THE UPGRADE OF THE ATLAS ELECTRON AND PHOTON TRIGGERS TOWARDS LHC RUN-2 AND THEIR PERFORMANCE

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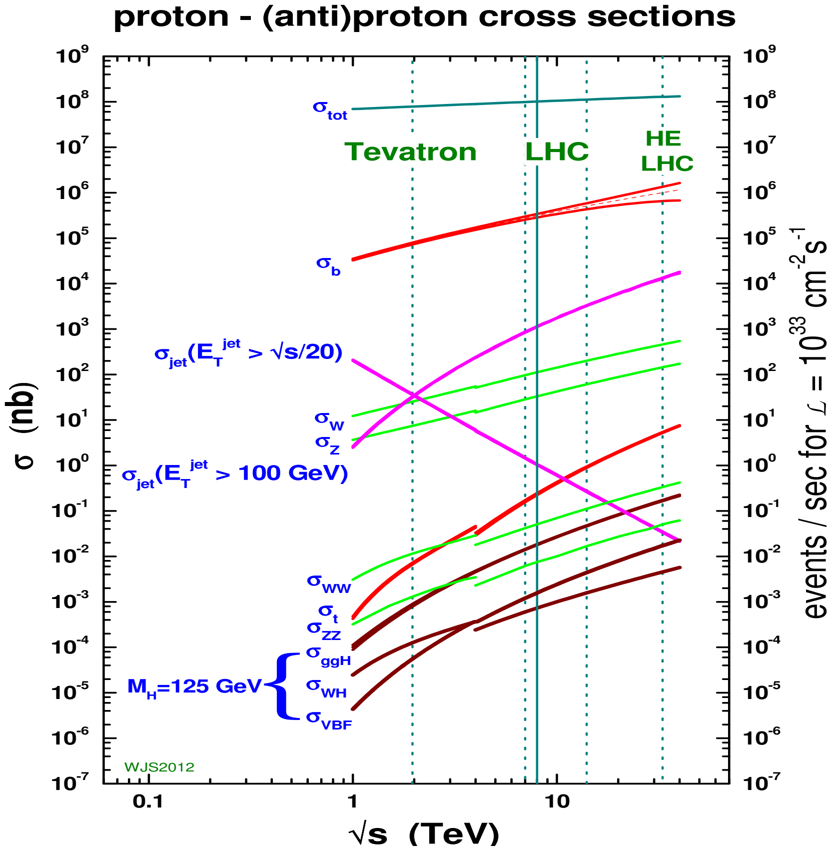


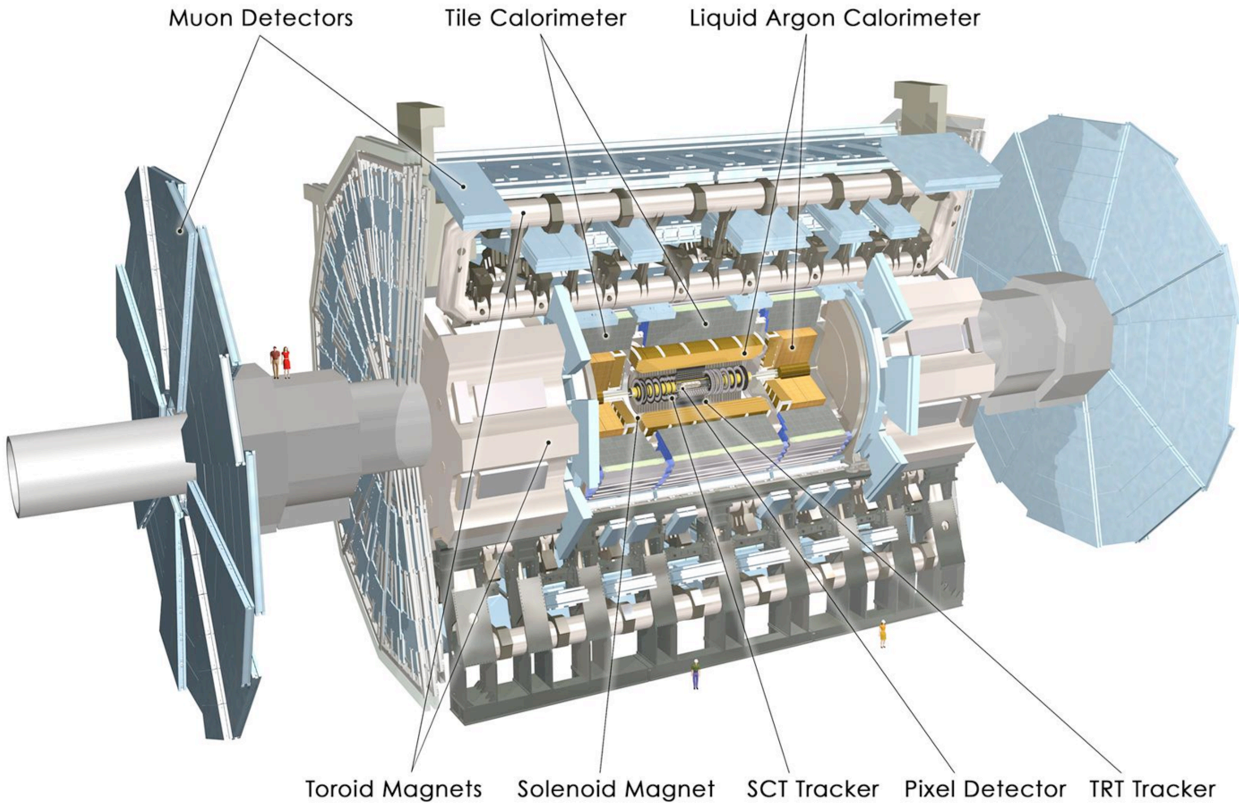
Introduction

- **Electron and photon triggers are essential for LHC physics**
  - Measure cross-sections of SM processes such as W/Z, di-boson, inclusive photon, di-photon, tt production
  - Measure the properties of the Higgs boson in H→$\gamma\gamma$, ZZ, WW final states as well as in H→$\tau\tau$ (τ→e) and associated VH and ttH production with H→bb when V, t decays leptonically
  - Look for new physics such as Z', G_{KK}, …

The trigger challenge:

- Cross-section of exciting physics many orders below total cross-section (e.g. 3 Higgs / 10^{10} pp collisions)
- From 40 MHz beam crossing rate only ~1 kHz can be recorded
- Pile-up conditions (i.e. number of interactions per beam crossing) affect detector performance: <μ> ~ 43 @ 1.6 · 10^{34} cm^{-2}s^{-1} with 25 ns bunch spacing
- **5x rate increase from Run-1 (2010-2012) to Run-2 (2015-2018) due to raise in energy and luminosity → trigger system upgrade**
- Quick commissioning to be ready for discoveries in new energy regime from day 1

The ATLAS detector



Finely segmented calorimeter system

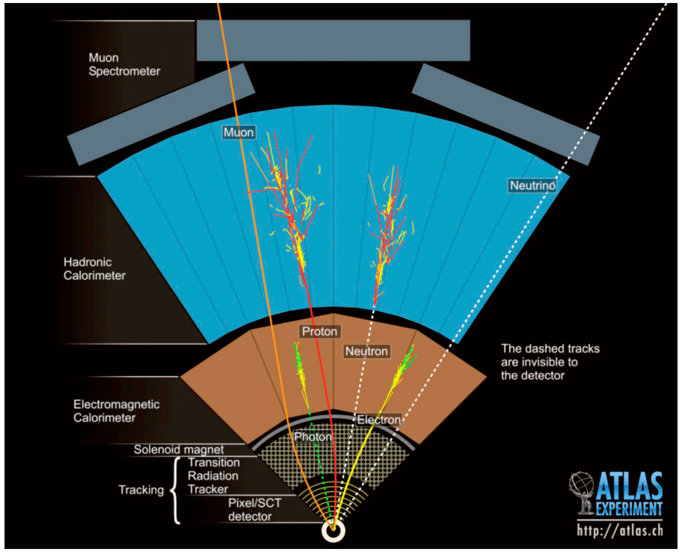
- LAr EM calorimeter
- LAr hadronic endcap
- Tile (Fe-scintillator) hadronic barrel

Trigger system

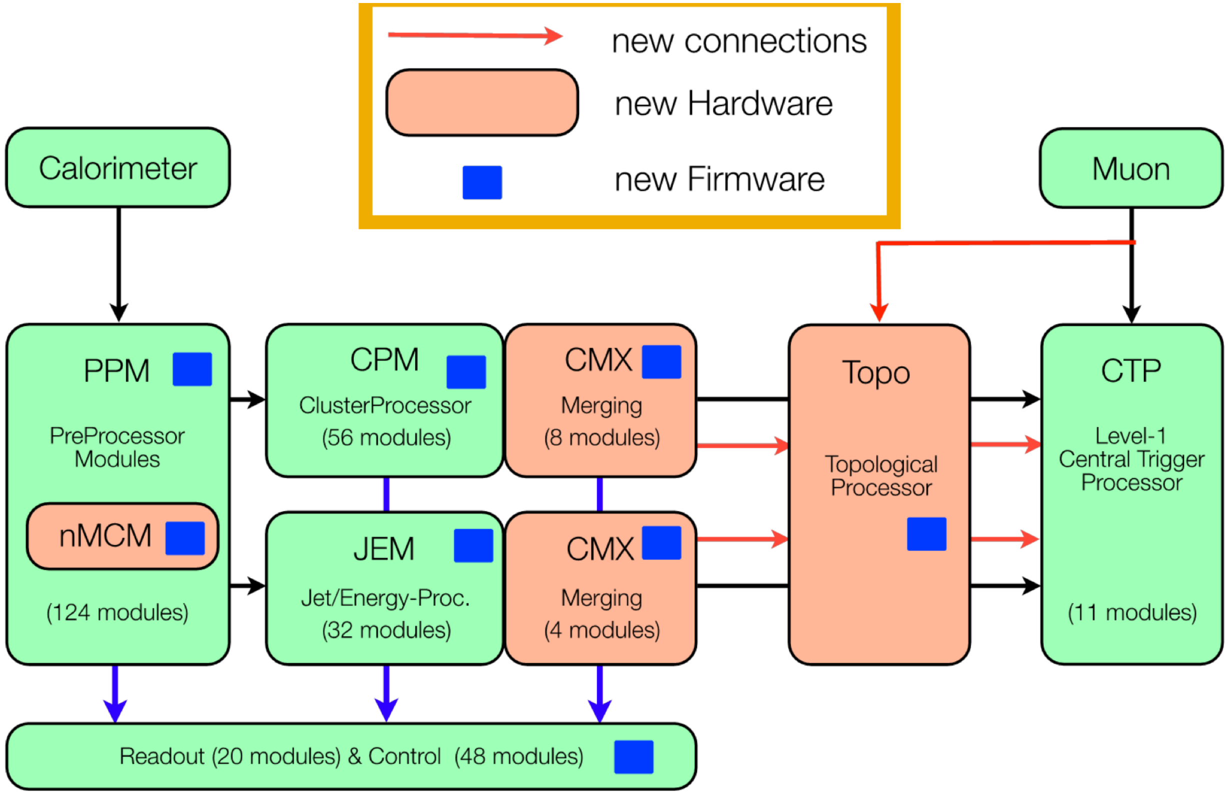
- Based on Region-of-Interest (RoI) concept
- Hardware-based Level-1 trigger (L1): calorimeter and muon detector inputs
- Software-based High Level Trigger (HLT): full detector info

Inner Detector within 2T solenoid magnet

- **New** Insertable B-Layer (Si pixel, r = 3.3 cm, 50x250 μm^2)
- Si Pixel detector (3 layers, 50x400 μm^2)
- Semi-Conductor Tracker (Si-strip detector, 80 μm pitch)
- Transition Radiation Tracker (<36 points / track)
  → **electron / hadron separation**



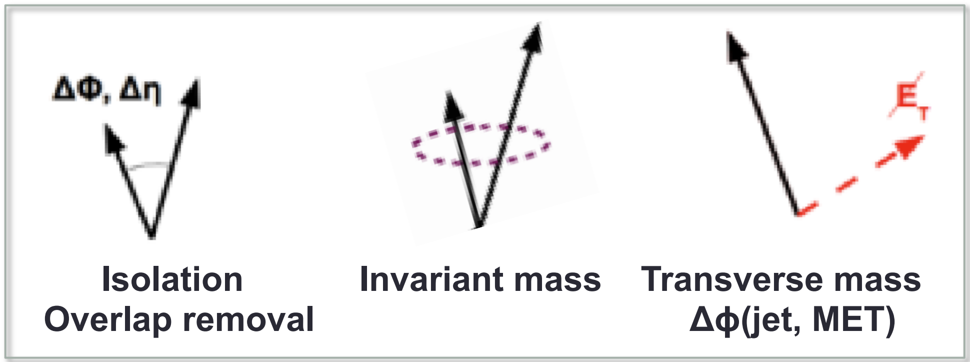
The level-1 calorimeter upgrade



New L1 topological trigger under commissioning

- Allows the design of dedicated triggers for specific final states (e.g. used for J/ψ→ee, W →eν tag-and-probe triggers that require an unbiased electron leg)
- Cuts rate early on by applying selection on masses, angular separation, etc.

L1 calorimeter trigger improved, as part of the trigger system upgrade (see talk by Kevin Black) during the LHC technical stop in 2013-2015: new hardware, firmware and updated software online (some features still under commissioning)



Level-1 electromagnetic trigger

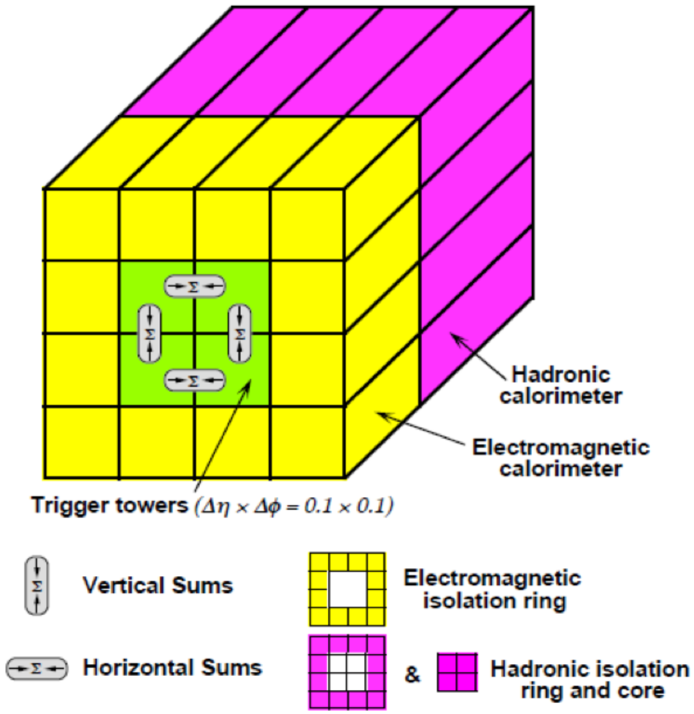
Run-1

- η-dependent E_T threshold with ΔE_T~1 GeV precision and Δη=0.4 granularity to correct for material effects
- Hadronic core isolation for main unprescaled EM triggers
  - H ≤ 1 GeV (EM scale raw E_T)

