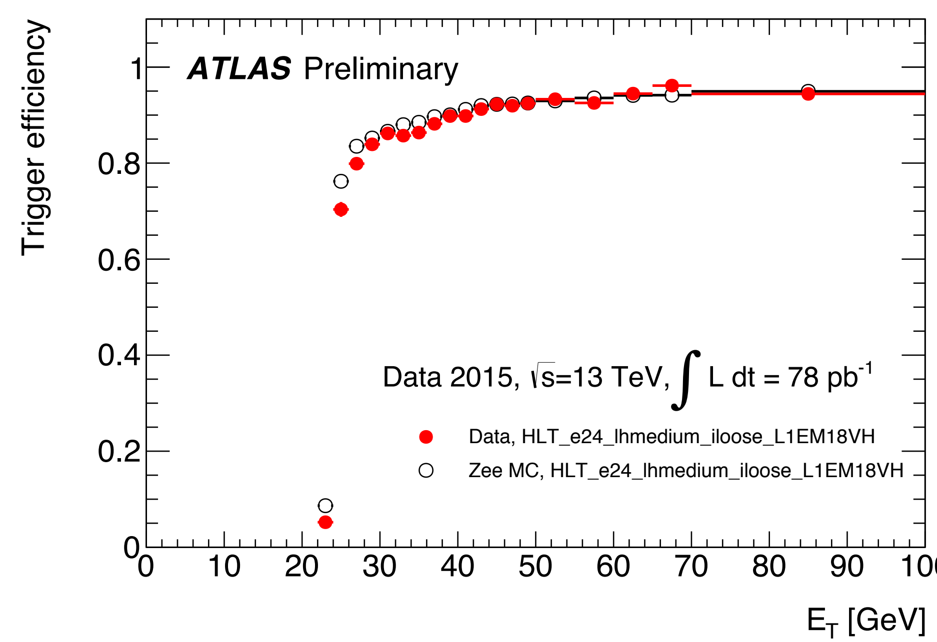
Run1 trigger efficiency at different stages of the HLT trigger

Run2 Electron Trigger Performance

Likelihood electron selection out-performs cut-based selection in Run2

- Expected LH selection efficiency from MC is 6% higher than cut-based selection with respect to same offline
  - Preliminary performance on data shows about 4% improvement
- 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
  - Tight selection 45% rate reduction with 7% efficiency loss
- LH better MC agreement than cut-based selection





Photon Trigger Performance Run2

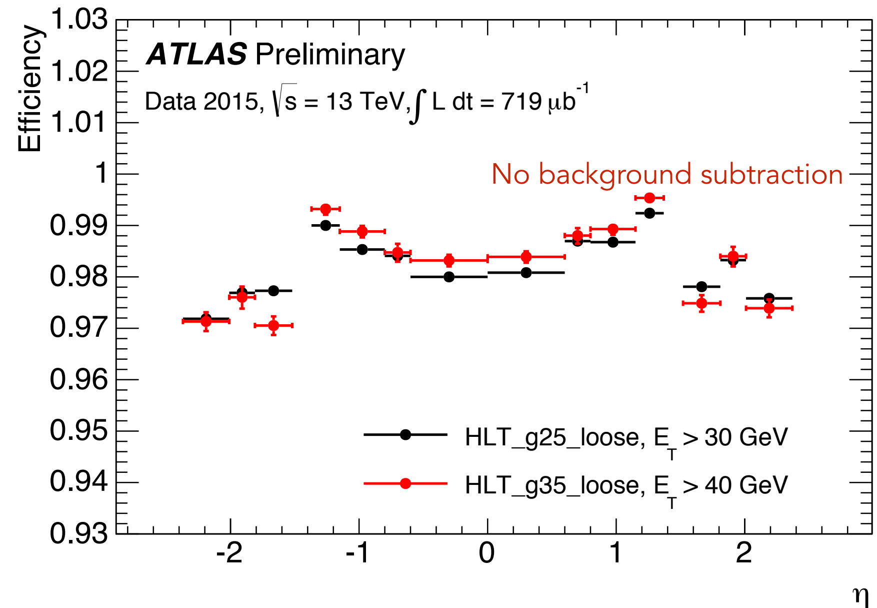
Efficiency plateau ~ 5 GeV above trigger threshold — similar performance to Run1

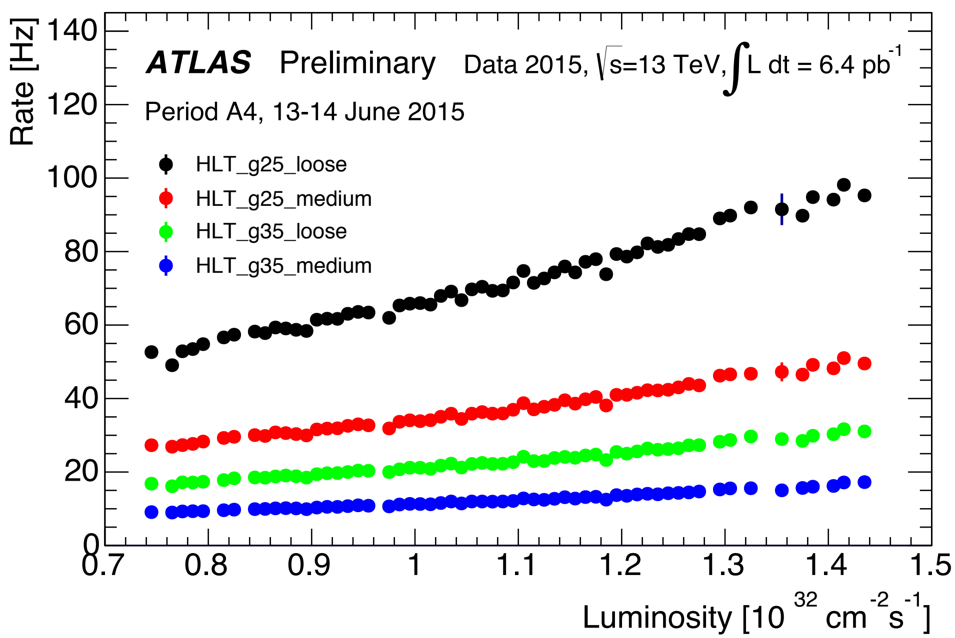
Loose to Medium selection little impact on efficiency but factor 2 rate improvement

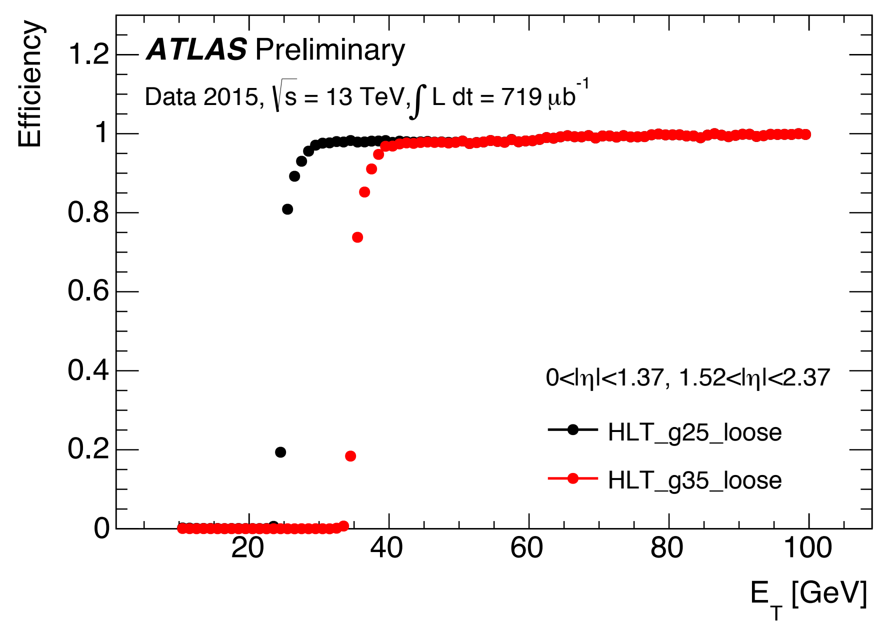
- Medium include lateral Energy ratio in first layer (discriminate $\pi^0 \rightarrow \gamma\gamma$)

Lowest E_T threshold unprescaled triggers @ L = 1.5 X 10 ^{34} cm^{-2}s^{-1}

- g35_medium_g25_medium
- g140_loose



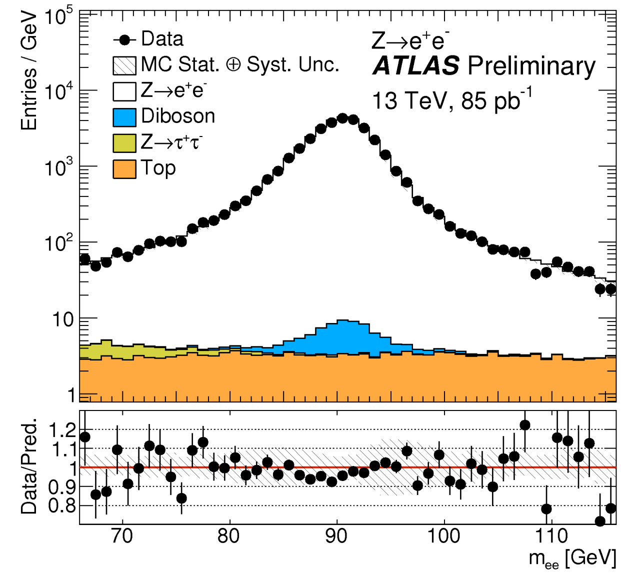




Conclusions

Successful Run2 startup with many new features — contributed to wealth of early physics measurements