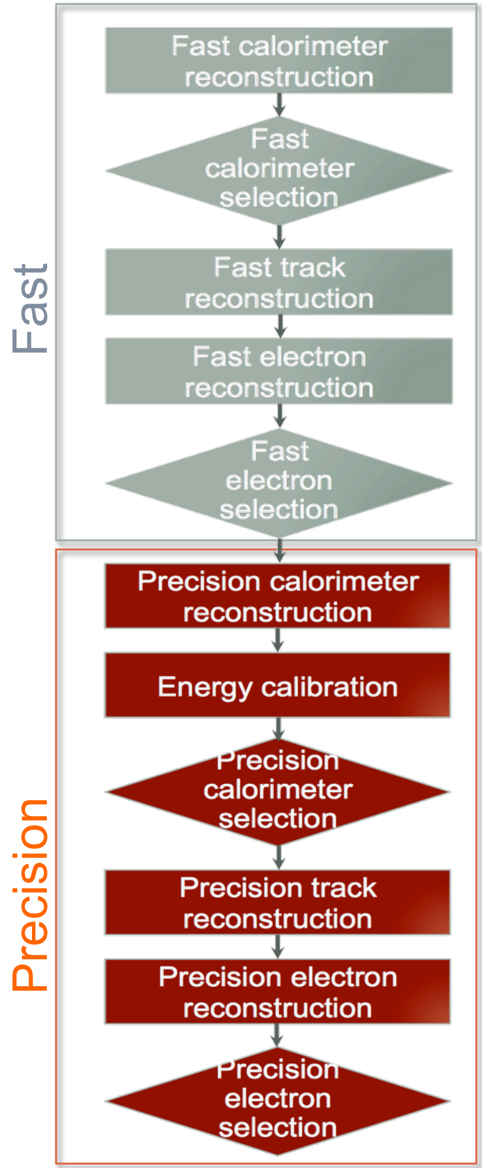
Run-2

- Signal processing: New Multi Chip Module (nMCM) in the Pre-Processor (PPM)
  - *Improved energy resolution* using noise autocorrelation filtering
  - Dynamic pedestal correction
- Clustering: Cluster Processor Module (CPM) firmware update
  - New isolation look-up table allowing 5 independent *E_T-dependent electromagnetic and/or hadronic isolation* cuts with *ΔE_T~0.5 GeV precision*
- Counting: New Extended Common Merger Module (CMX)
  - *Doubles max. number of E_T thresholds to 16*
  - E_T thresholds can be set by *Δη=0.1 granularity*

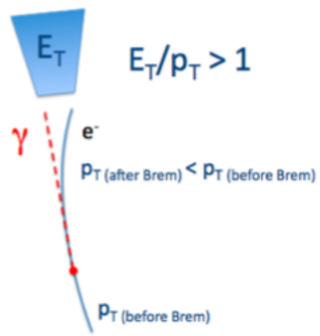
L1 EM sliding-window cluster



HLT electron / photon reconstruction



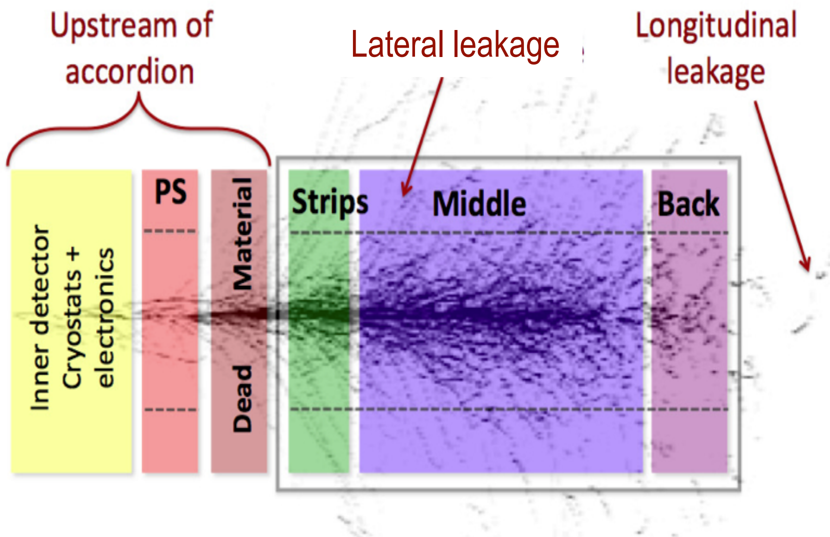
- **Photon**: energy cluster (no requirement on track)
- **Electron**: energy cluster matched to reconstructed p_T>1 GeV track with Si hits
- Seeded by Level-1 region-of-interest (RoI)
- For Run-2, the previously two-level HLT merged: common data preparation for fast and precision HLT steps
  - Fast reconstruction (simple & efficient) to cut rate early
    - In Run-2, trigger algorithm sequence can skip fast calorimeter reconstruction & selection
    - Fast track reconstruction always needed to seed precision algorithm
  - Precision reconstruction uses offline-like algorithms
- Improved, closer to offline clustering and tracking algorithms
- New energy calibration based on a multivariate analysis technique
- New electron identification relies on a likelihood technique (cut-based in Run-1)

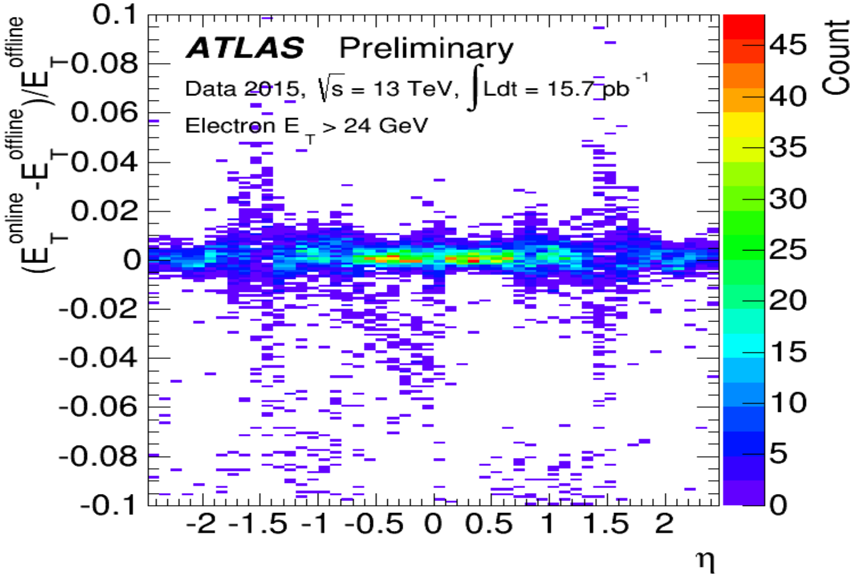


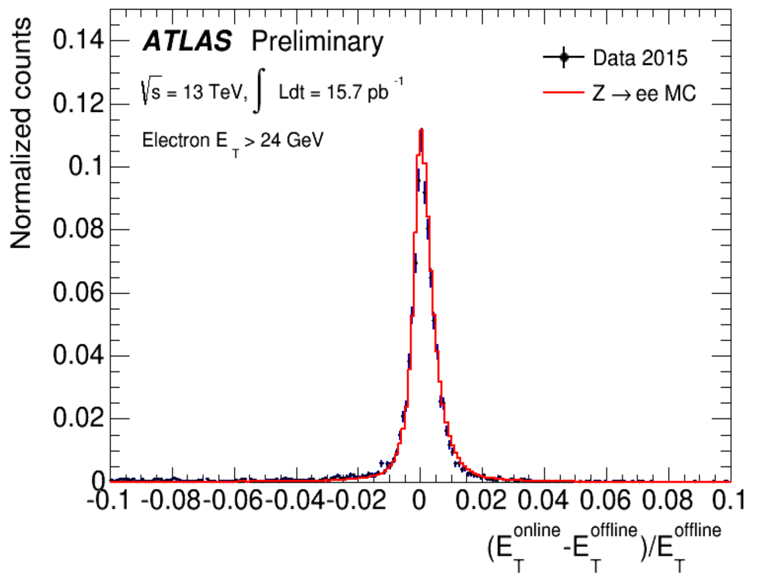
For info on the Run-1 system, see ATLAS-CONF-2011-114

Cluster energy calibration performance

- Adopt a simplified version of the new offline energy calibration
- New MC-based calibration relies on a boosted decision tree to determine the correction factor
  - Electron and photon calibration tunes separate
  - Photons not separated to converted and unconverted categories (major source of difference wrt offline)
- No data-driven pre- and post-corrections online
- Good energy resolution
  - Further improvement for converted photons could be achieved by running conversion reconstruction at HLT, especially in the endcap (|η|>1.52) region

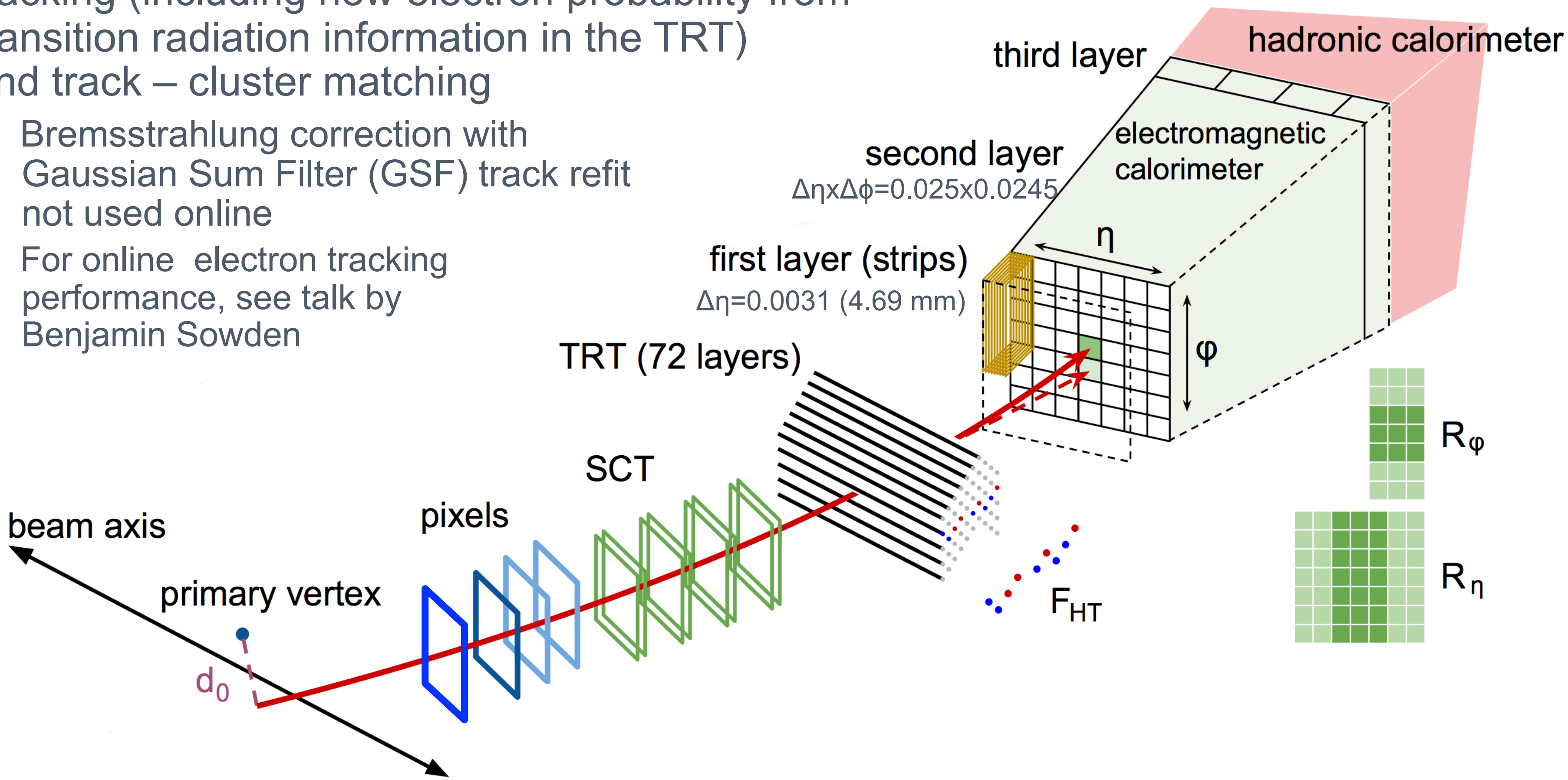






Electron and photon identification at a glance

- **Photon ID**: cut-based selection relying on shower-shape information
  - Offline: separate converted and unconverted photon categories
  - Online: use looser selection from the two for all photons
- **Electron ID**: adopt new likelihood-based (LH) selection from offline to improve purity with input from shower-shapes, tracking (including new electron probability from transition radiation information in the TRT) and track – cluster matching
  - Bremsstrahlung correction with Gaussian Sum Filter (GSF) track refit not used online
  - For online electron tracking performance, see talk by Benjamin Sowden



Shower-shape variables

Variables and Position

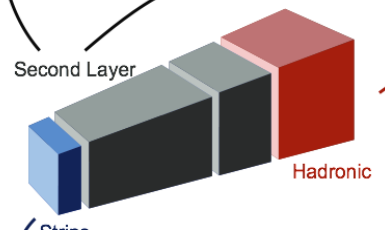
	Strips	2nd	Had.
Ratios	f_1, f_{side}	R_η*, R_ϕ	$R_{Had.}$*
Widths	$w_{s,3}$, $w_{s,tot}$	$w_{\eta,2}$*	-
Shapes	ΔE, E_{ratio}		

* Used in PhotonLoose.

Energy Ratios

$$R_\eta = \frac{E^{S2}_{3\times7}}{E^{S2}_{7\times7}} \qquad R_\phi = \frac{E^{S2}_{3\times3}}{E^{S2}_{3\times7}}$$

φ η



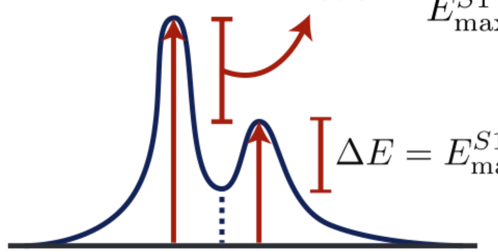
$$R_{Had} = \frac{E_T^{Had}}{E_T}$$

$$f_1 = \frac{E_{S1}}{E_{Tot.}}$$

$$f_{side} = \frac{E^{S1}_7 - E^{S1}_3}{E^{S1}_3}$$

Shower Shapes

$$E_{ratio} = \frac{E^{S1}_{max,1} - E^{S1}_{max,2}}{E^{S1}_{max,1} + E^{S1}_{max,2}}$$

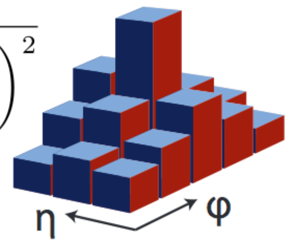


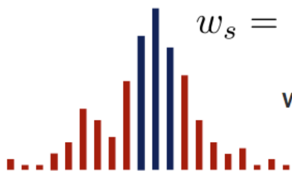
$$\Delta E = E^{S1}_{max,2} - E^{S1}_{min}$$

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 3x5 (Δη×Δφ) region of cells in the second layer.





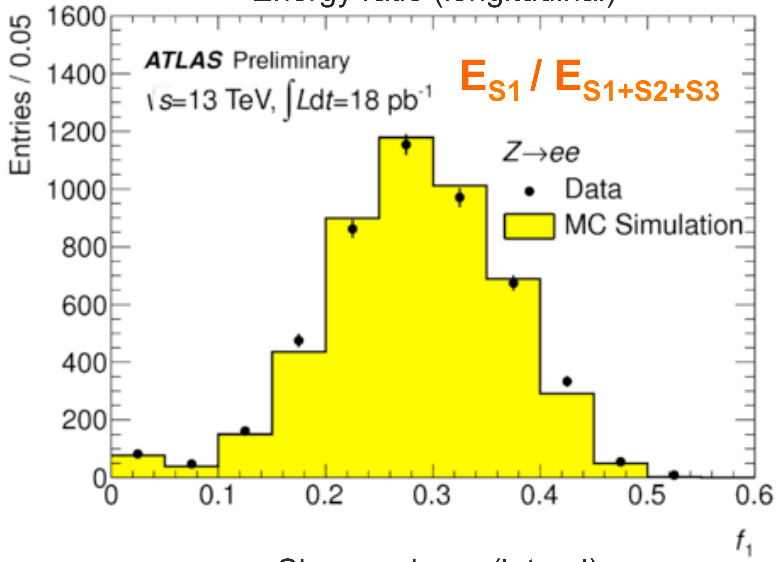
$$w_s = \sqrt{\frac{\sum E_i (i - i_{max})^2}{\sum E_i}}$$

ws3 = w_1 uses 3 strips in η; wstot is defined similarly, but uses 20 strips.