- Improved HLT structure (single HLT trigger level)
- New HLT tracking in Run2 (see upcoming talk from Qin Yang)
- New likelihood-based electron triggers successfully commissioned
- New features at L1
  - ➡Finer granularity in η for threshold variation
  - ➡Double number of L1 thresholds
  - ➡Relative isolation

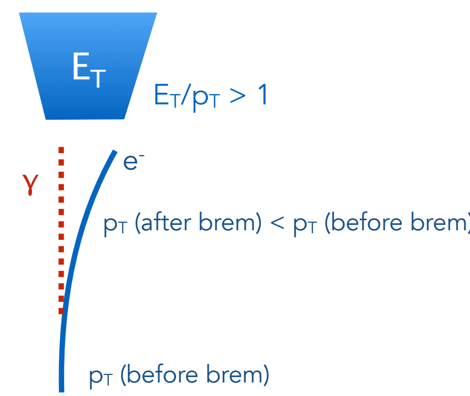


Evaluation of performance ongoing

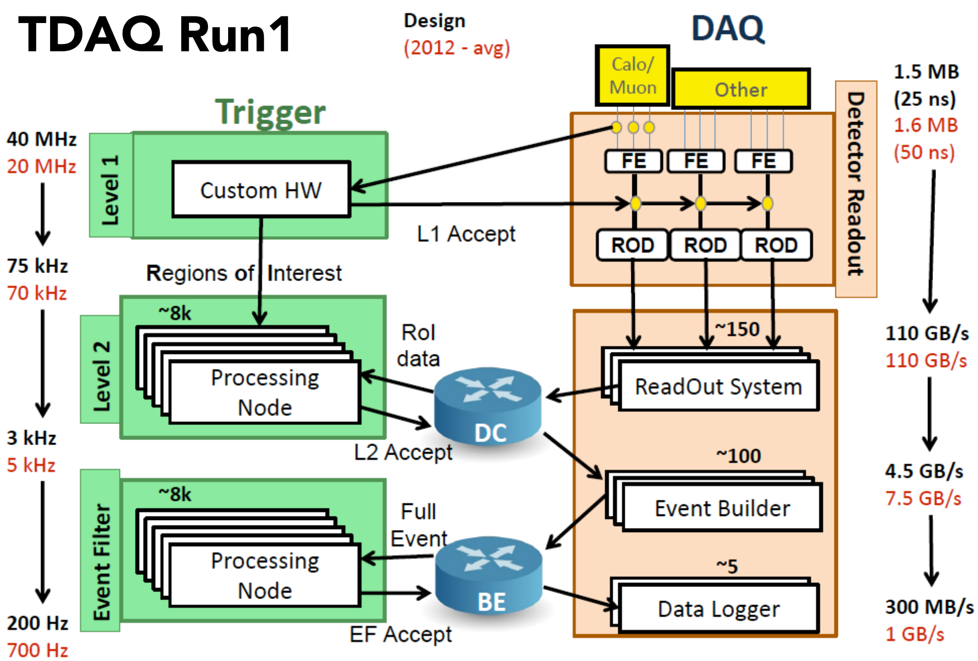
- 90% efficient electron triggers in barrel region (similar to Run1 performance)
- Photon triggers perform similar to run1 with very high efficiency
- Detailed study of inefficiencies required to understand losses at HLT in Run2

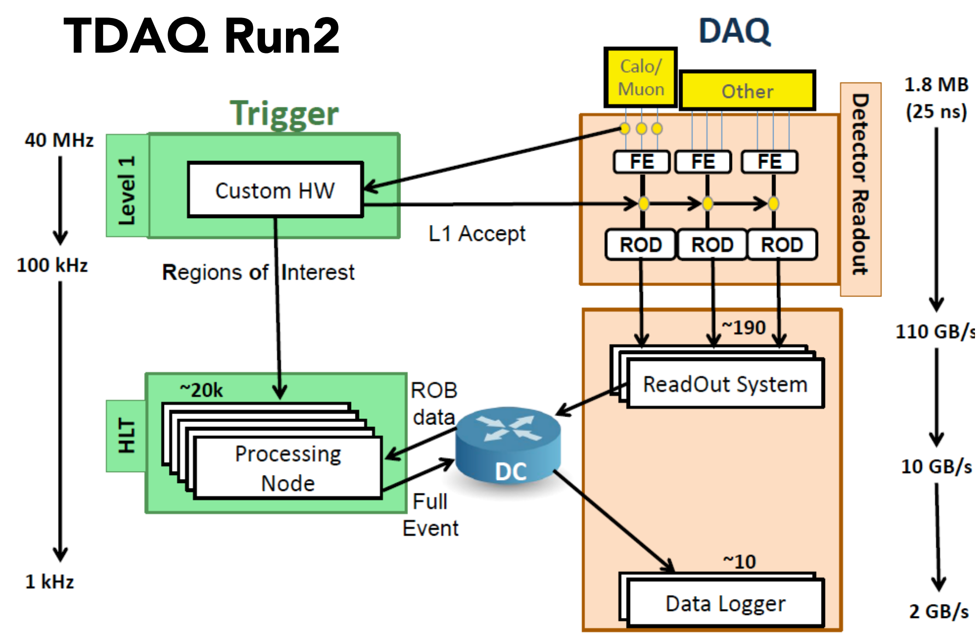
More studies to go with more features for 2016

- Offline electron reconstruction refits tracks to account for bremsstrahlung
- Converted photons reconstructed offline which provides additional information for calibration
  - Track information at trigger level can distinguish electrons from photons (rate reduction)
- Calorimetric isolation based on topological clusters also a possibility for further rate reduction



BACKUP

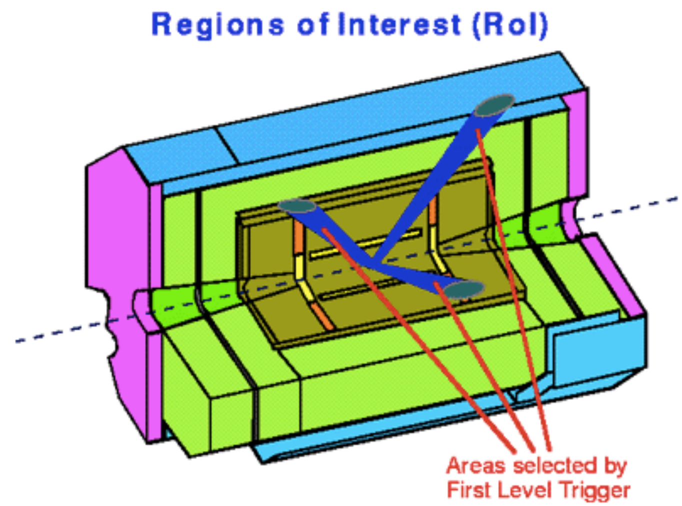

TDAQ Run1
Design
(2012 - avg)
DAQ
Calo/
Muon
Other
Detector Readout
Trigger
Level 1
Custom HW
FE
FE
FE
ROD
ROD
ROD
L1 Accept
40 MHz
20 MHz
75 kHz
70 kHz
3 kHz
5 kHz
200 Hz
700 Hz
Regions of Interest
Level 2
~8k
Processing
Node
RoI
data
DC
L2 Accept
~150
ReadOut System
~100
Event Builder
Event Filter
~8k
Processing
Node
Full
Event
BE
EF Accept
~5
Data Logger
1.5 MB
(25 ns)
1.6 MB
(50 ns)
110 GB/s
110 GB/s
4.5 GB/s
7.5 GB/s
300 MB/s
1 GB/s

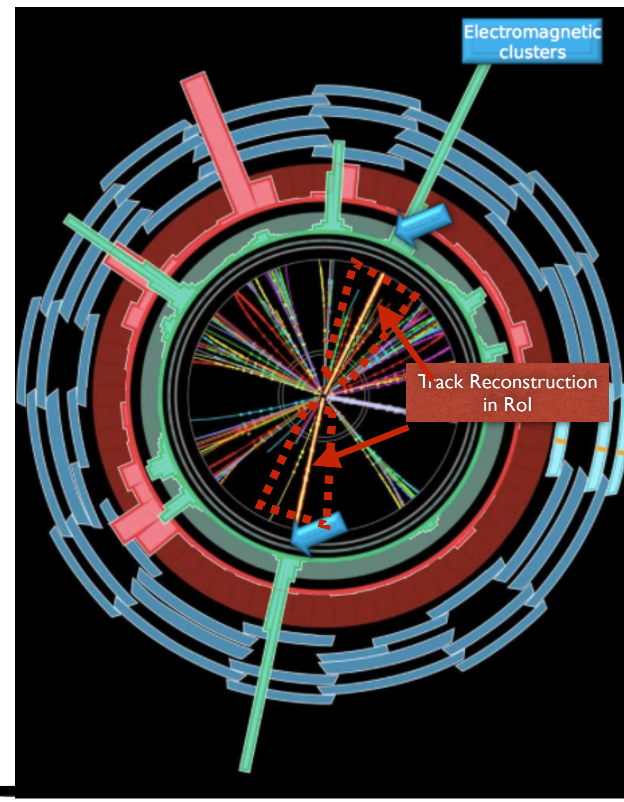

TDAQ Run2
DAQ
Calo/
Muon
Other
Detector Readout
Trigger
Level 1
Custom HW
FE
FE
FE
ROD
ROD
ROD
L1 Accept
40 MHz
100 kHz
1 kHz
Regions of Interest
HLT
~20k
Processing
Node
ROB
data
DC
Full
Event
~190
ReadOut System
~10
Data Logger
1.8 MB
(25 ns)
110 GB/s
10 GB/s
2 GB/s

Overview of Egamma Trigger

The Egamma trigger is based on reconstructing objects within a Region of Interest (RoI)

- Two-step trigger system is used in Run2
  - Level-1 (hardware) Calorimeter Trigger
  - High-level (software) electron / photon trigger
- L1 E_T threshold computed in the calorimeter ($\Delta\eta$ X $\Delta\varphi$ = 0.1 X 0.1) define the RoI for e/γ candidates
- The RoIs seed the High-level software trigger [**HLT**]
  - Data is prepared once in the RoI
  - Reconstruct objects [**FEX**] (tracks, clusters, e/γ)
  - Hypothesis algorithms [**HYPO**] identify electrons and photons
- HLT is sequential combination of **FEX** and **HYPO**
  - Reject events early
  - Higher latency (more precise **FEX**) run later in sequence
- **FEX** always begin with calorimeter cluster building —> always require a cluster to build electron or photon.
  - Tracks only reconstructed for electron triggers —> no track no electron reconstructed, but cluster still can give a photon.
- **HYPO** for electrons and photons kept as close as possible to offline identification criteria.
  - Trigger w/ different levels of discrimination for higher efficiency but lower purity (loose, medium, tight), kept as loose as possible until rate demands tightening criteria.





Electron / Photon Trigger Sequence

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L1 Calo

Each HLT item seeded by Level-1 RoI

Photon: energy cluster (no requirement on track)

Electron: energy cluster matched to reconstructed p_T > 1 GeV track with Si hits

Common merged data-preparation step for fast and precision HLT steps

- Same cells used to reconstruct EM clusters for fast and precise algorithms
- Fast track reconstruction seeds precision track reconstruction (electrons)

Loose preselection requirements on variables from Fast reconstruction variables

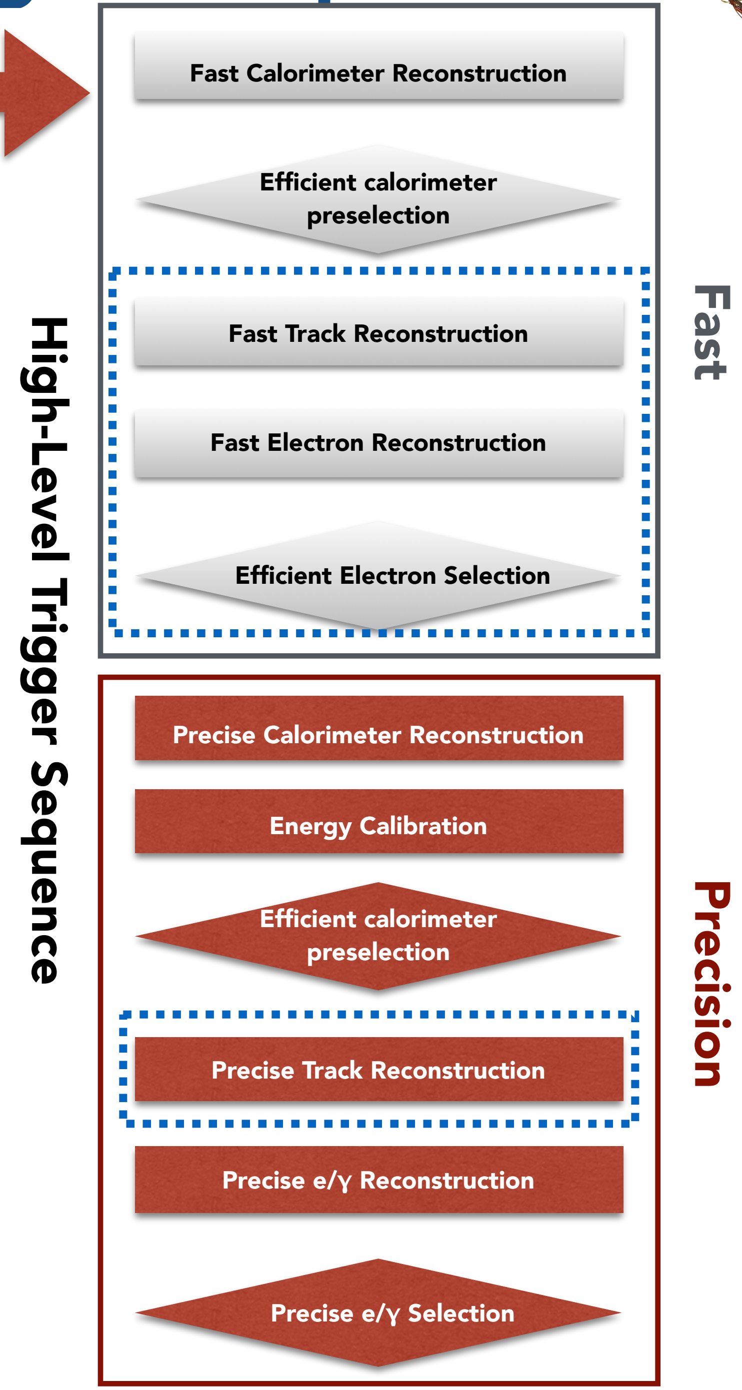
- Calorimeter preselection (e/γ)
- Electron preselection (cluster-track matching)

Precision calorimeter reconstruction

- New Cluster Energy calibration based on multivariate analysis technique
- Loose preselection on calorimeter variables

Precise Identification as close to offline identification as possible

- Electron likelihood identification for Run2
- Photon cut-based identification



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Trigger Menu for e/gamma

Lumi	(-3) e33	(3-5) e33	(5 - 10) e33
L1_EM	EM18VH	EM20VH	EM20VHI
1e	e24_medium_iloose_L1EM18VH	e24_medium_iloose_L1EM20VH	e24_tight_iloose
	e60_medium		
	e120_loose		e140_loose
1g	g120_loose		g140_loose
L1_2EM	2EM10VH	2EM10VH	2EM13VH
2e	2e12_loose_L12EM10VH	2e12_loose_L12EM10VH	2e15_loose_L12EM13VH
L1_2EM	2EM15	2EM15VH	
2g	g35_loose_L1EM15_g25_loose_L1EM15	g35_loose_g25_loose	g35_medium_g25_medium
	2g50_loose		
	2g20_tight		
L1_3MU	EM15VH_3EM7		
3e	e17_loose_2e9_loose		
3g	3g15_loose		2g20_loose_g15_loose

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L1 Trigger Naming Convention

Hadronic core isolation applied
(E_T-dependent in Run2, no isolation for L1 $E_T > 50$ GeV

Electromagnetic ring **I**solation applied
(E_T-dependent, no isolation cut for L1 $E_T > 50$ GeV

L1_EM20VHI

Varying Eta-dependent trigger energy threshold applied which follows the variation in η of the energy response (within +2 GeV to -3 GeV of nominal threshold)

Nominal Energy Threshold

Examples: EM12, EM15I, EM18VH, EM20VHI
Multi-Objects: 2EM15VH, 3EM7, EM15VH_3EM7
Combined Items: EM15VH_MU10, EM15HI_TAU40

Trigger Naming Convention

Track isolation applied on electron

Object Multiplicity

HLT Trigger threshold on cluster E_T

e24_lhmedium_iloose_L1EM18VH

Object type (**e**lectron / **p**hoton)

Non-default L1 item

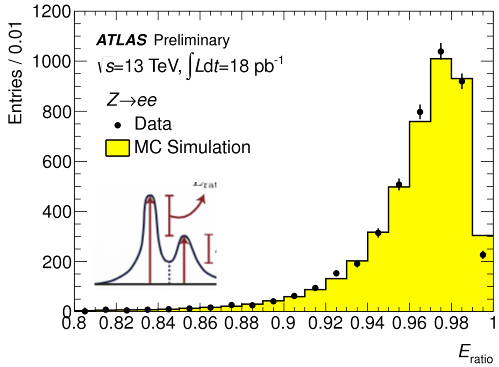
Particle Identification (Hypothesis test): etcut, v(lh)loose, (lh)loose, (lh)medium, (lh)tight, + special chain modifiers (nod0, idperf, trkcut, …)

Example chains: e24_lhtight_iloose, e60_lhmedium_HLTCalo, g0_perf_L1EM3_EMPTY, e17_lhloose_nod0_L1EM15
MultiObjects: 2e17_lhloose, 2g20_tight
Combined items: e17_loose_mu14, e18_etcut_trkcut_xs20

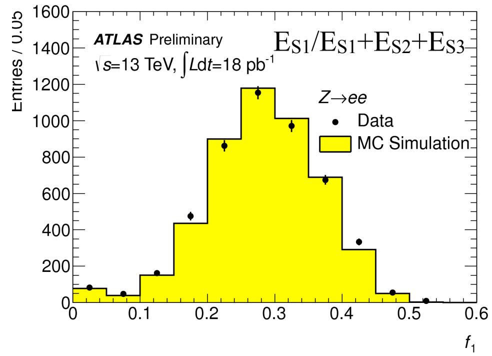
Shower Shape Identification Variables

Offline reconstructed shower shapes with comparison to MC

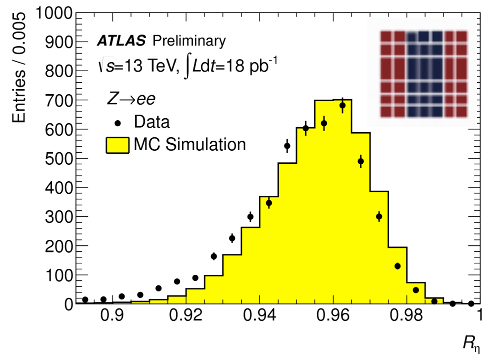
Energy Ratio (Lateral)