ATL-COM-PHYS-2013-600

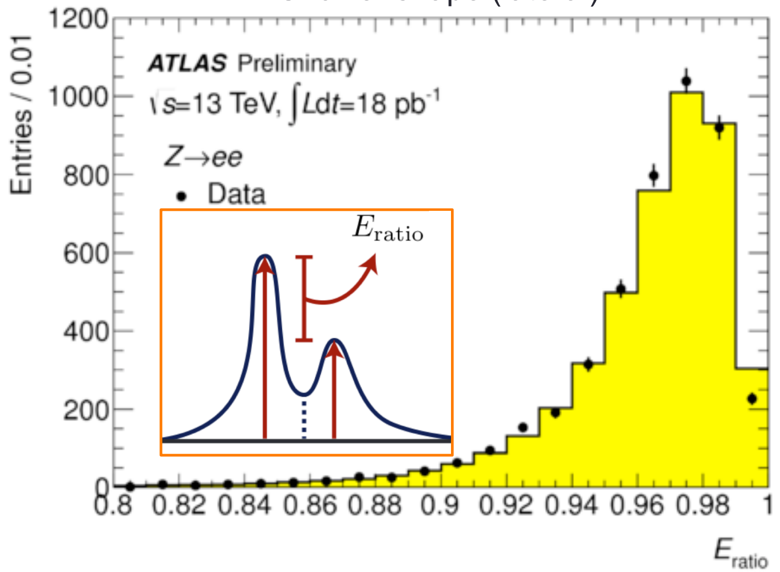
Electron identification variables in Run-2: Data – MC comparison

Energy ratio (longitudinal)

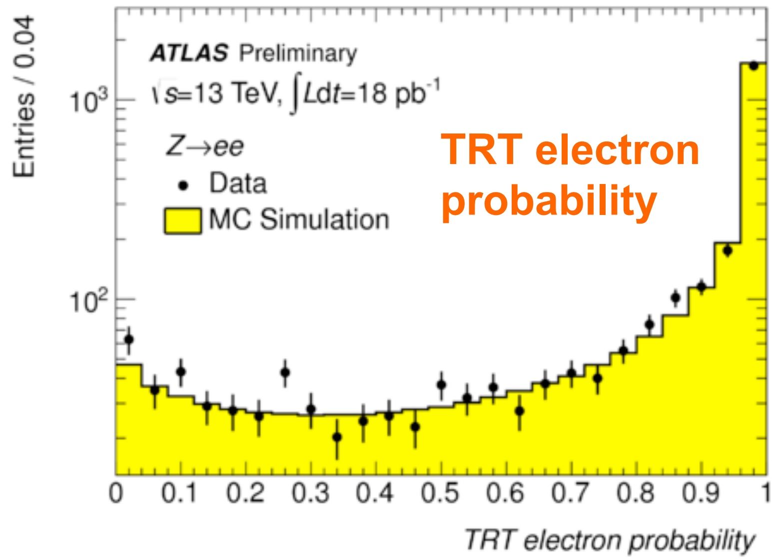


- Finely segmented calorimeter provides good discrimination against hadrons
- Offline reconstruction shows similar degree of agreement between data and MC than we had in Run-1
- New variable giving electron probability based on TRT transition radiation hit information shows good agreement

Shower shape (lateral)



Transition radiation hit information



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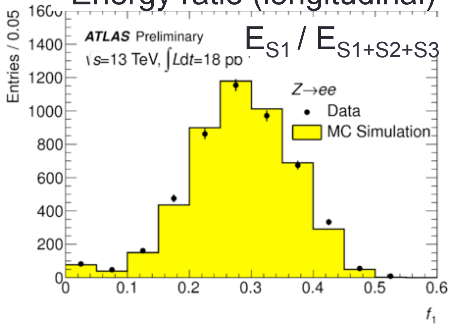
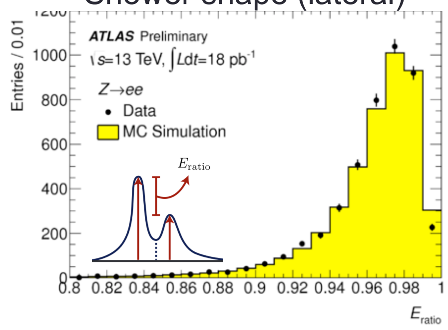
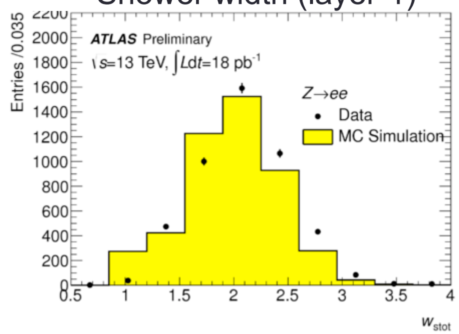


Shower shape (lateral)

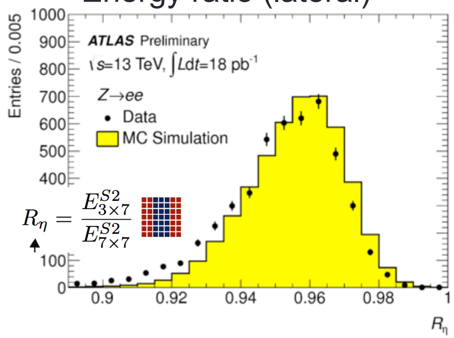


Shower width (layer-1)



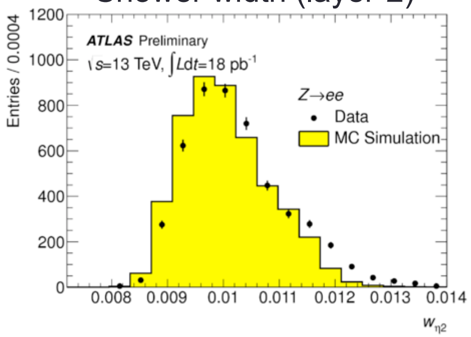
More comparisons…

Energy ratio (lateral)

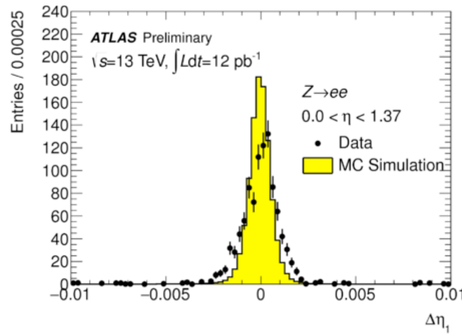


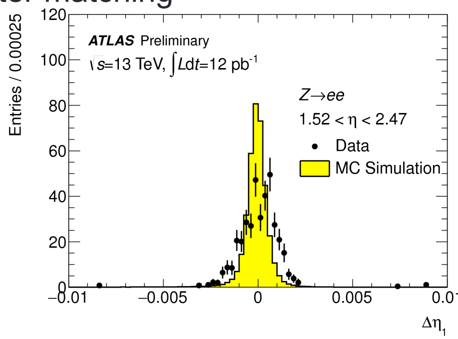
$$R_\eta = \frac{E^{S2}_{3\times7}}{E^{S2}_{7\times7}}$$

Shower width (layer-2)

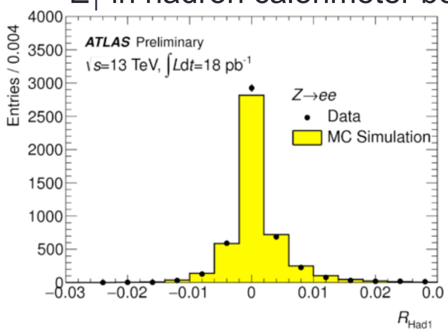


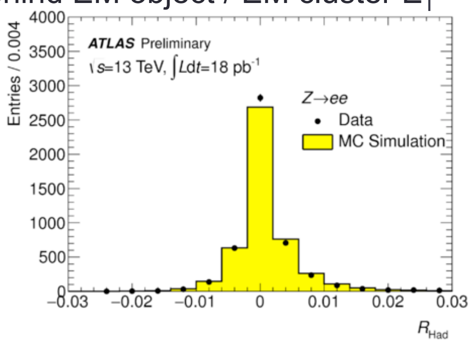
Track – cluster matching



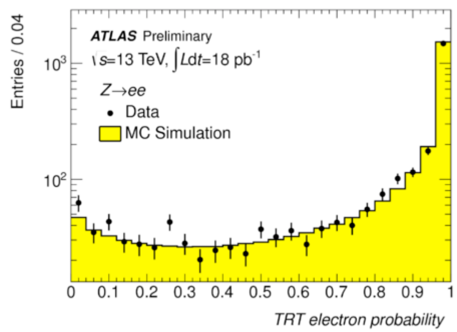


E_T in hadron calorimeter behind EM object / EM cluster E_T





Transition radiation hit information



Definition of variables e.g. in ATLAS-CONF-2014-032

Detour: trigger names

e24_lhmedium_iloose_L1EM20VH

HLT E_T threshold [GeV]: 24

Identification tightness at HLT: lhmedium

Track isolation at HLT: $p_T^{iso,R=0.2} / E_T < 0.1$: iloose

Level-1 EM seed (if not default for given HLT threshold): L1EM20VH

Object type: electron (e), photon (g)
If more objects required: 2e, 3g or e*_g*…

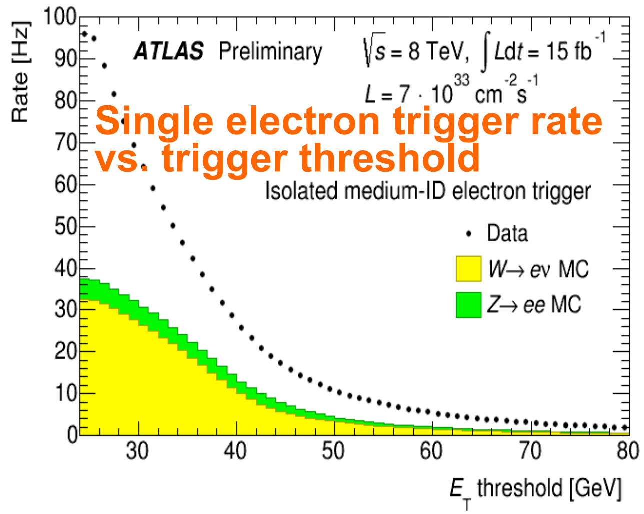
L1 E_T threshold [raw E_T]: 20

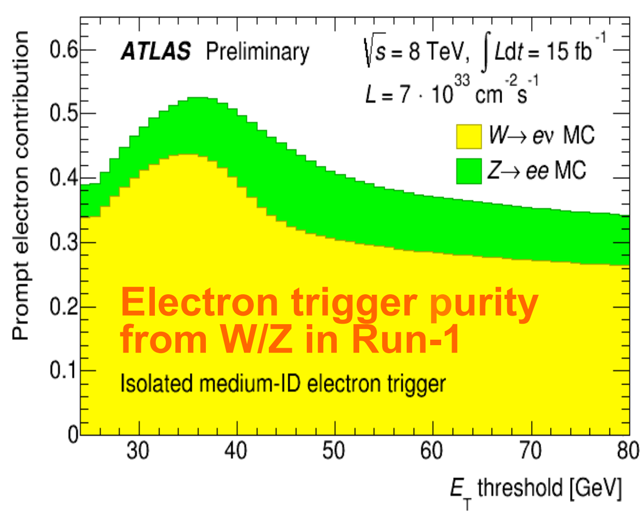
L1 threshold varies with η to correct for material before EM calorimeter: V

L1 isolation: hadronic (H), EM (I): H

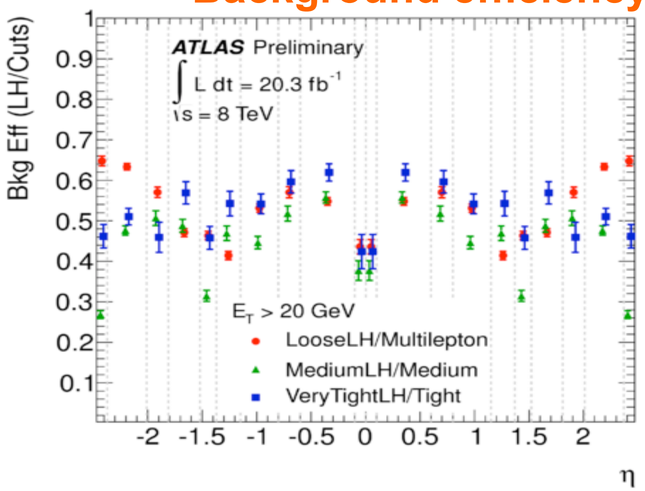
HLT electron strategy: improve purity

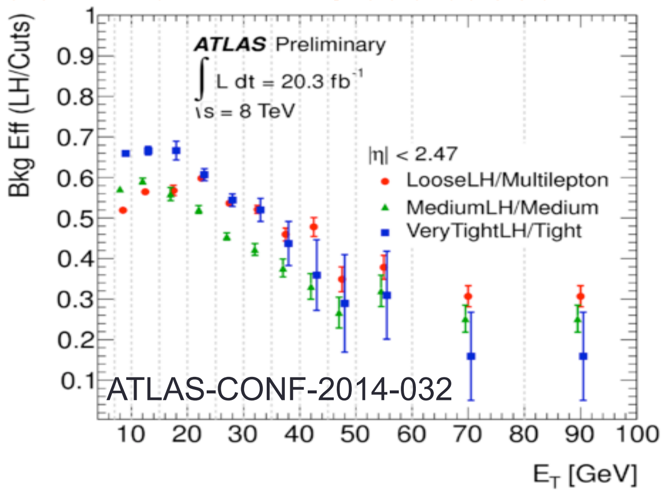
- Rate depends steeply on E_T threshold (but physics potential is hurt by raised thresholds)
- Purity (~40-50% in 2012) could be improved by a tighter or a smarter selection





Background efficiency ratio in Run-1: LH / cut-based





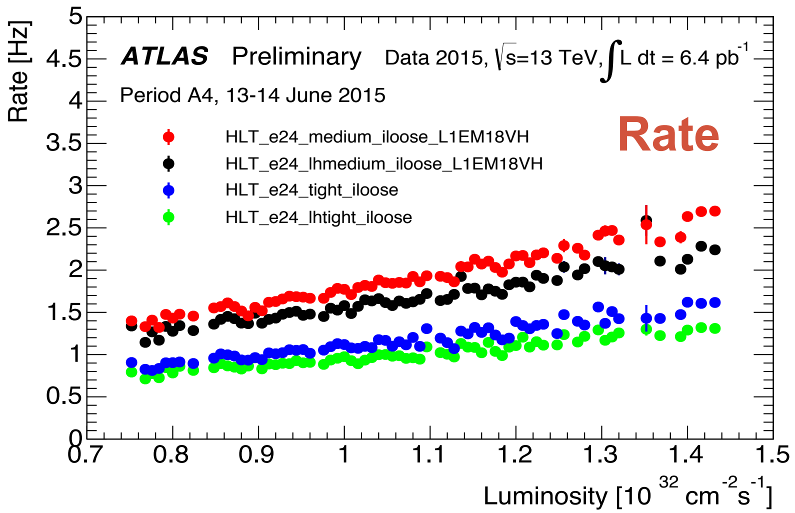
Offline likelihood-based selection for same signal efficiency provides a factor 2 improvement in background rejection

→ LH electron ID implemented online for Run-2

HLT electron strategy in Run-2

Keep threshold at Run-1 level as long as possible by tightening L1 and HLT selections, e.g. lowest unprescaled single electron trigger:

Peak instantaneous luminosity [10^{34} $cm^{-2}s^{-1}$]		HLT E_T threshold [GeV]	HLT identification	HLT track isolation		L1 E_T threshold [GeV]	L1 isolation
<0.8 [Run-1]	e	24_	medium1_	iloose_	L1EM	18V	H
<0.3 [Run-2]	e	24_	lhmedium_	iloose_	L1EM	18V	H
<0.5 [Run-2]	e	24_	lhmedium_	iloose_	L1EM	20V	H
<1.0 [Run-2]	e	24_	lhtight_	iloose	(L1_EM	20V	HI)
<1.5 [Run-2]	e	26_	lhtight_	iloose	(L1_EM	22V	HI)