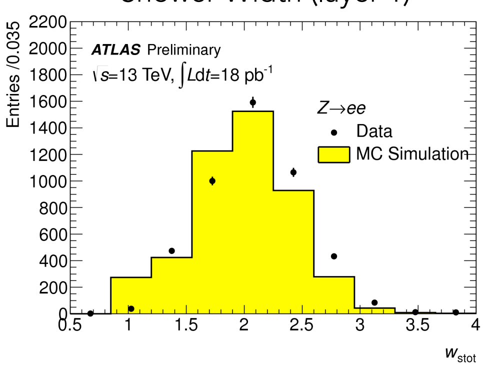
Energy Ratio (longitudinal)



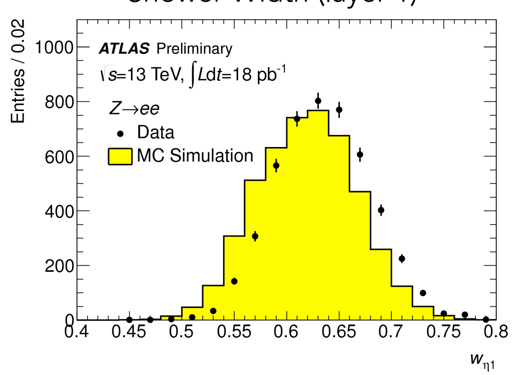
Energy Ratio (lateral)



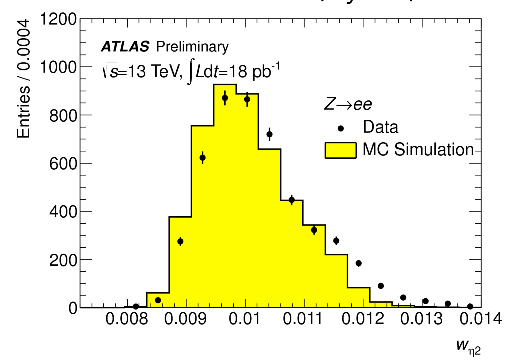
Shower Width (layer-1)



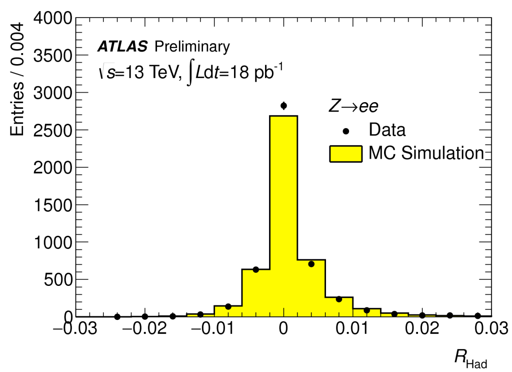
Shower Width (layer-1)

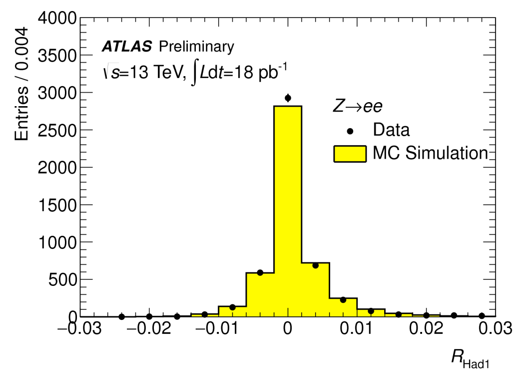


Shower Width (layer-2)



E_T in hadron calorimeter / EM Cluster E_T



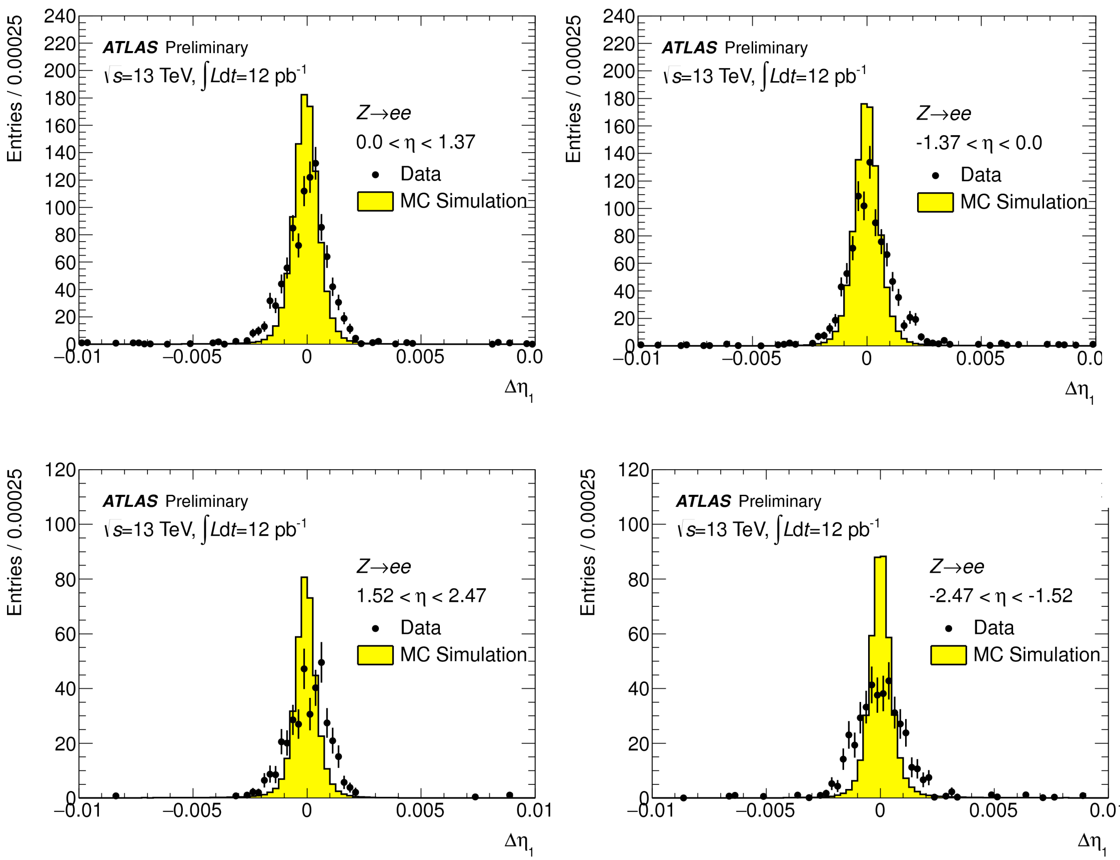


Electron Identification and Tracking

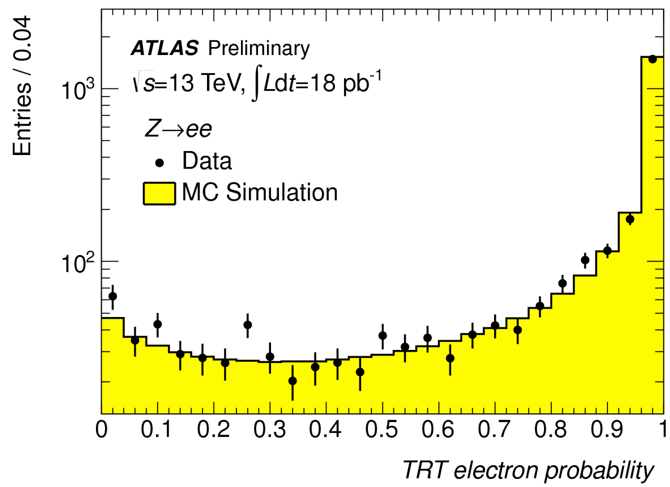
Electron identification relies on shower shapes and tracking related information

- Track quality information, i.e. number of hits in inner silicon and pixel layers
- Transition radiation information — electron identification probability to discriminant against hadrons
- Track-to-calo matching distributions