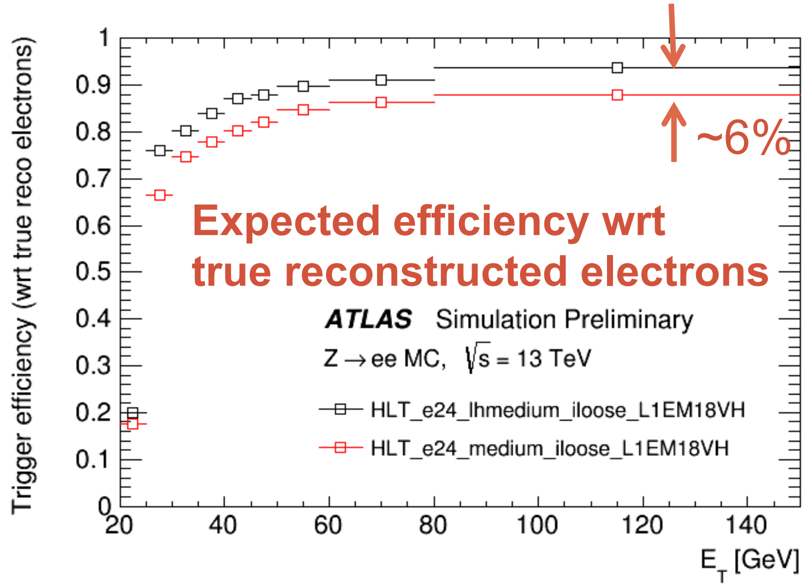
Dielectron trigger:
HLT_2e12_lhloose_L12EM10VH → HLT_2e17_lhloose (L1_2EM15VH)

HLT rate decreases in very first Run-2 data

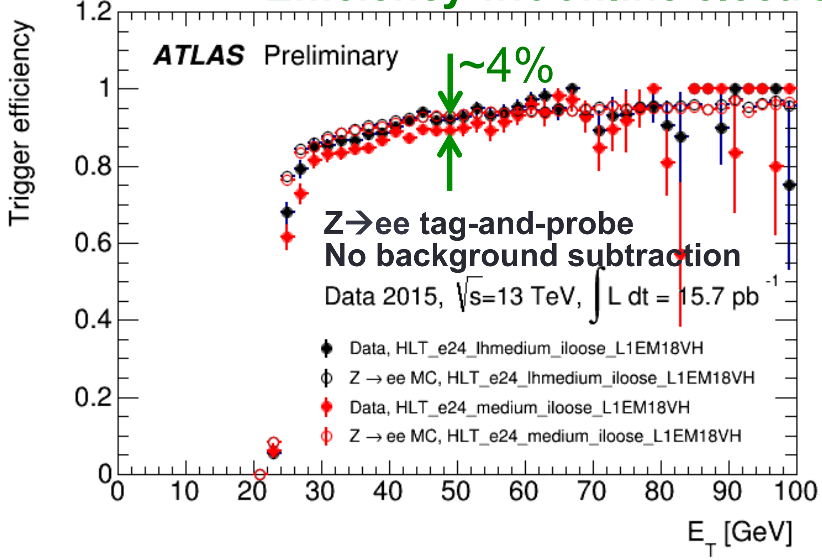
- by ~45% from **lhmedium** to **lhtight** (adding also EM isolation "I" at L1)
- by ~20% from cut-based **medium** (**tight**) to LH **lhmedium** (**lhtight**) selection

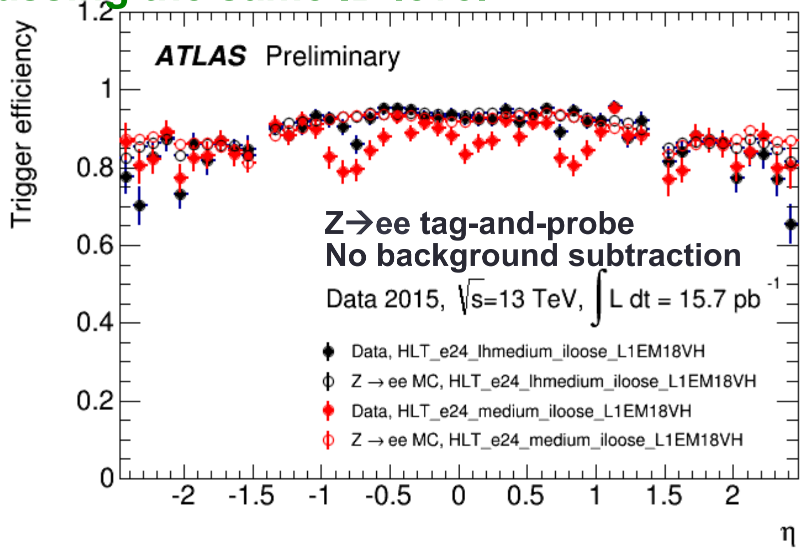
Electron trigger in 2015: efficiencies, rates

- In first Run-2 data, LH ID performs better than cut-based, as expected
- Due to its better expected rejection, tuned to have **~6% higher efficiency for true Z→ee electrons**
- Still provides ~20% rate reduction wrt cut-based ID (→ rate plot on previous slide)
- Shows better data – MC agreement
  - **Cut-based ID suffers ~4%** efficiency loss wrt corresponding offline selection (under investigation)



Efficiency wrt offline electrons passing the same ID level

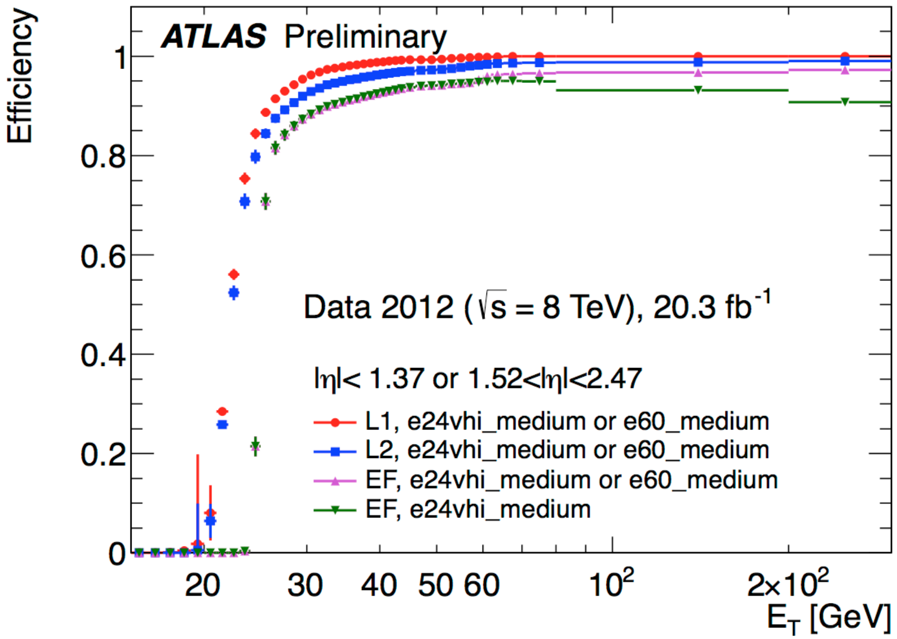


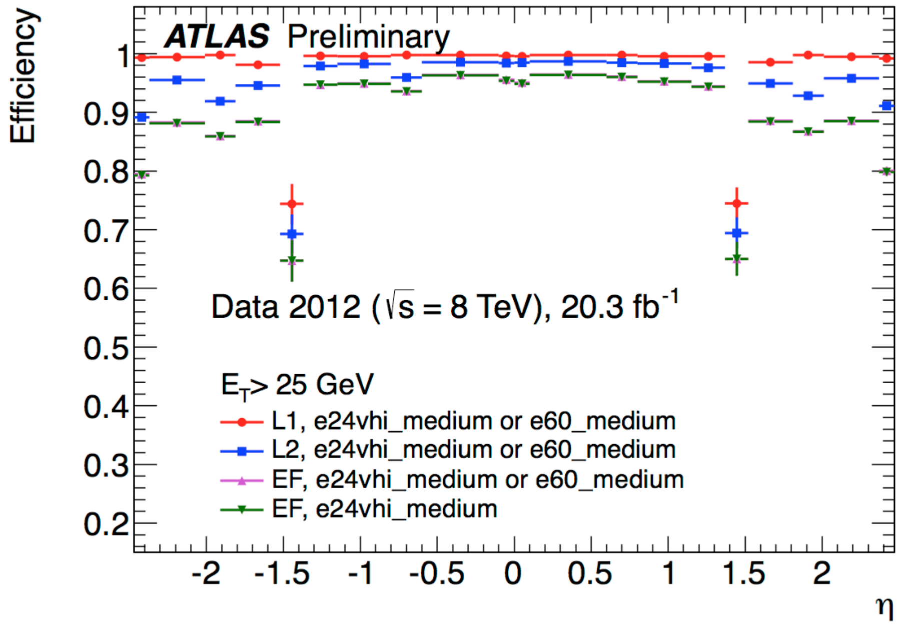


Where do we loose efficiency?

- L1 energy resolution contributes significantly close to the turn-on
- At HLT, both fast (L2) and precision (EF) selections have inefficiencies
- At high E_T, HLT track isolation losses become important
  → OR with a non-isolated higher threshold trigger

Efficiency of Run-1 single electron trigger at different stages of the selection wrt offline medium electrons

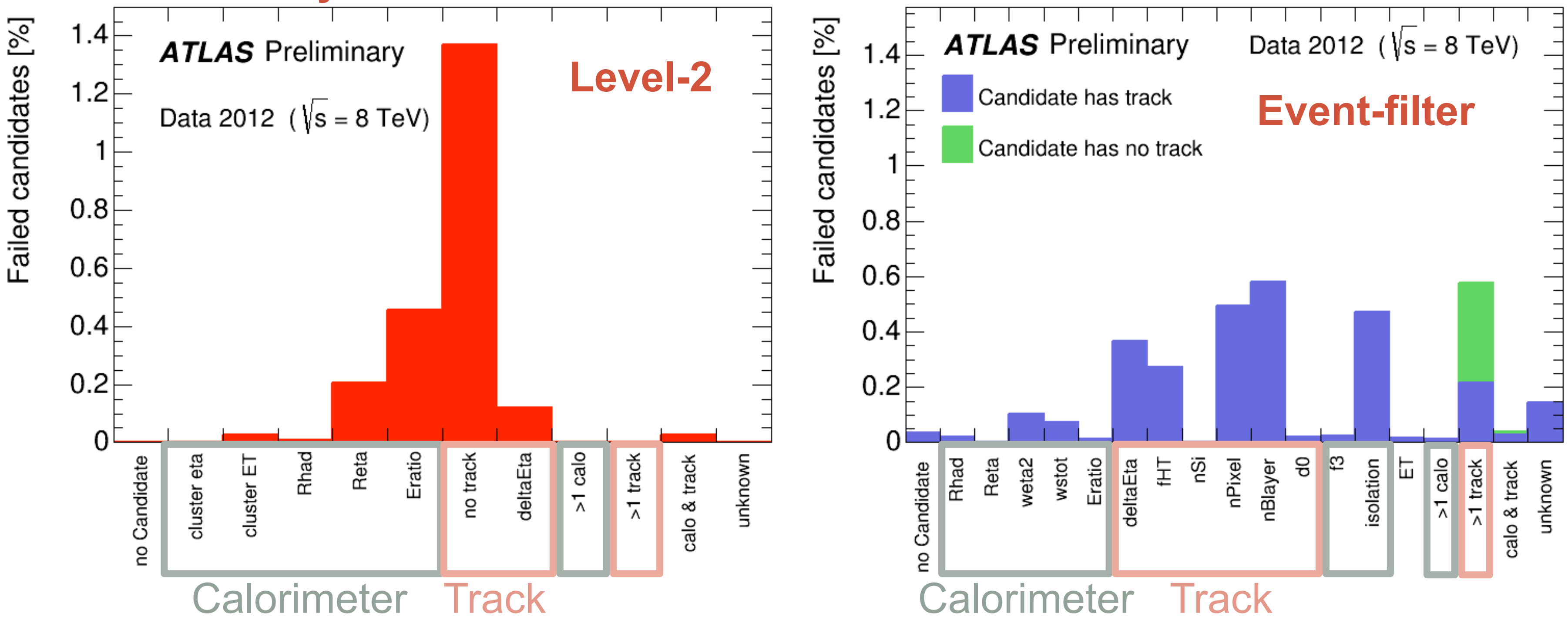




Where do we loose efficiency in the HLT?

- Dominant source of efficiency loss: tracking related selections
  → move online tracking closer to offline (bremsstrahlung reconstruction,…)
- In the merged Run-2 HLT system, L2 selection could be be decommissioned to improve efficiency

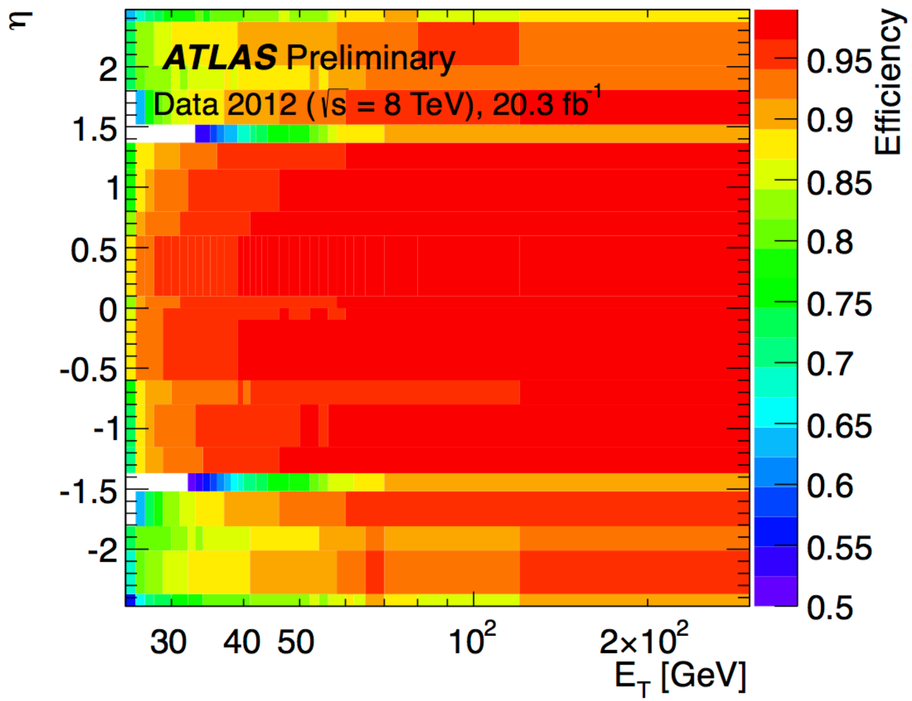
Inefficiency wrt offline electrons due to individual selection cuts in Run-1

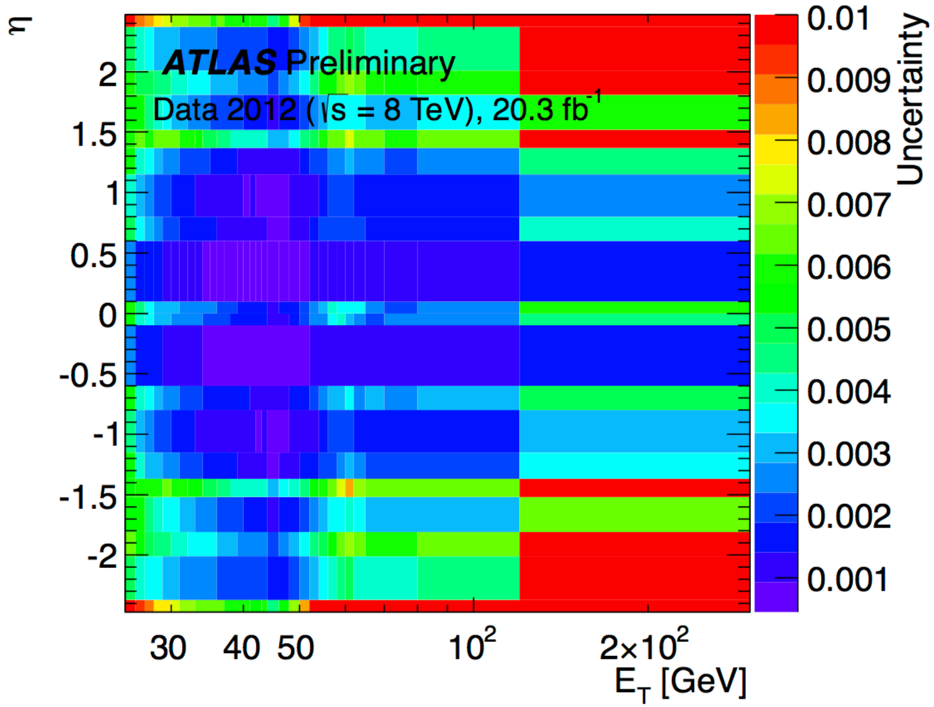


Run-1 electron trigger efficiency measurement

- In most of the (E_T,η) space: efficiency ~95% wrt offline selection
- In the barrel region or for E_T = 30 – 50 GeV: reached ~0.1% precision
- At low and high E_T, as well as for high pseudorapidity: uncertainties up to 1%

Single electron trigger efficiency wrt offline medium electrons and its uncertainty

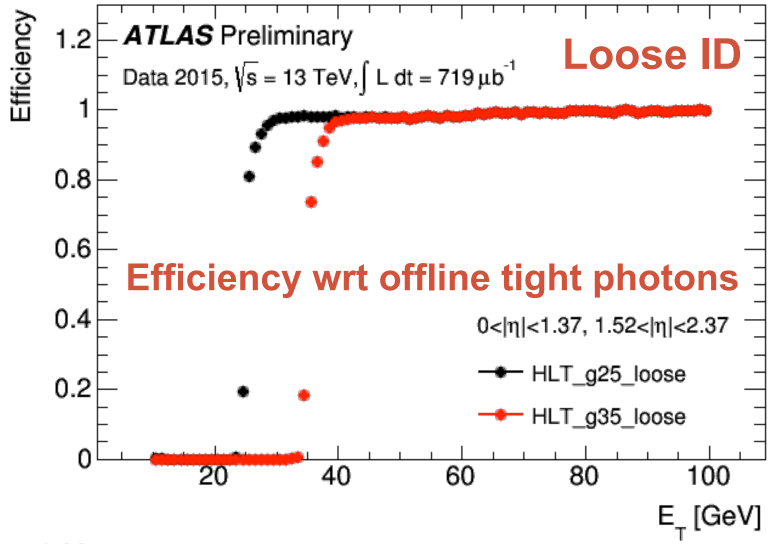


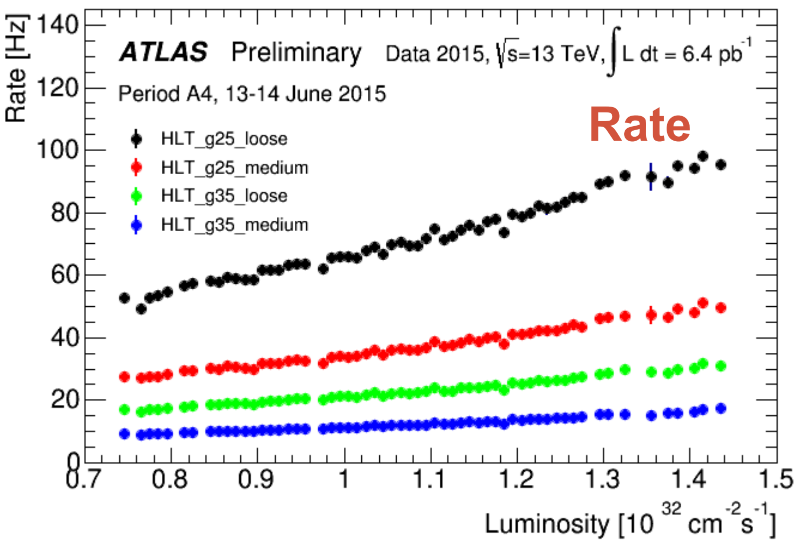


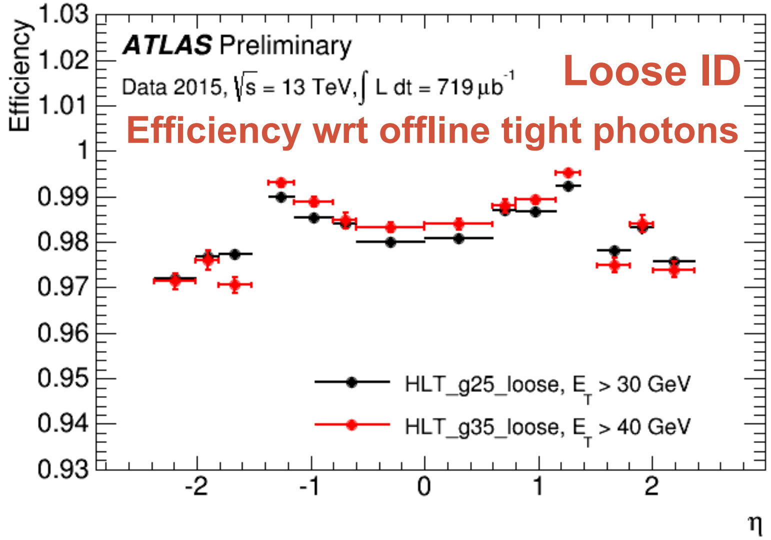
Photon trigger in 2015: efficiencies, rates

- Efficiency plateau reached at ~5 GeV above HLT E_T threshold
- From loose to medium ID
  - Negligible loss of efficiency
  - Almost factor 2 rate reduction
- Lowest E_T threshold unprescaled triggers @ $L = 1.5 \cdot 10^{34}\ cm^{-2}s^{-1}$
  - HLT_g140_loose
  - HLT_g35_medium_g25_medium

No background subtraction applied
Bootstrap from (fully efficient) L1_EM7







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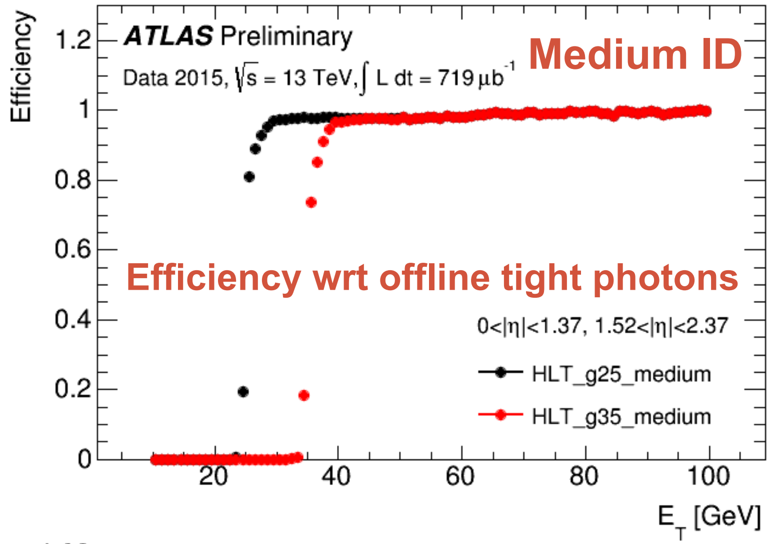
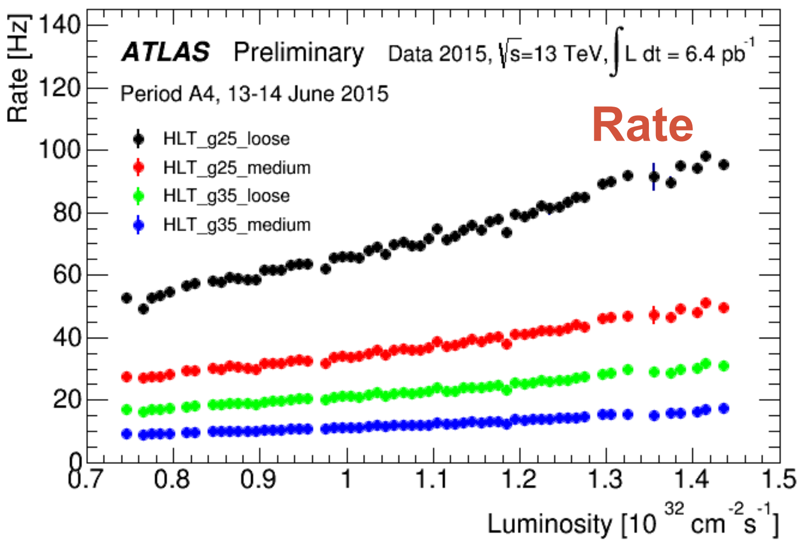
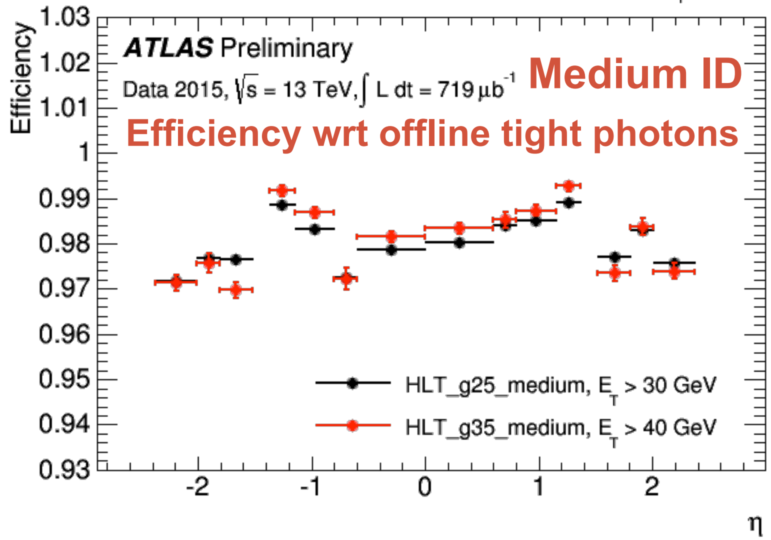
  - Negligible loss of efficiency
  - Almost factor 2 rate reduction
- Lowest E_T threshold unprescaled triggers @ L = $1.5 \cdot 10^{34}$ $cm^{-2}s^{-1}$
  - HLT_g140_loose
  - HLT_g35_medium_g25_medium

No background subtraction applied
Bootstrap from (fully efficient) L1_EM7



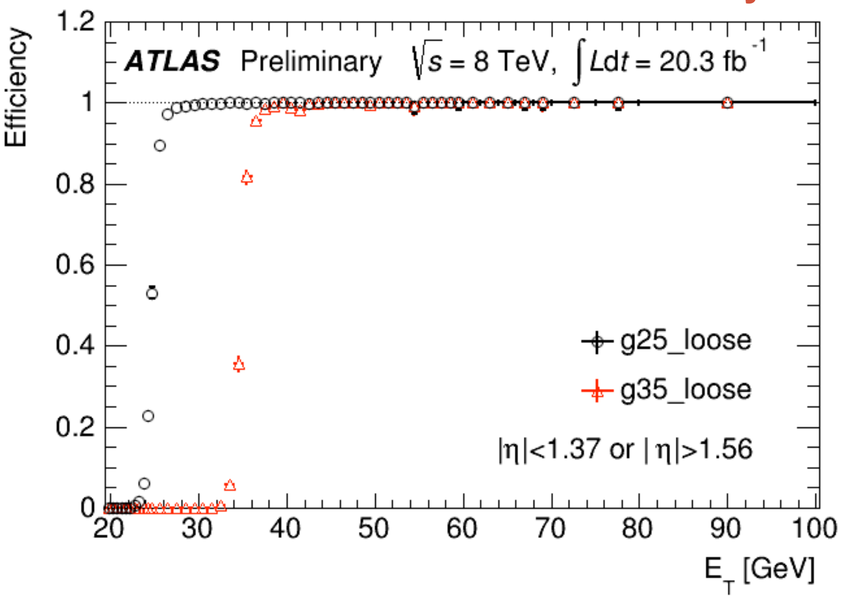


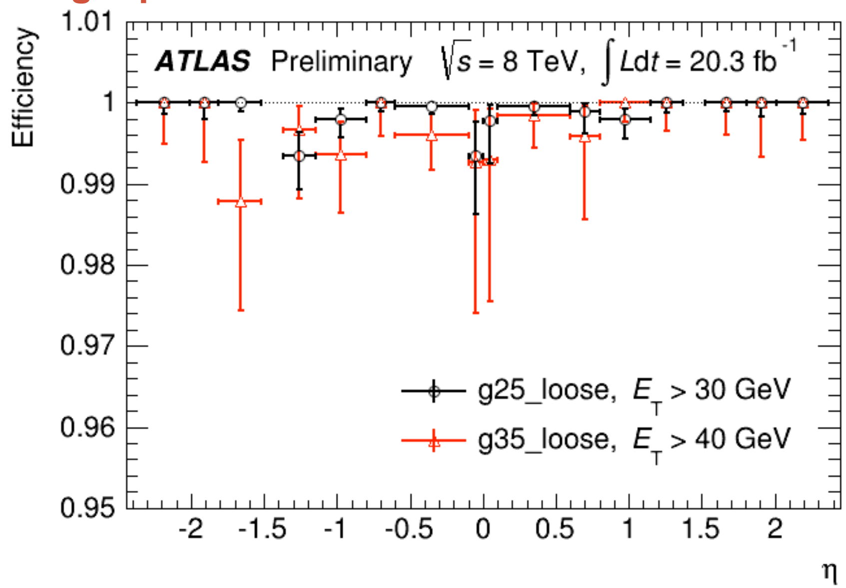


2012 results: photon triggers

- Performance measured by two methods:
  - Bootstrap from fully efficient, low threshold L1 item that provides low statistical uncertainties but requires background subtraction
  - Very clean but statistically limited Z→llγ tag-and-probe technique
- Very high efficiency wrt offline selection

Efficiency wrt offline tight photons



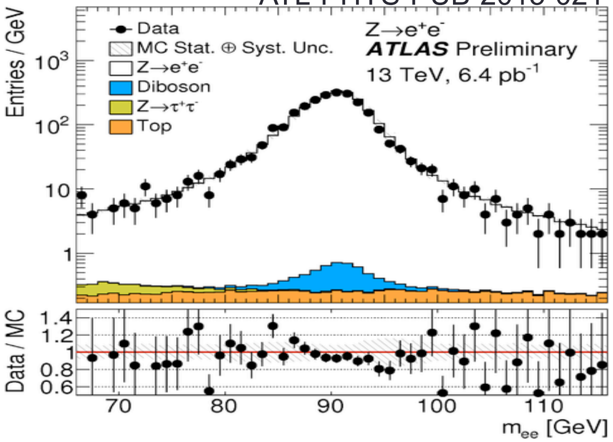


- Main di-photon trigger efficiency (HLT_g35_loose_g25_loose) measured to be 99.5% with 0.15% uncertainty

Conclusion

- Many improvements for Run-2 to keep trigger thresholds at (or close to) Run-1 levels
- Fast commissioning of triggers in 2015 allowed to have first physics results promptly
- Further improvements expected for 2016

ATL-PHYS-PUB-2015-021



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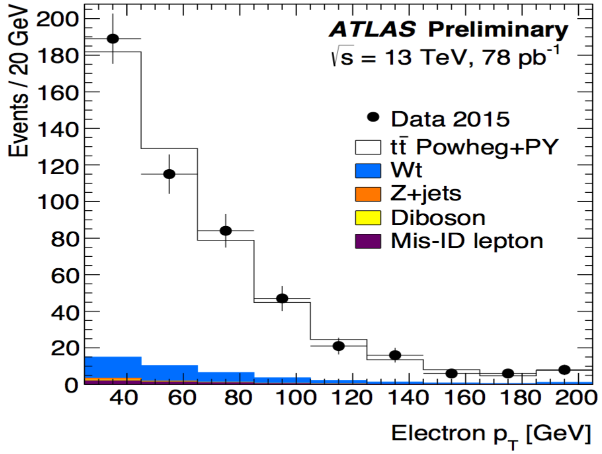