Track-cluster matching



Transition Radiation Hit Information



HLT Electron Trigger Strategy for Run2

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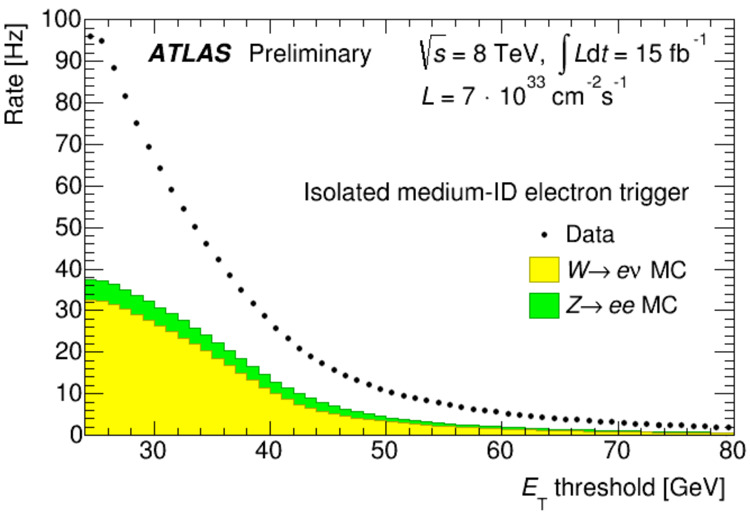
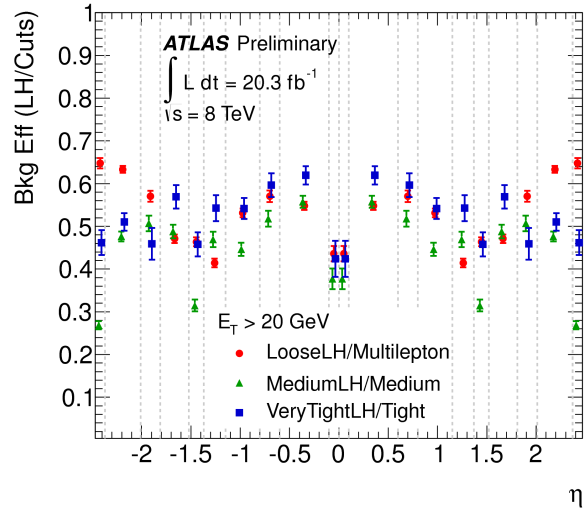
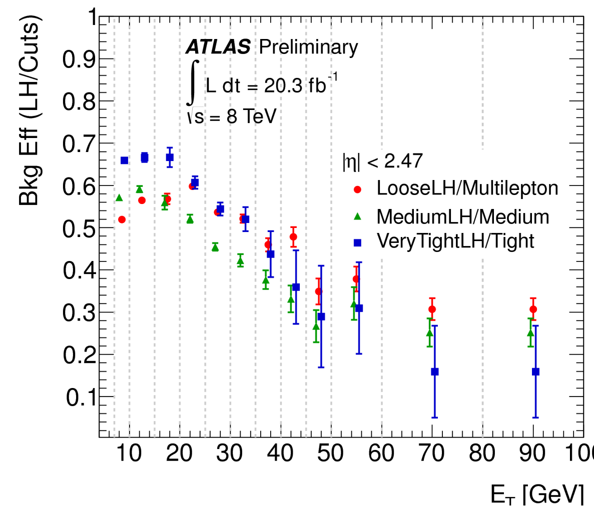
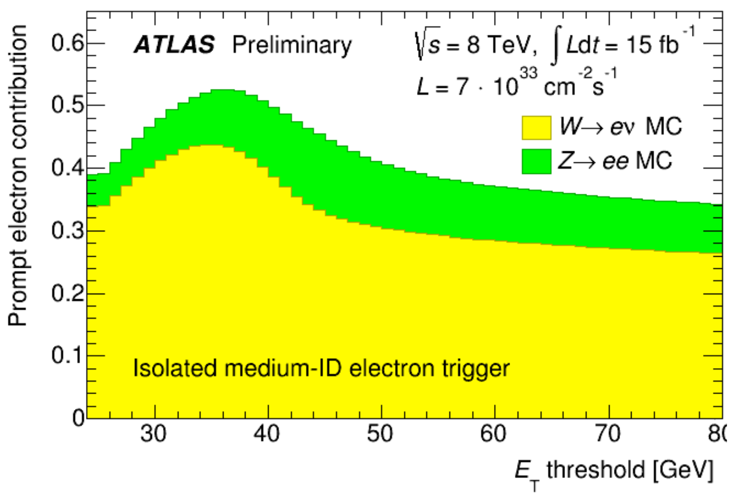
Rate depends steeply on the E_T threshold

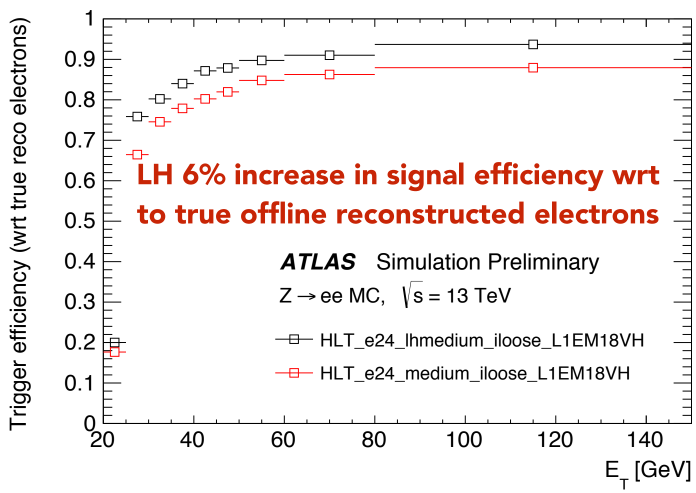
- Physics potential significantly affected by raising trigger threshold
- Improve purity of samples (40% - 50% in Run1) with tighter selection and multivariate discriminants.