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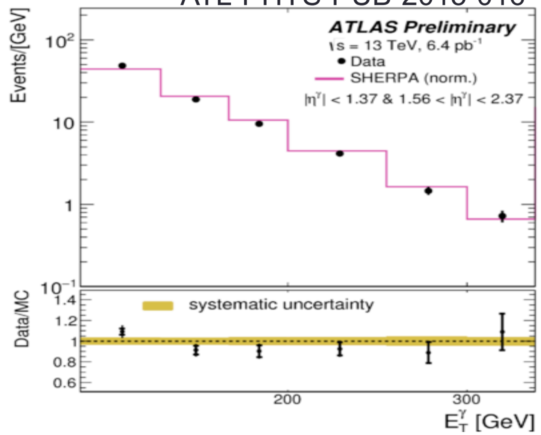
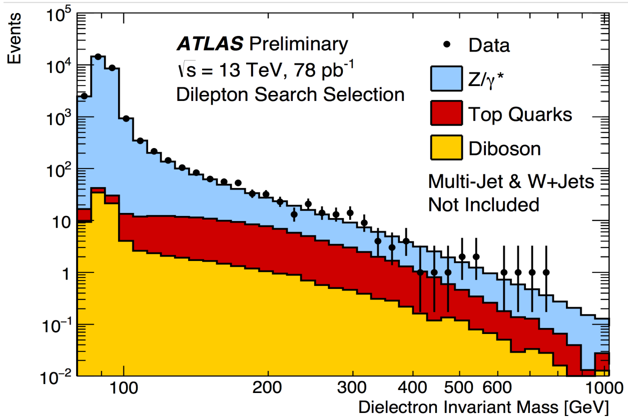
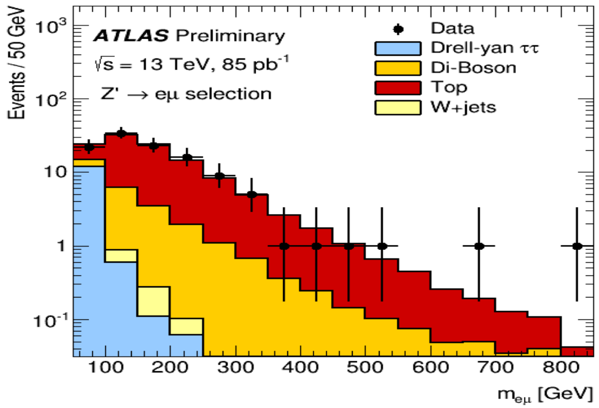
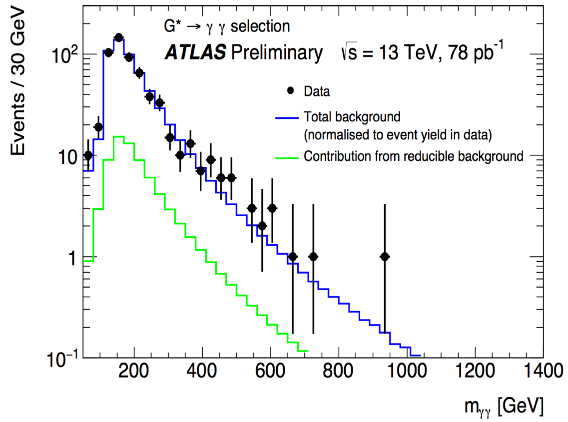


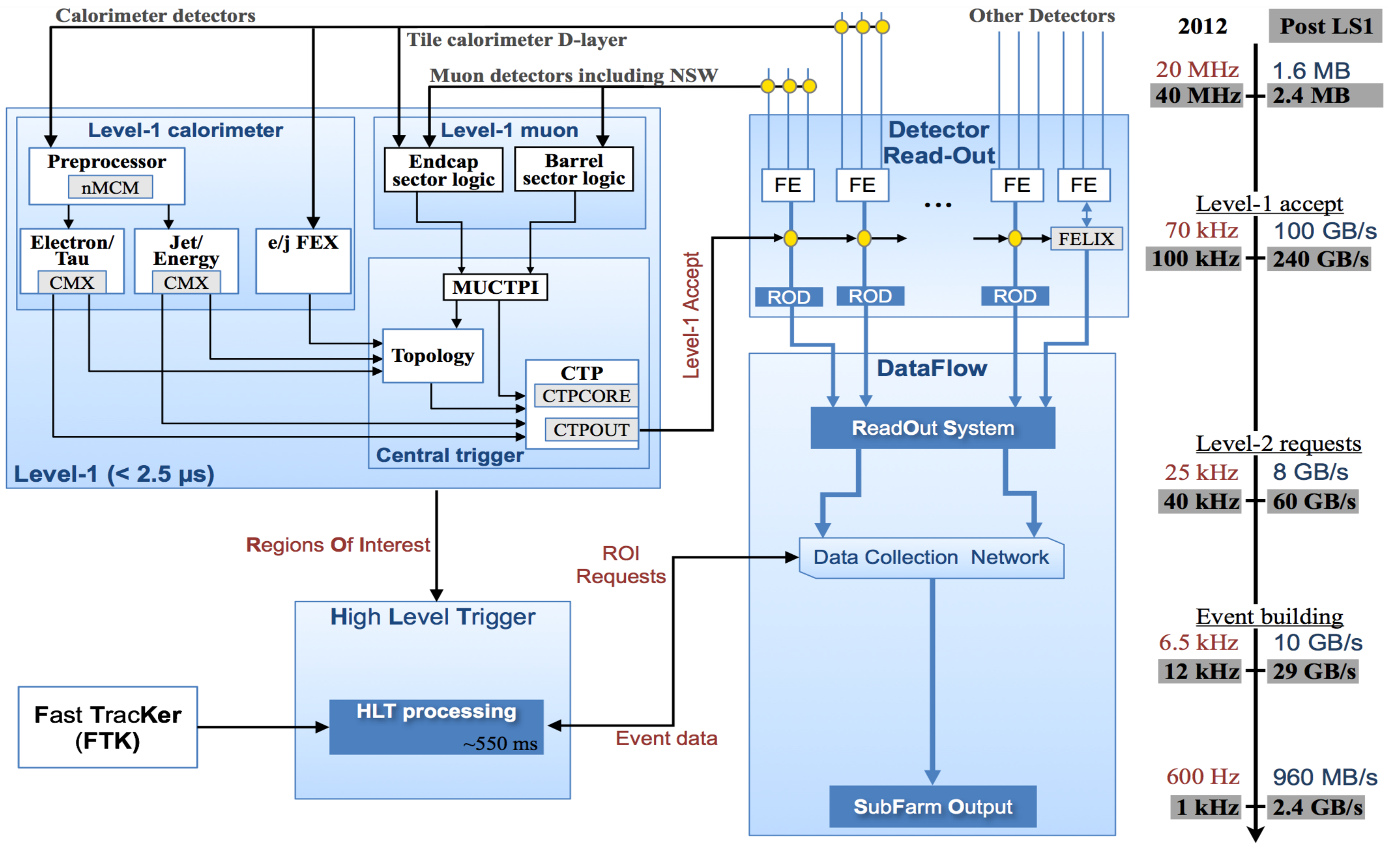






Extra

The trigger system from Run-1 to Run-2

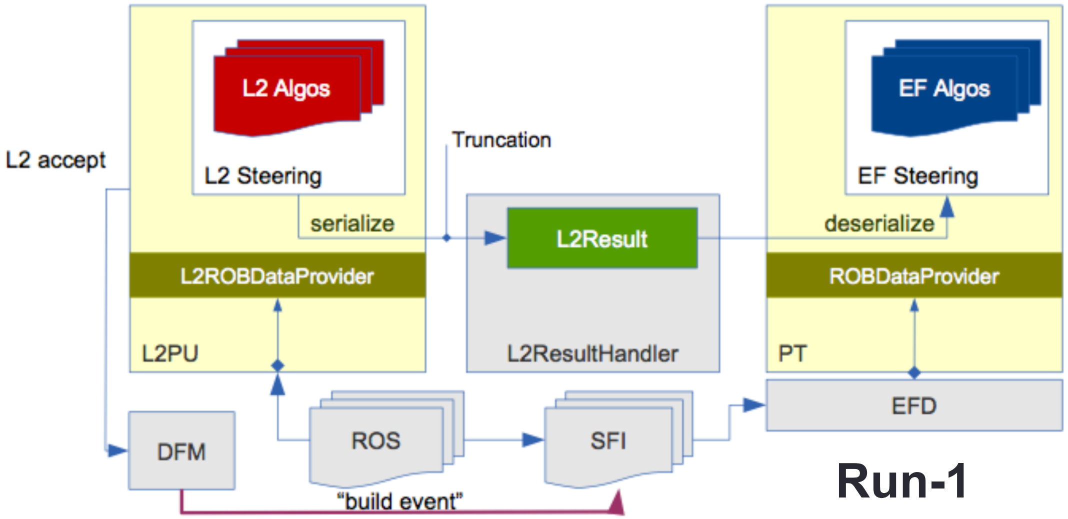


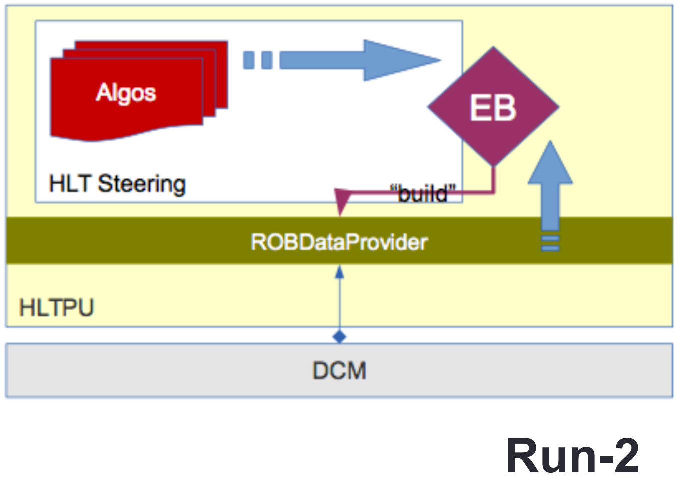
For more details see talk by Kevin Black

- **Upgraded L1 calorimeter** and muon **trigger** systems
- New L1 **Topological Trigger Processor**
- New Central Trigger Processor with # of output bits doubled to 512
- Upgraded detector read-out to **raise peak L1 output rate** from 70 to 100 kHz
- New **hardware Fast TracKer** operating at 100 kHz providing tracks in 100 ms to HLT (partial system in parasitic mode in 2015, full system by end of 2016)
- **Merged L2 and EF computer farms** allowing to apply offline-like selection earlier
- Additional Sub-Farm Output to allow **higher HLT output rate** (limited to 1.1 – 1.5 kHz by storage capacity)

The High Level Trigger

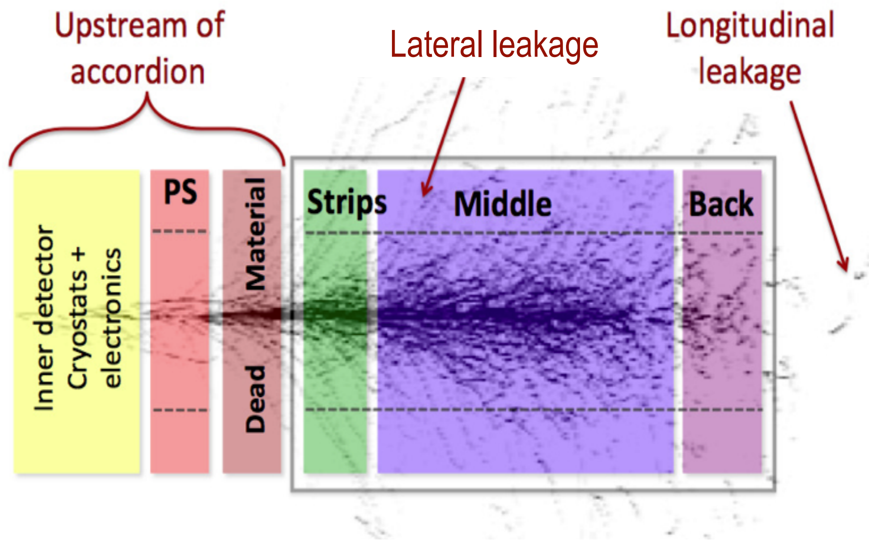
- Run-1: Level-2 + Event Filter
- Run-2: merged HLT
  - Reduced complexity, more flexibility
  - Common data-preparation more resource efficient
  - Average processing time ~0.2 s
  - Offline-like reconstruction and selection can n applied earlier
  - Online / offline harmonisation improves selection efficiency, reduces code duplication
- Main changes for e/γ triggers: improved tracking, new energy calibration, likelihood electron identification

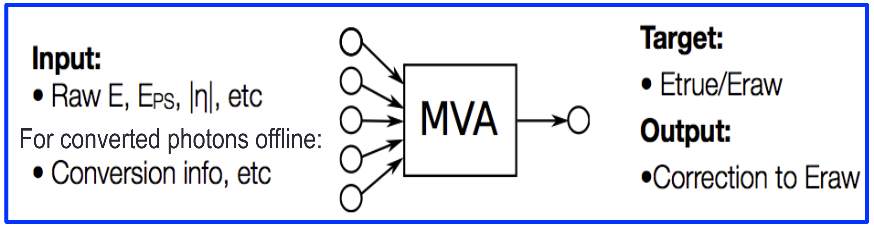


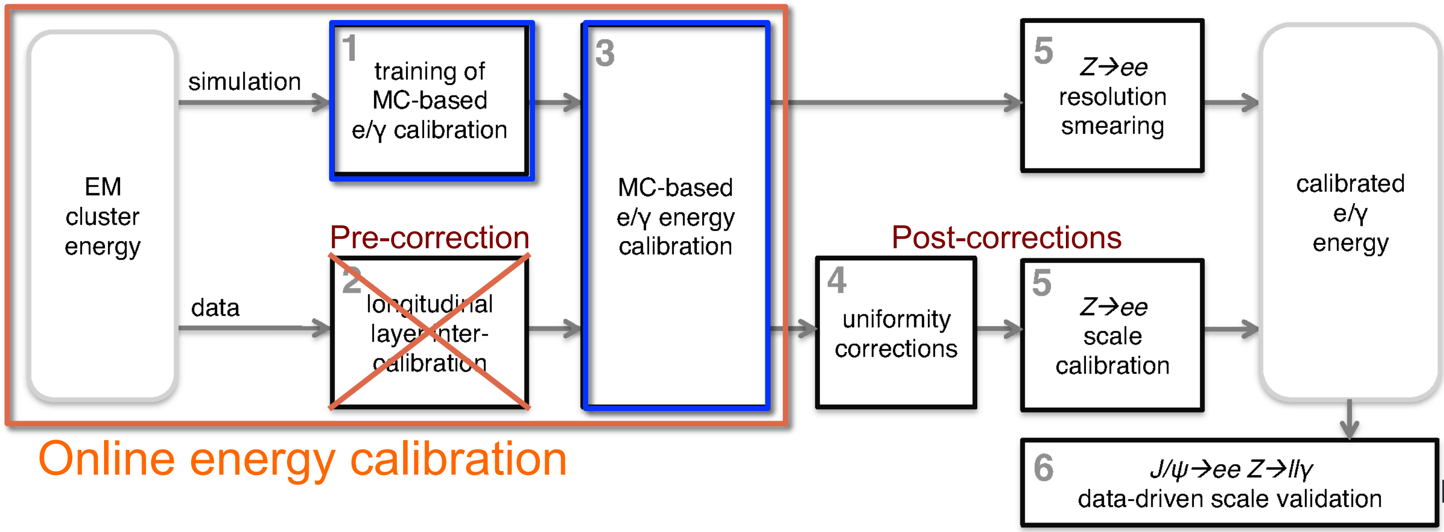


Cluster energy calibration

- Adopt a simplified version of the new offline energy calibration
- New MC-based calibration relies on a boosted decision tree
  - Electron and photon calibration tunes separate
  - Photons not separated to converted and unconverted categories (major source of difference wrt offline)
- No data-driven pre- and post-corrections online







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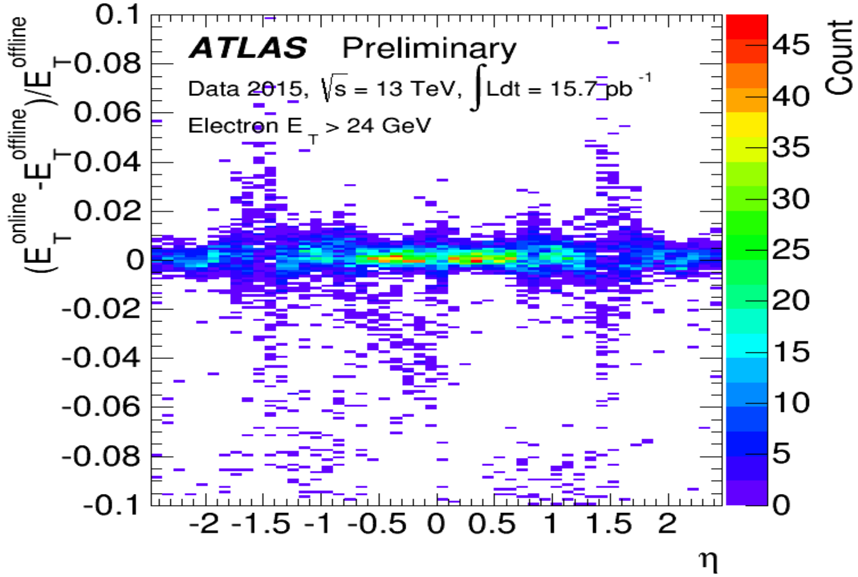
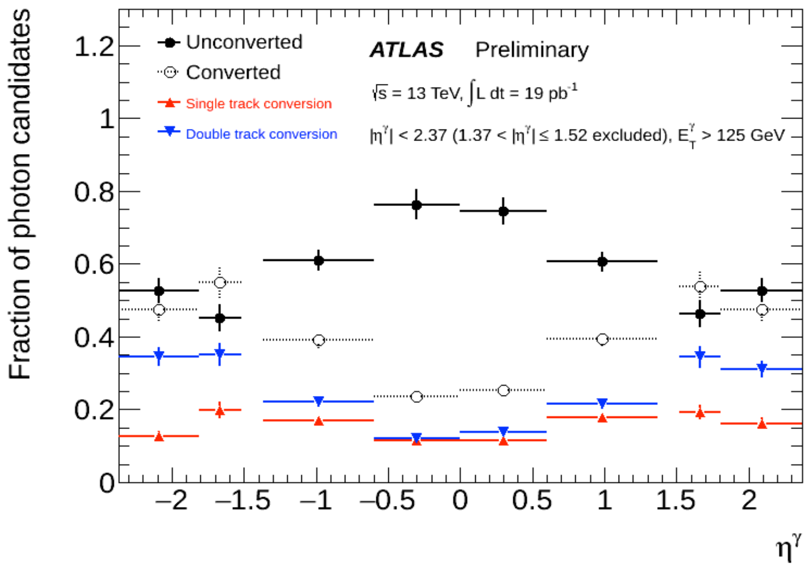
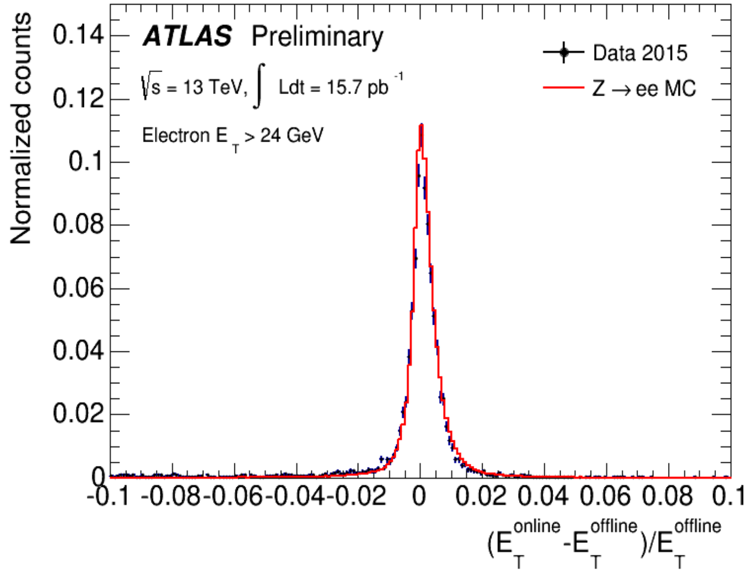
Cluster energy calibration performance

- Adopt a simplified version of the new offline energy calibration
- New MC-based calibration relies on a boosted decision tree
  - Electron and photon calibration tunes separate
  - Photons not separated to converted and unconverted categories (major source of difference wrt offline)
- No data-driven pre- and post-corrections online
- Good energy resolution
  - Further improvement for converted photons could be achieved by running conversion reconstruction at HLT, especially in the endcap (|η|>1.52) region

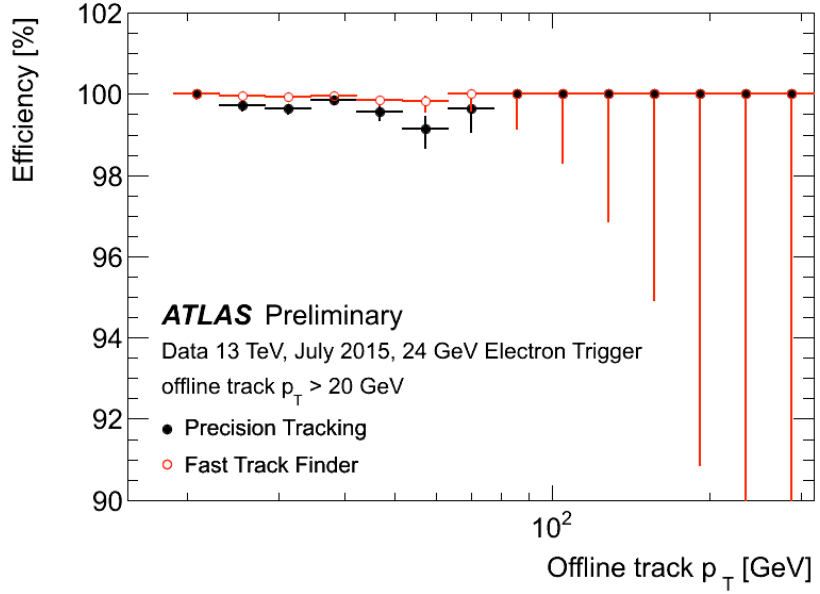


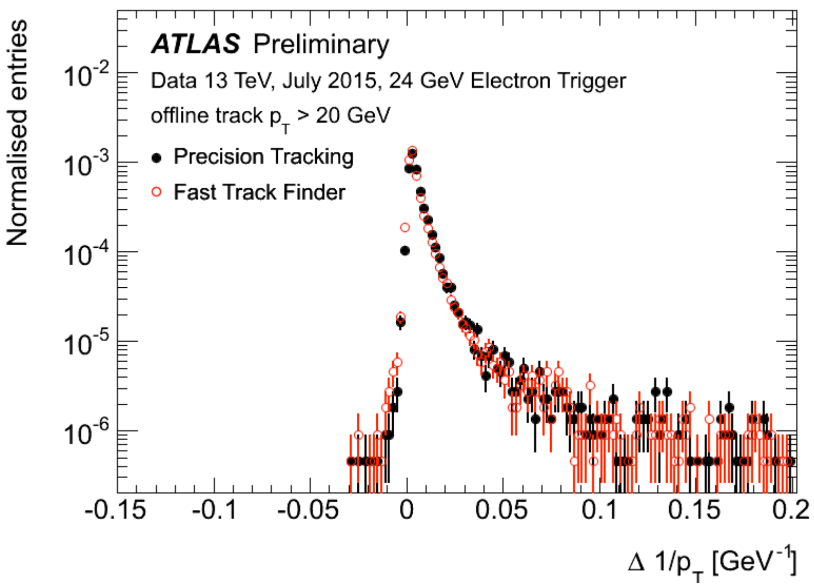


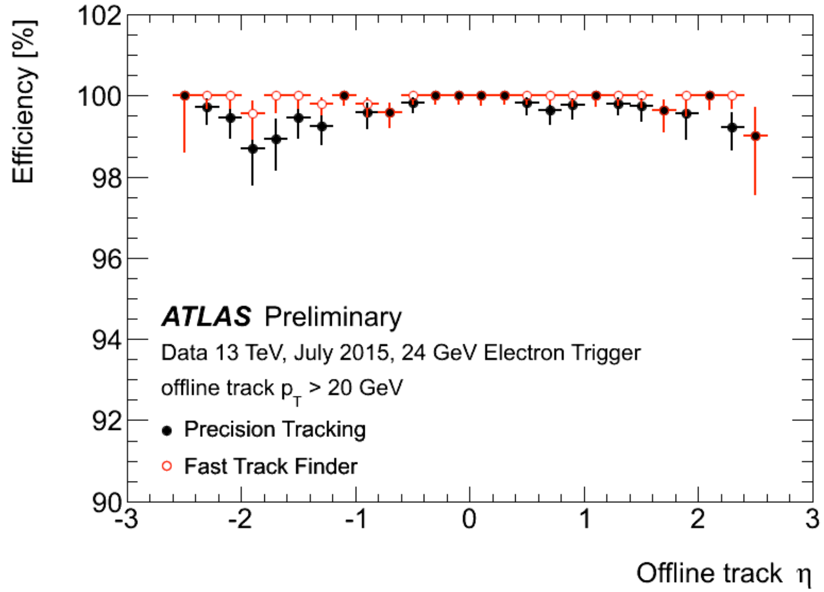


Online electron tracking performance

- High efficiency
- Momentum resolution vs offline has high positive tail due to no Bremsstrahlung correction online

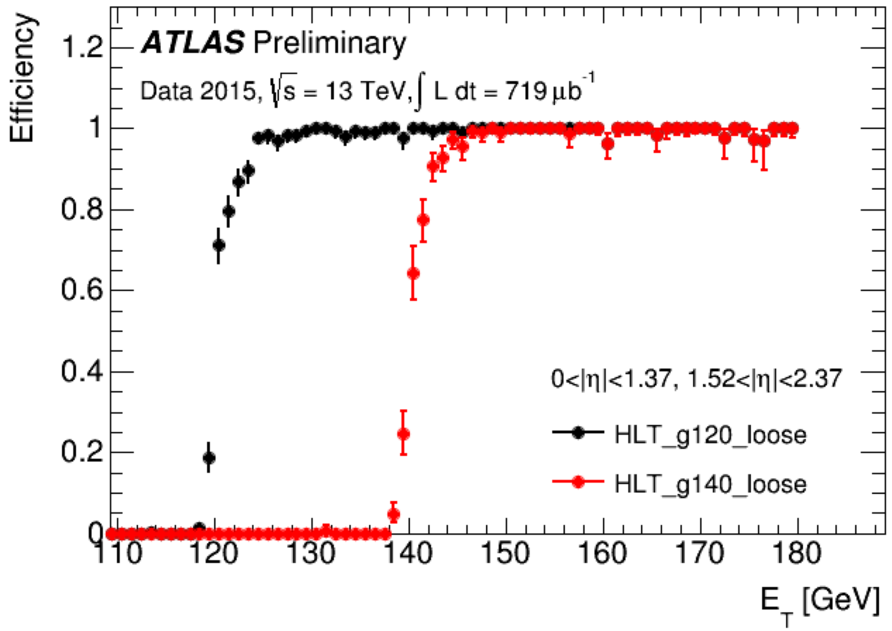


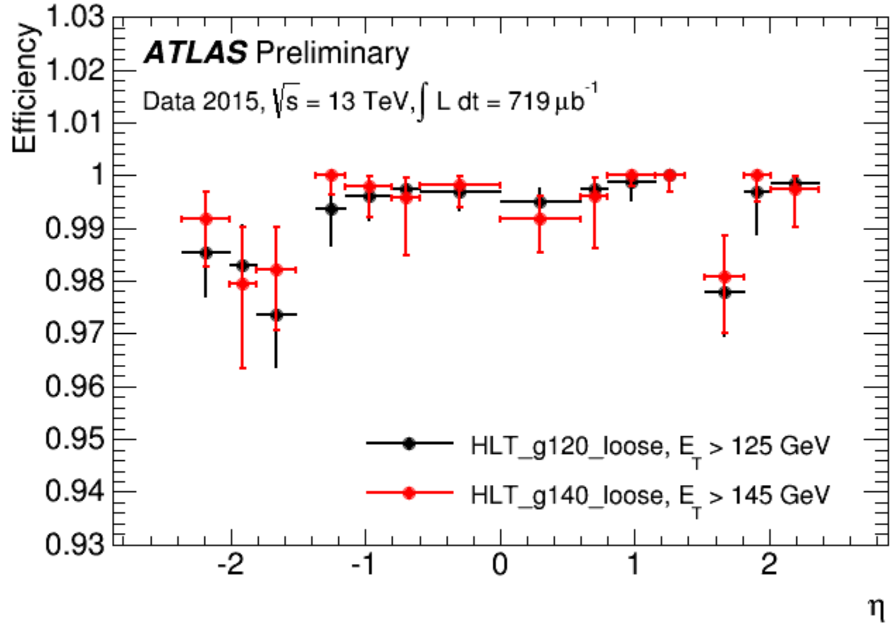




Lowest E_T unprescaled photon trigger

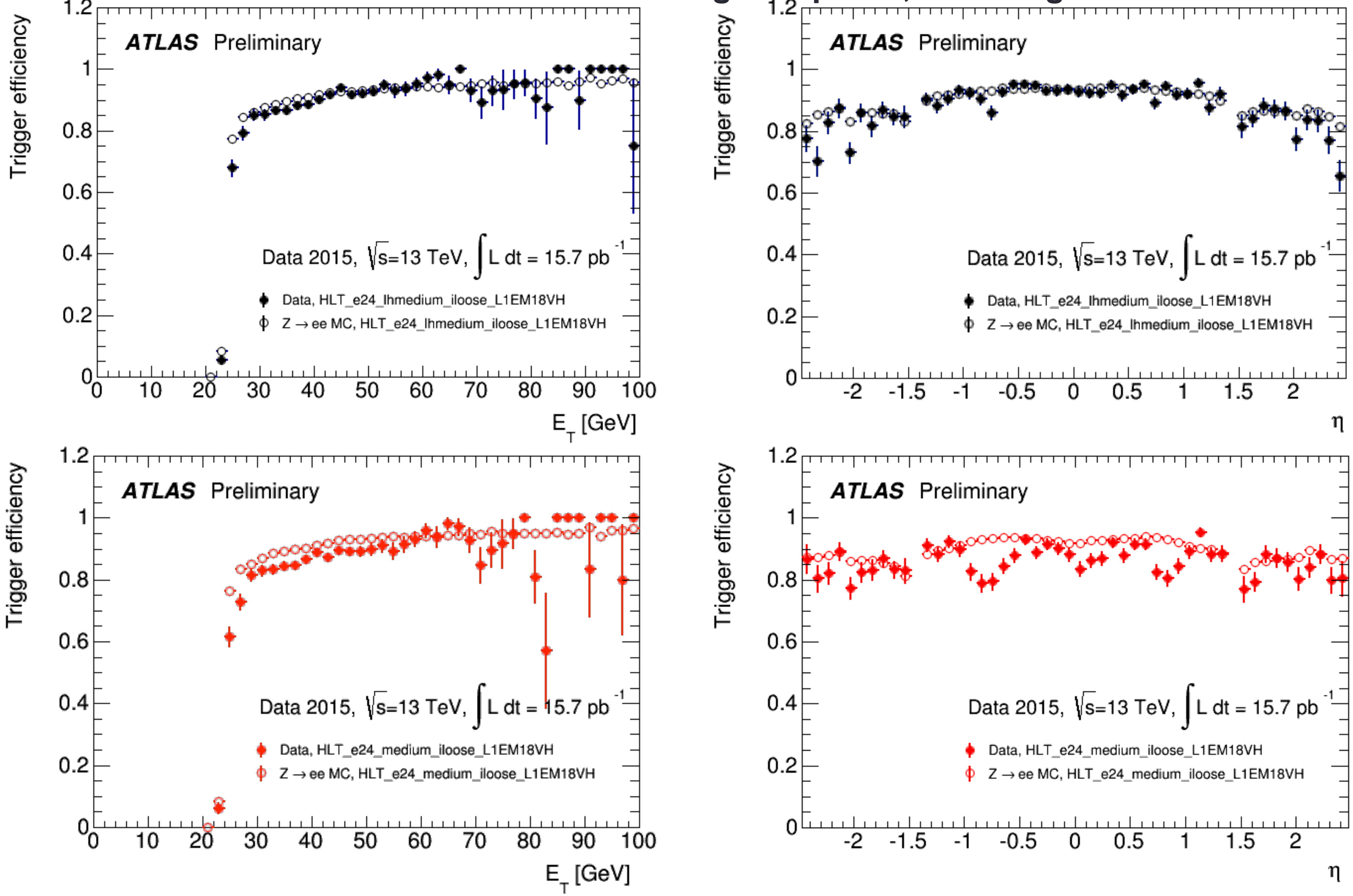
- Run-1: g120_loose
- Run-2: g120_loose up to @ L = $0.5 \cdot 10^{34}$ cm^{-2}s^{-1}
  g140_loose up to @ L = $2.0 \cdot 10^{34}$ cm^{-2}s^{-1}