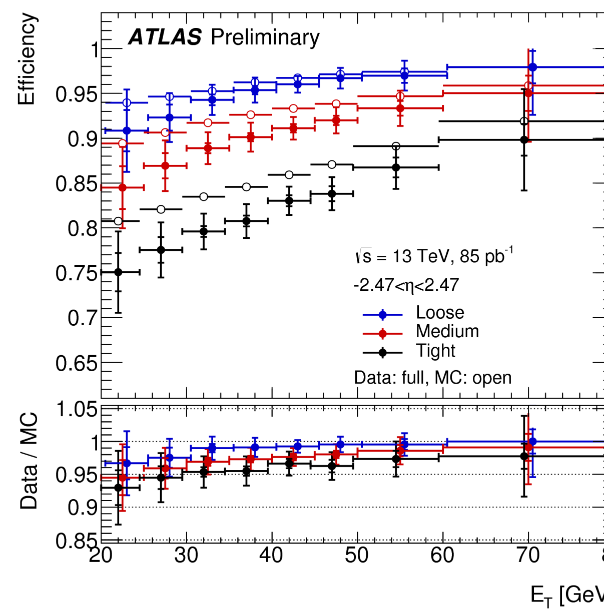








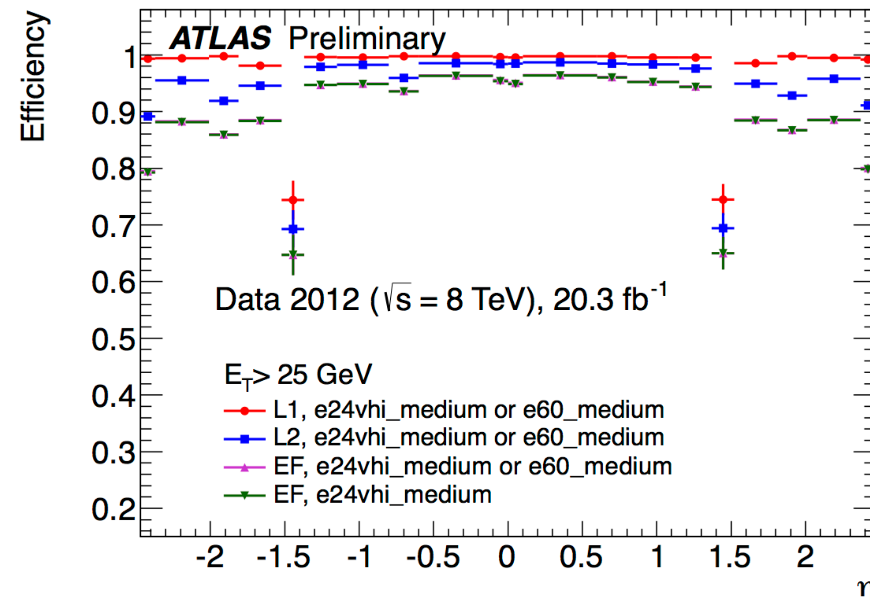


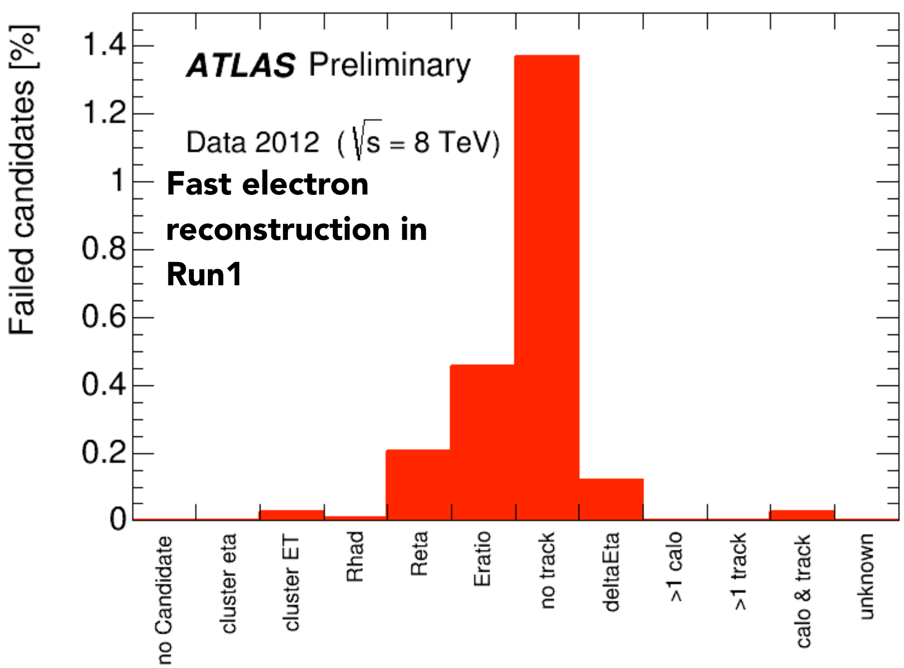


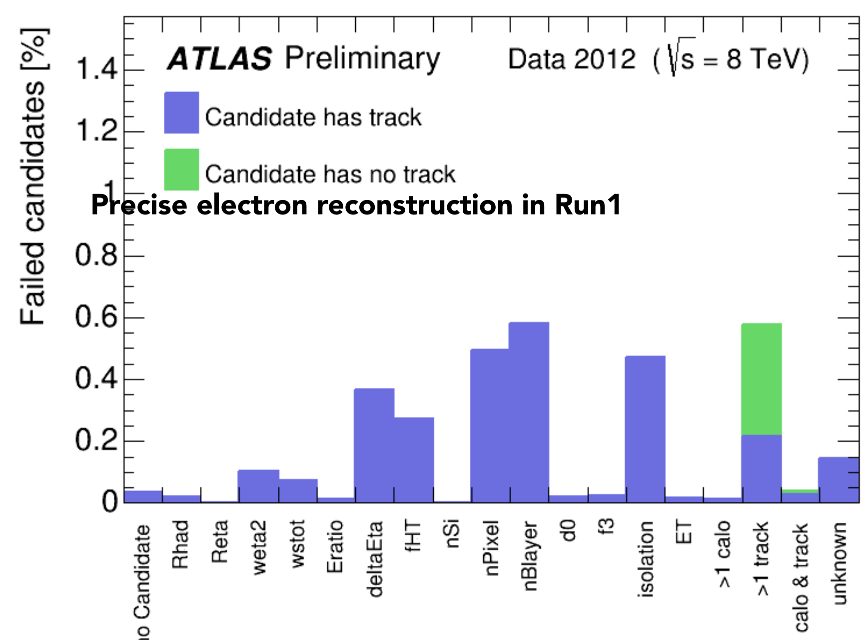
Run1 Performance

Detailed study of small event sample to determine largest sources of inefficiency

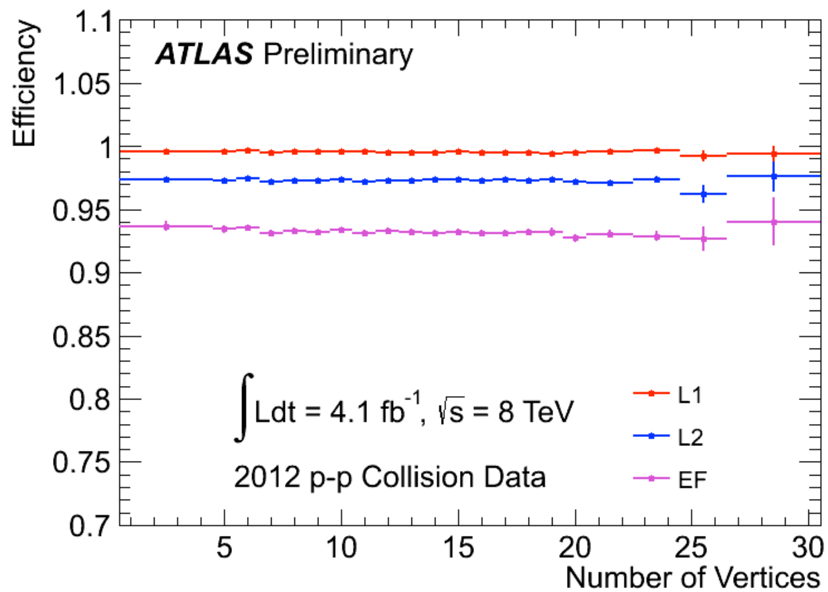
- During Run1 dominant sources of inefficiency due to tracking related quantities
- Fast electron reconstruction
  - Fast tracking >1% loss due to inefficiency
  - ~0.5% loss in shower shape cuts
- Precision electron reconstruction
  - ~0.5% loss due to track-calo matching, hit requirements and isolation

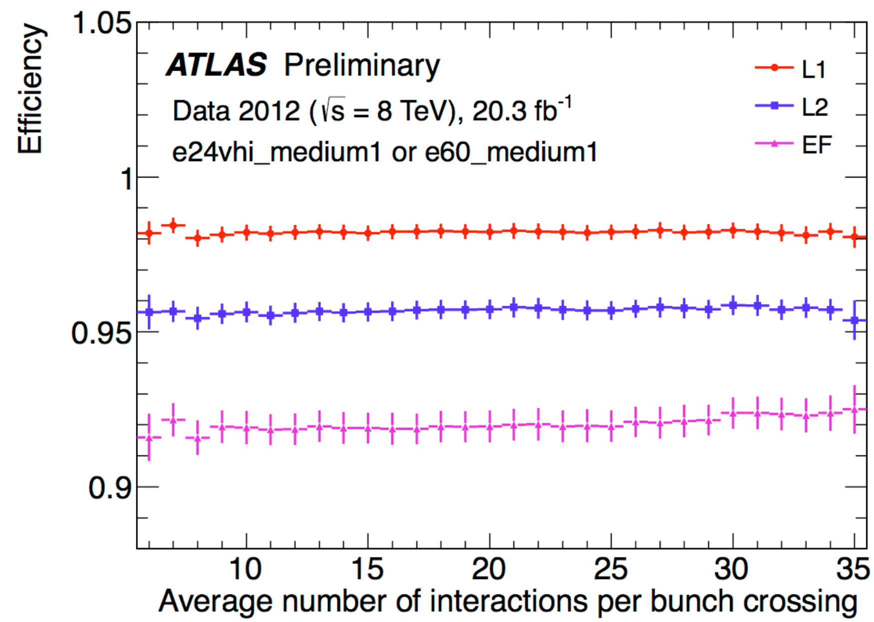






Pileup-Dependence in Run1





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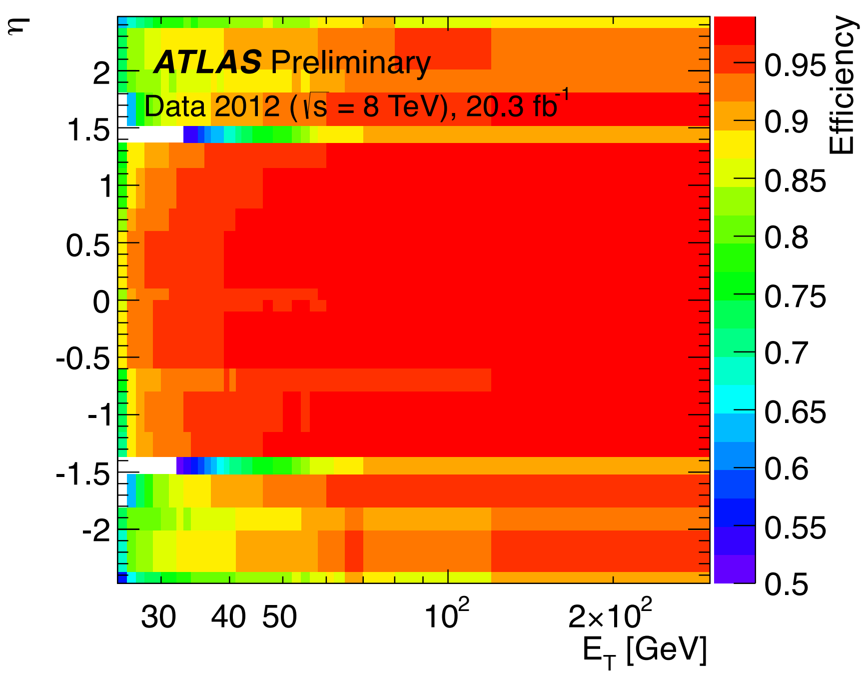
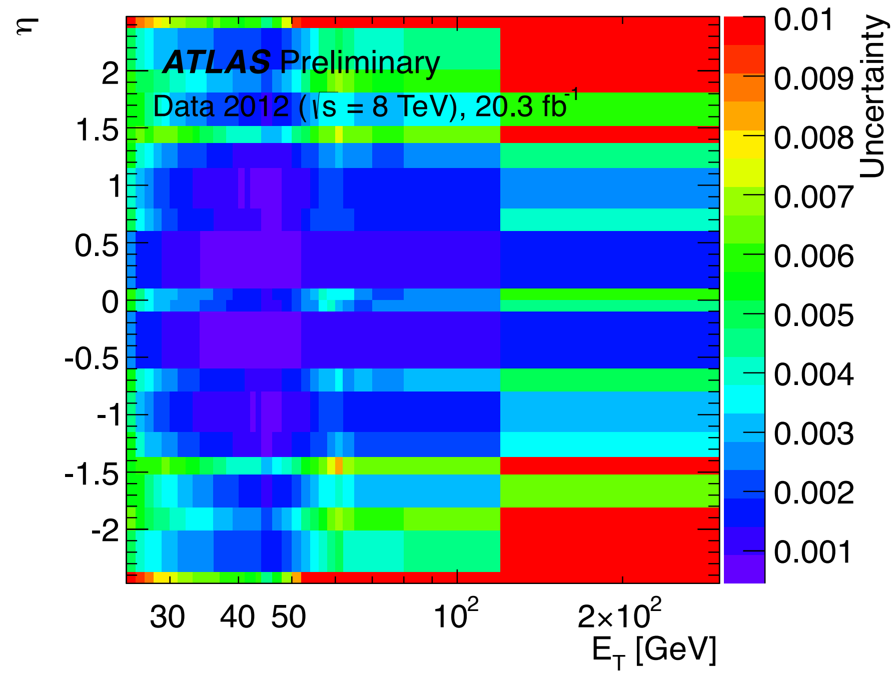
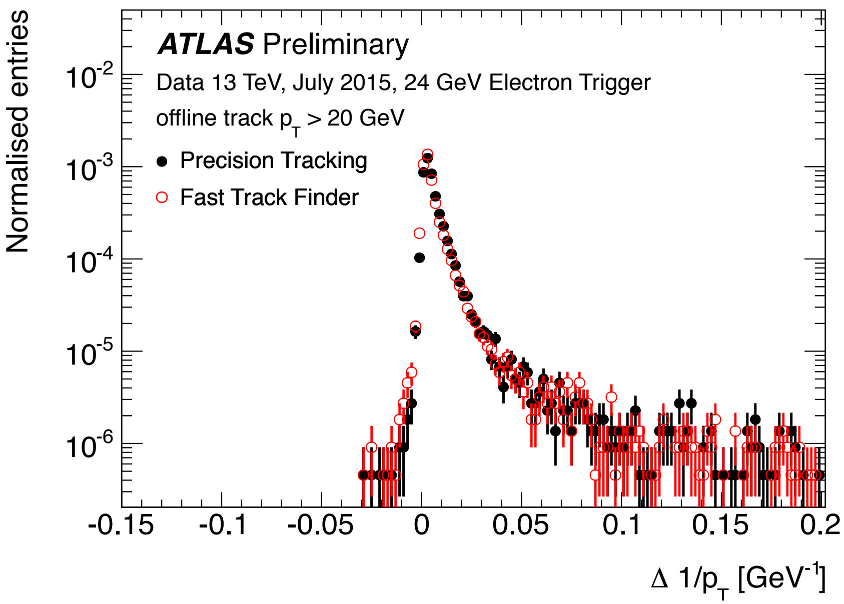
Run1 Trigger Performance

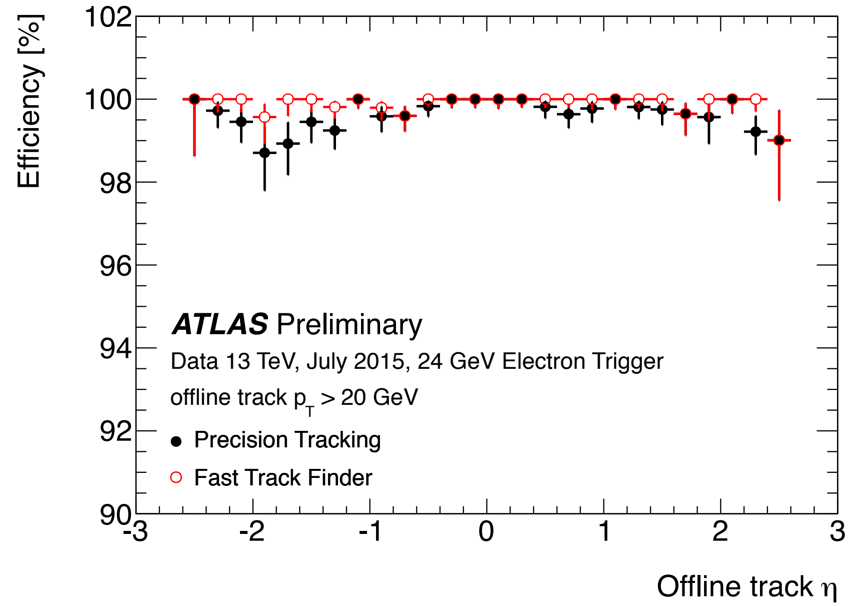
- In most of the (E_T,η) space 95% efficiency wrt offline selection
- In barrel region or 30 GeV to 50 GeV E_T region reach 0.1% precision
- At low and high E_T and in endcaps uncertainties up to 1%

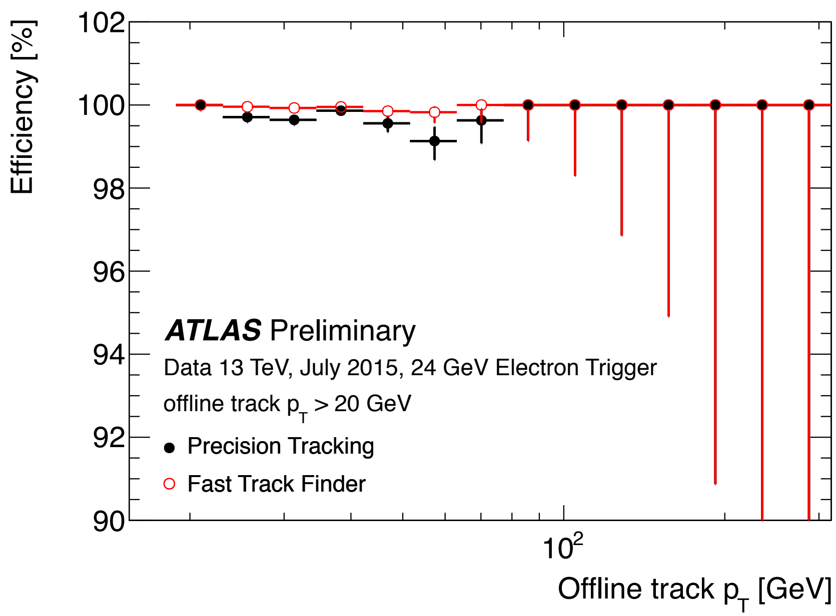




HLT Tracking performance for Electrons



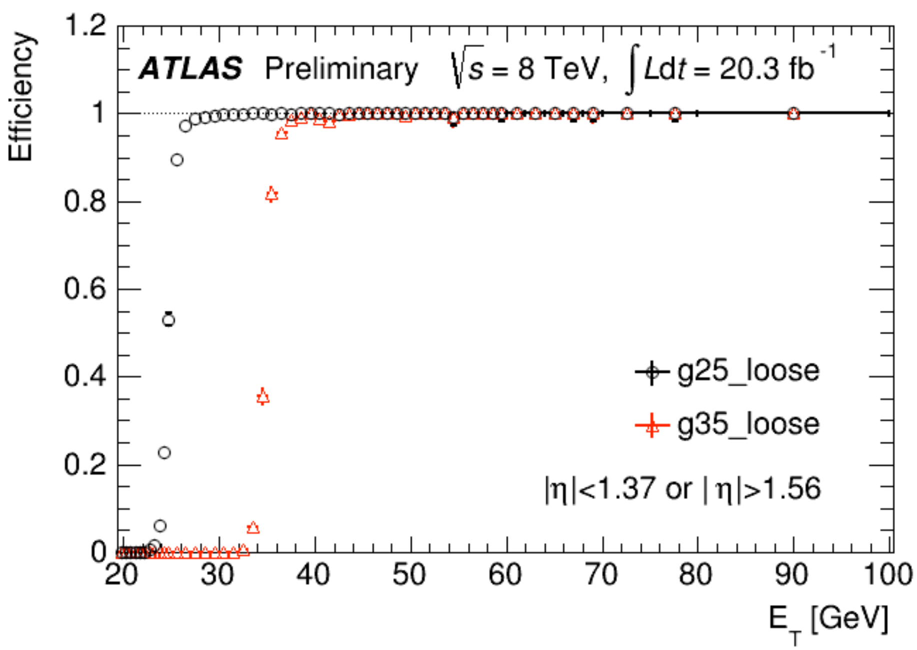


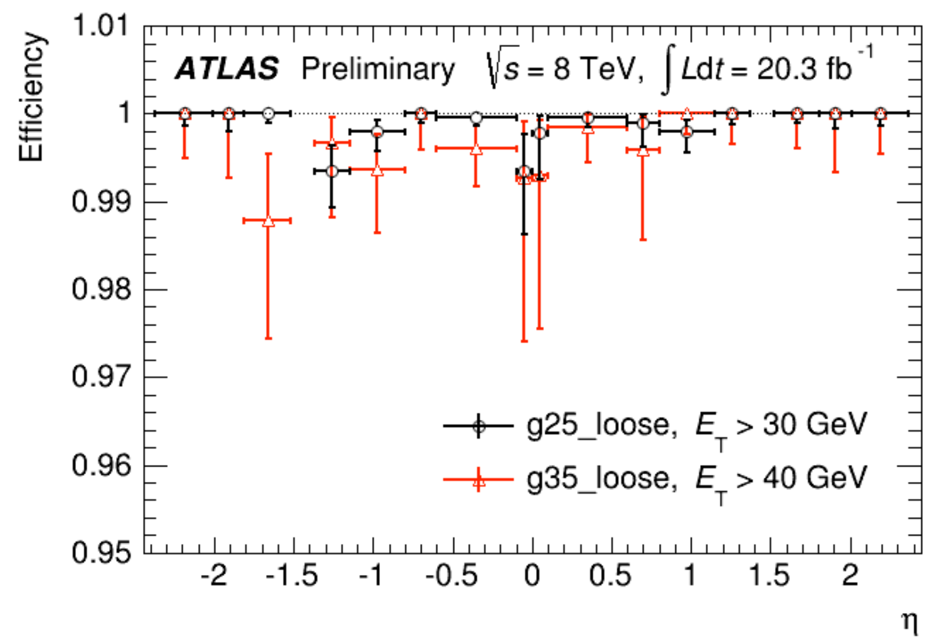


Photon Trigger Performance Run1

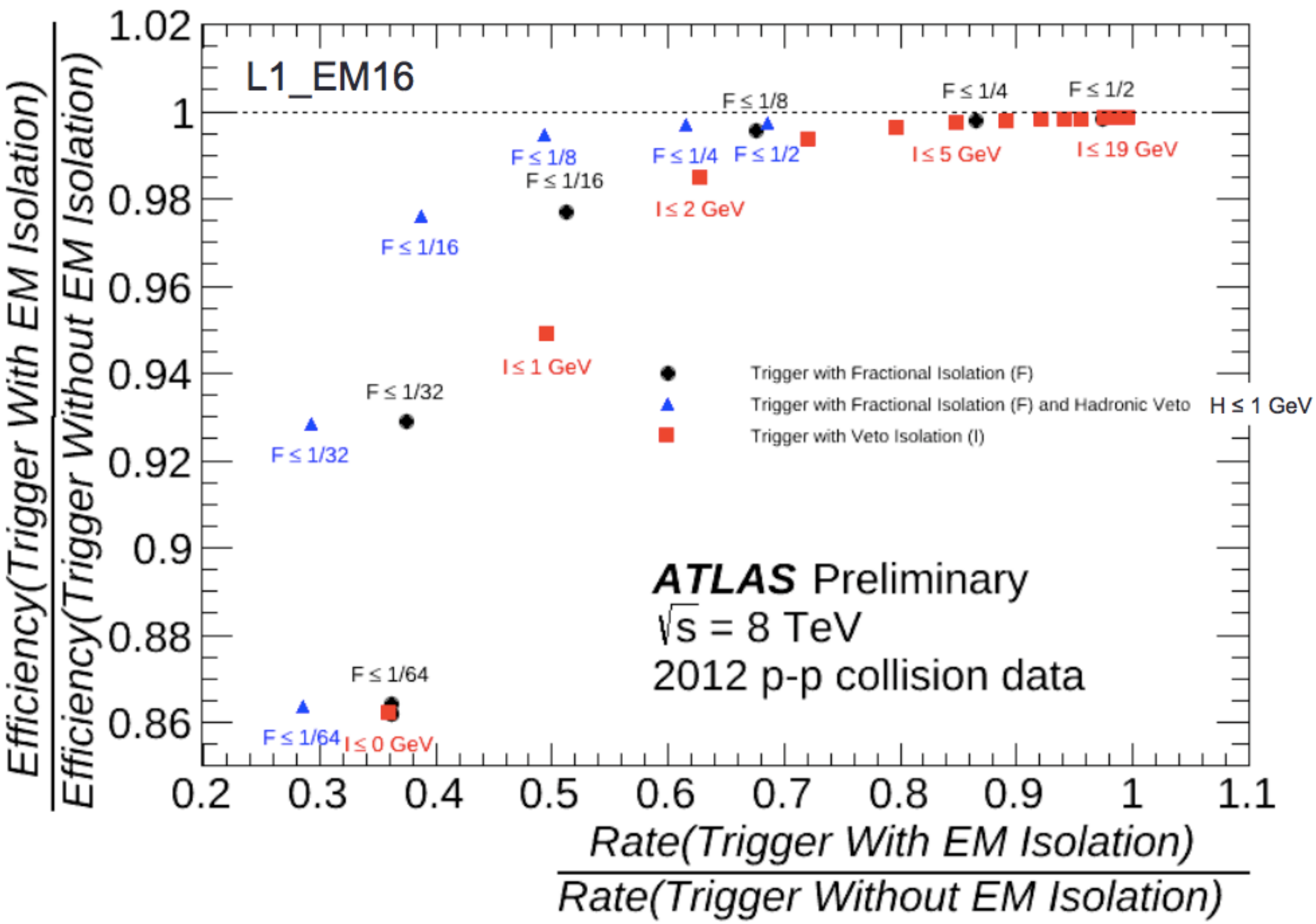
Performance measured with 2 methods

- Bootstrap from full efficient low threshold L1 item that provides low statistical uncertainty but requires background estimation
- Very clean Z➔llγ tag-and-probe method but statistics limited
- Main di-photon trigger efficiency 99.5% +/- 0.15% total uncertainty





Relative EM Ring Isolation



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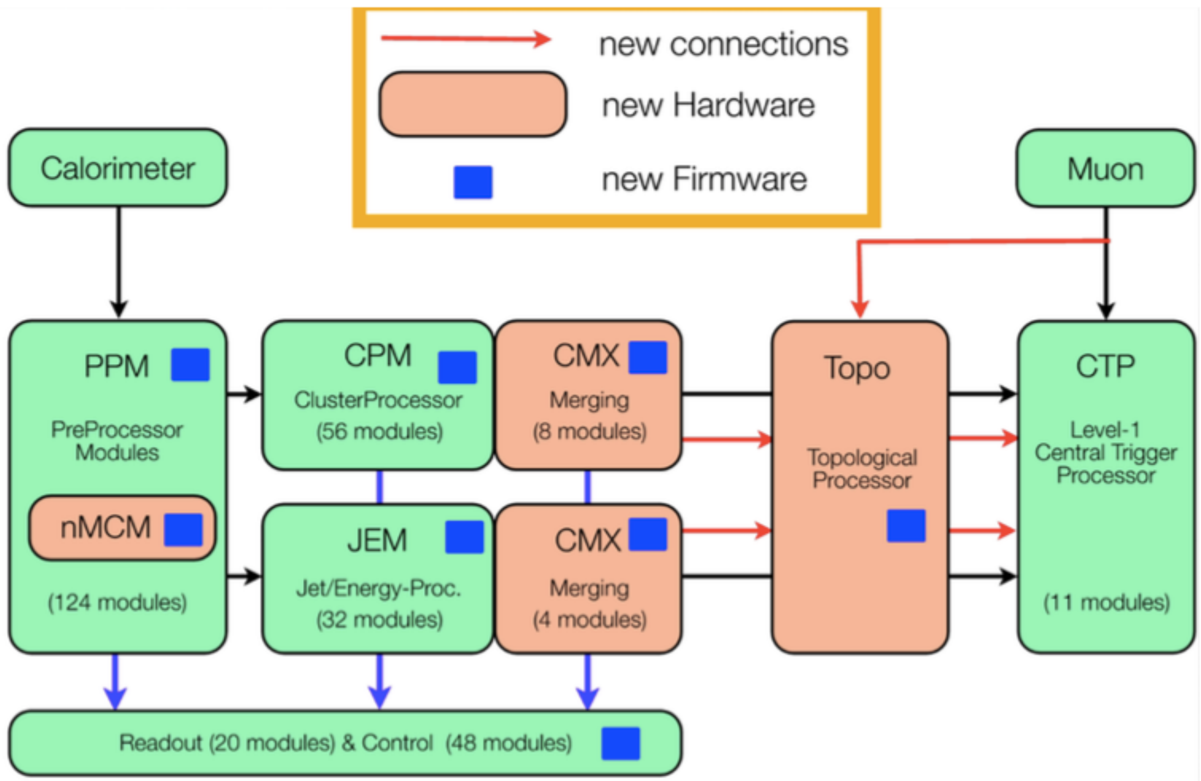
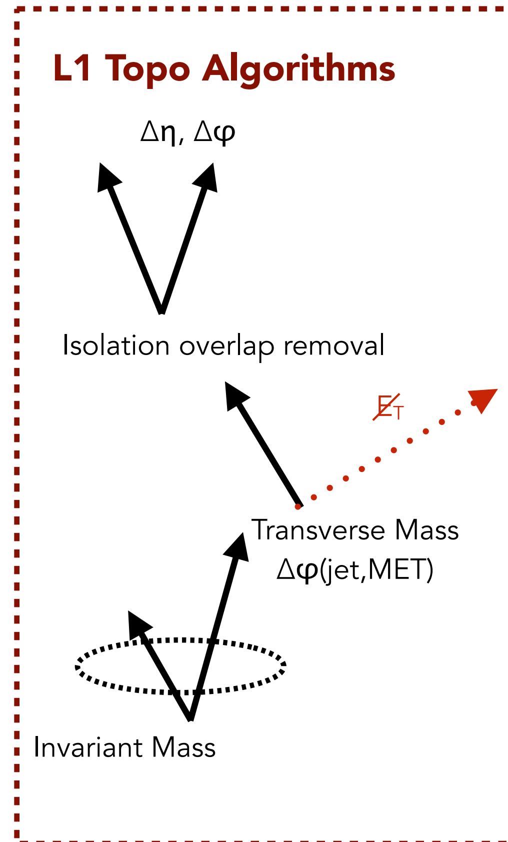
L1 Calorimeter Trigger Upgrade and L1 Topological Processor





Hardware and firmware upgrades for L1 Calo and updated online software.

L1Calo and L1 Muon provide input to new L1 topological trigger

- Design of L1 triggers for dedicated final state signatures such as J/ψ➔ee and W➔eν
- Offers potential of significant rate reduction while maintaining efficient selection of events that cannot be achieved with traditional triggers

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Menu Design – Mitigating Losses at HLT for Run2

Flexible menu design allows for supporting triggers to study inefficiency or recover potential problems:

- tracking impact parameter resolutions
  - Special triggers w/o d0 requirements
- track-to-calo matching and misalignment of ID and LAr
  - Special triggers w/ loose requirements on track-to-calo variables
- Fast algorithms may have poorer resolution
  - Special triggers sequences using only precise reconstruction and identification
- Preselection w/ cuts on shower shapes can remove signal events that otherwise are identified with Likelihood
  - Use of shower-shape based likelihood for calo-only preselection