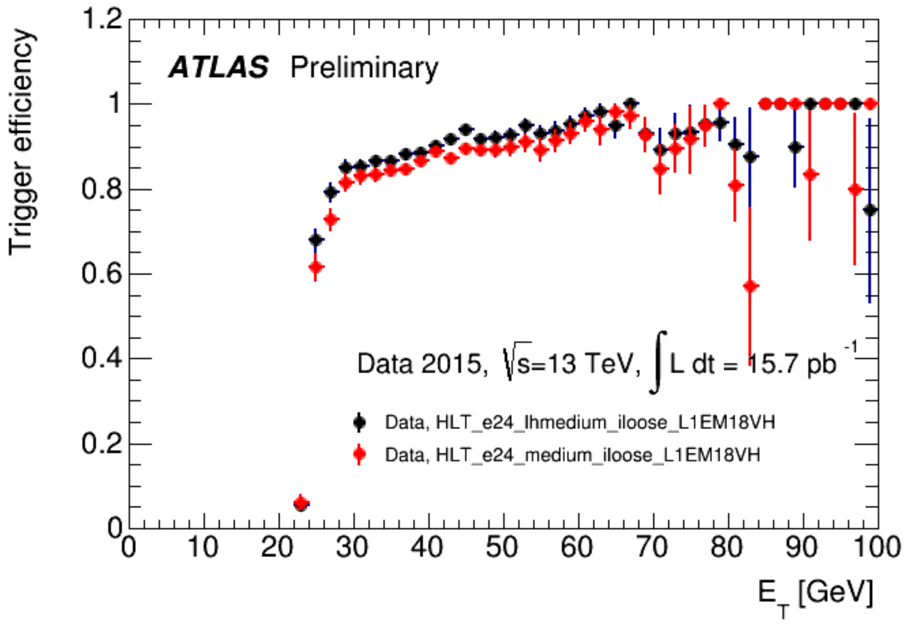
2015 electron trigger performance: data vs MC

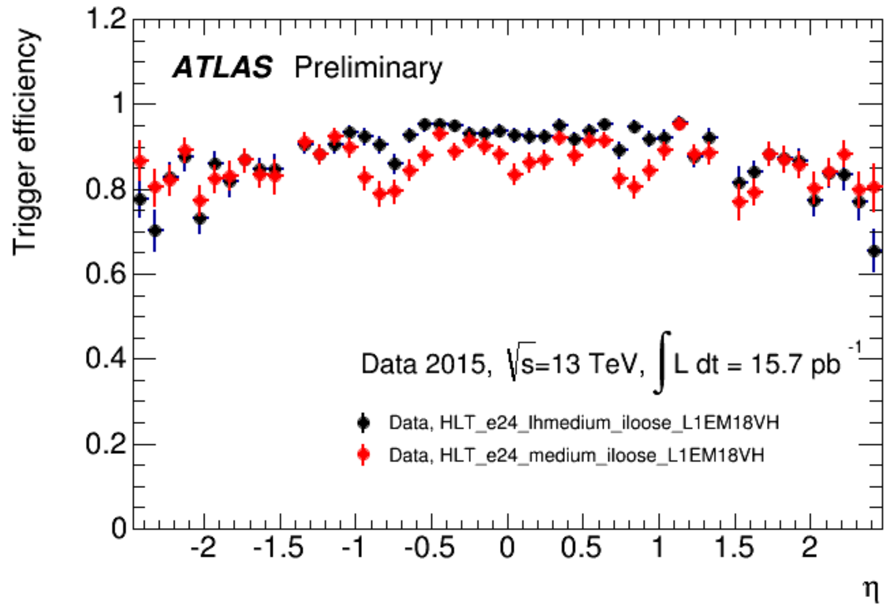
Z→ee tag-and-probe, no background subtraction



2015 electron trigger performance: cut-based vs. likelihood in data

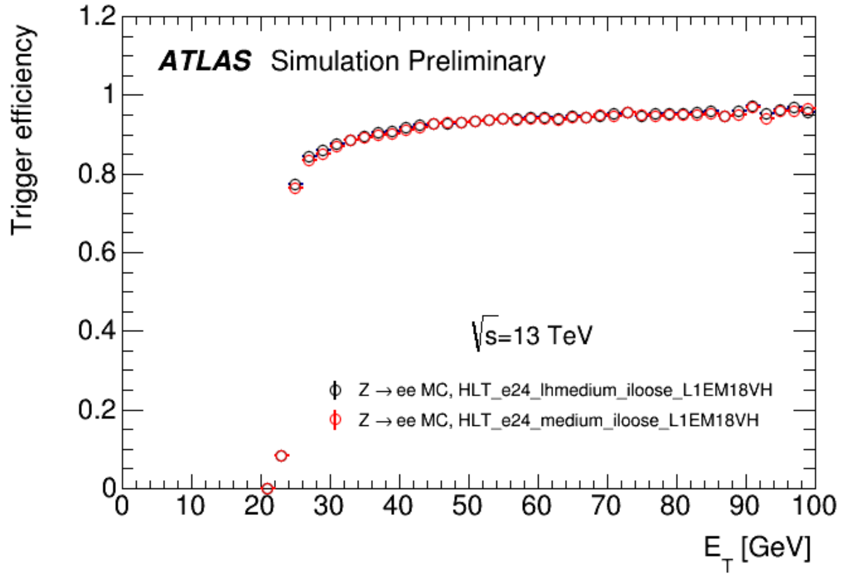
Z→ee tag-and-probe, no background subtraction

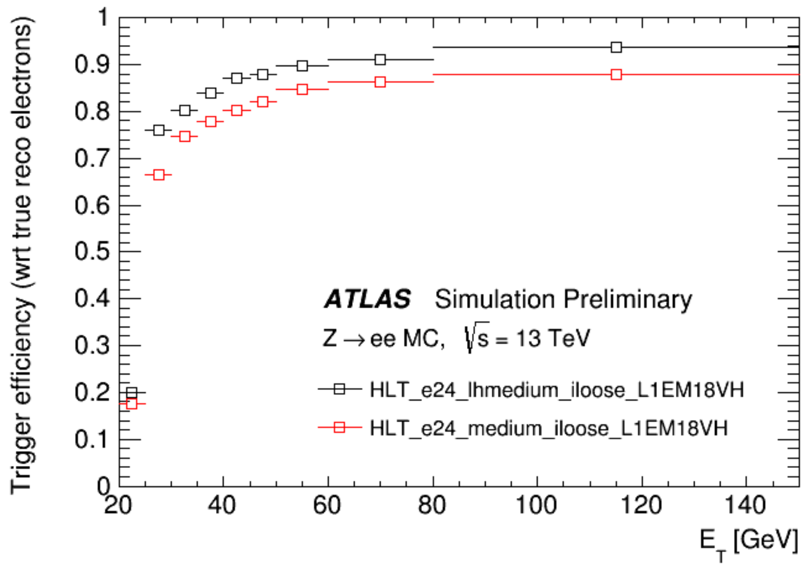


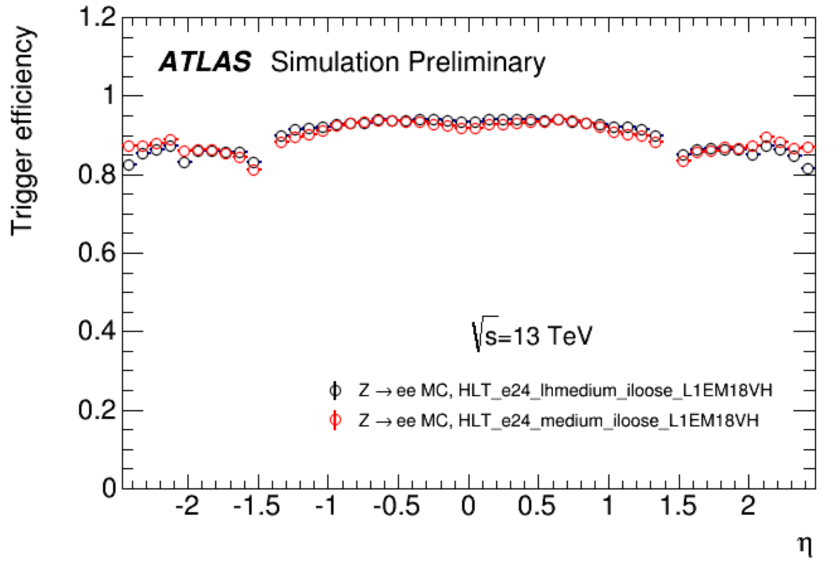


2015 electron trigger expected performance

- Can afford higher efficiency wrt true electrons for same ID working point (tightness)
- Very similar expected efficiency wrt corresponding offline ID

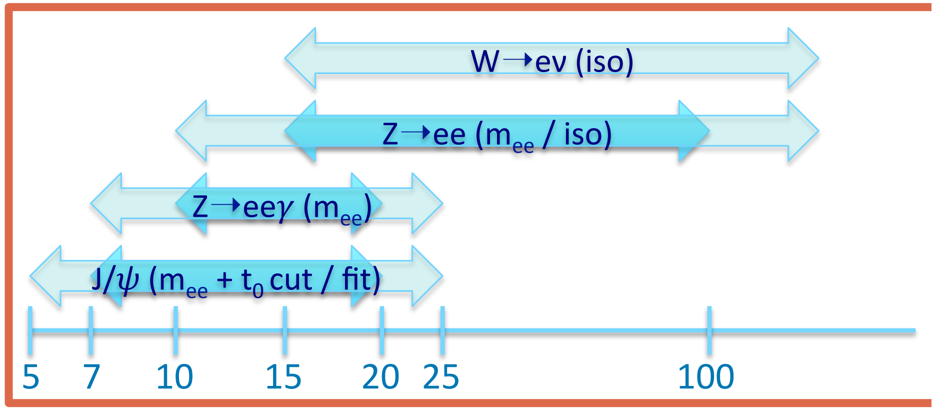


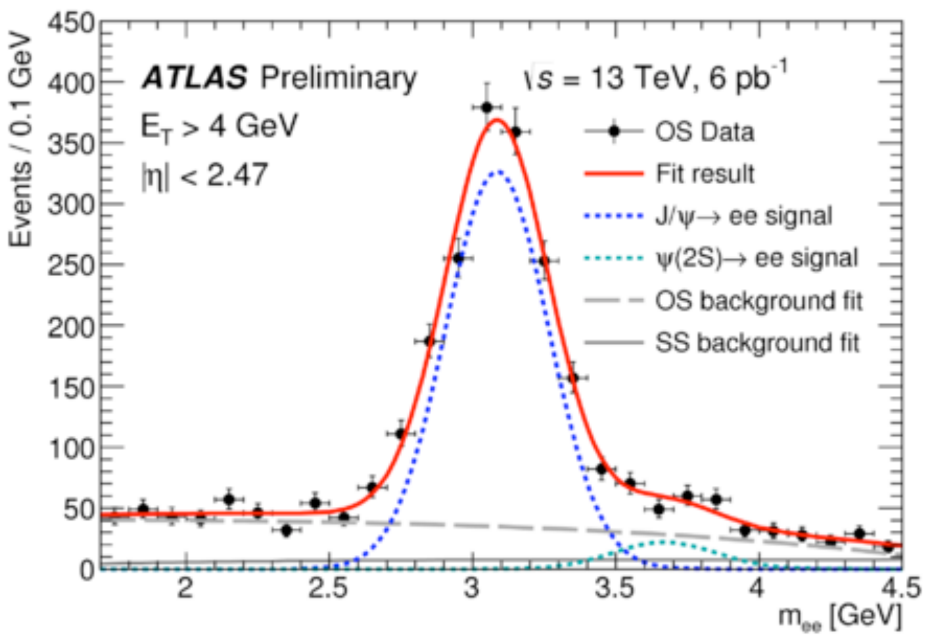




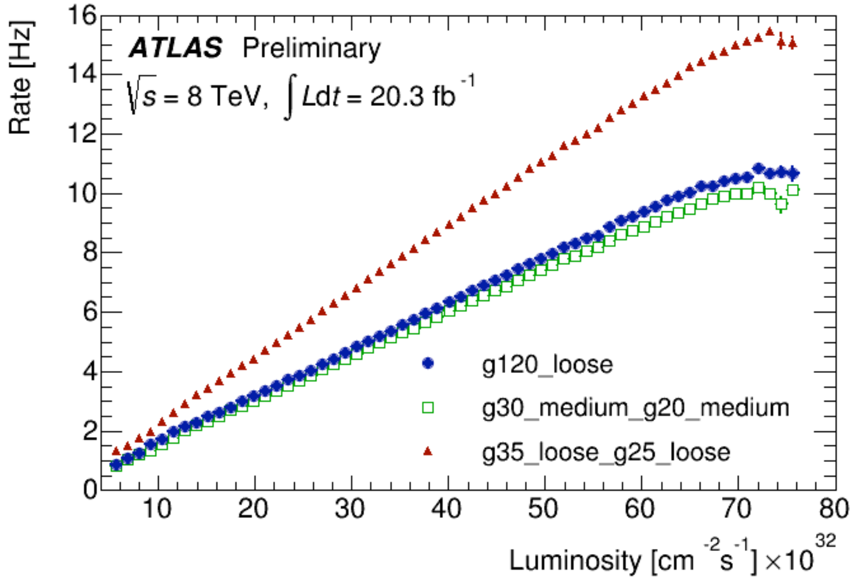
Supporting triggers

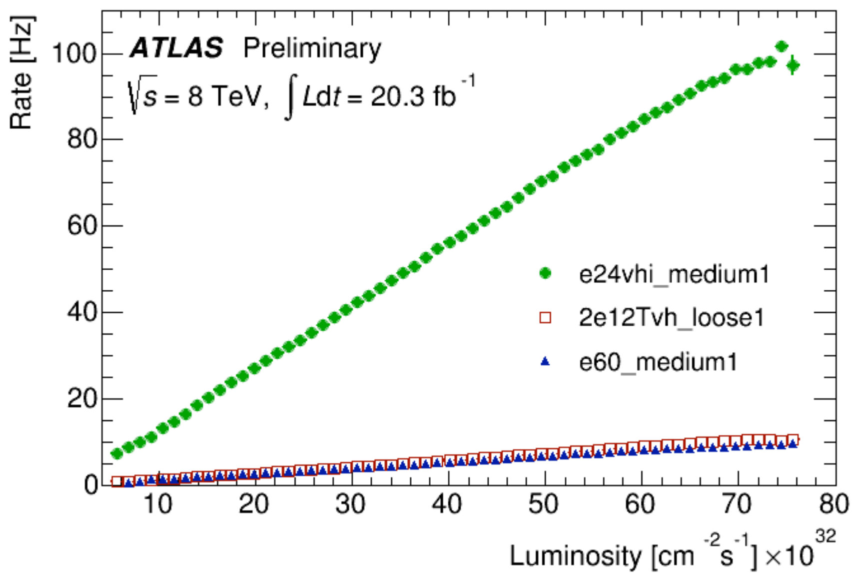
- Collect calibration data
- Tag-and-probe triggers for electron performance studies
- J/ψ → ee : "tight" e + "reco" e
  - ee system close to $m_{J/\psi}$
- W → eν: $E_{T,missing}$ + "reco" e
  - m_T(eν) consistent with m_W
  - significant and isolated $E_{T,missing}$
- Topological selections already at L1 (in Run-1 at HLT only)
-



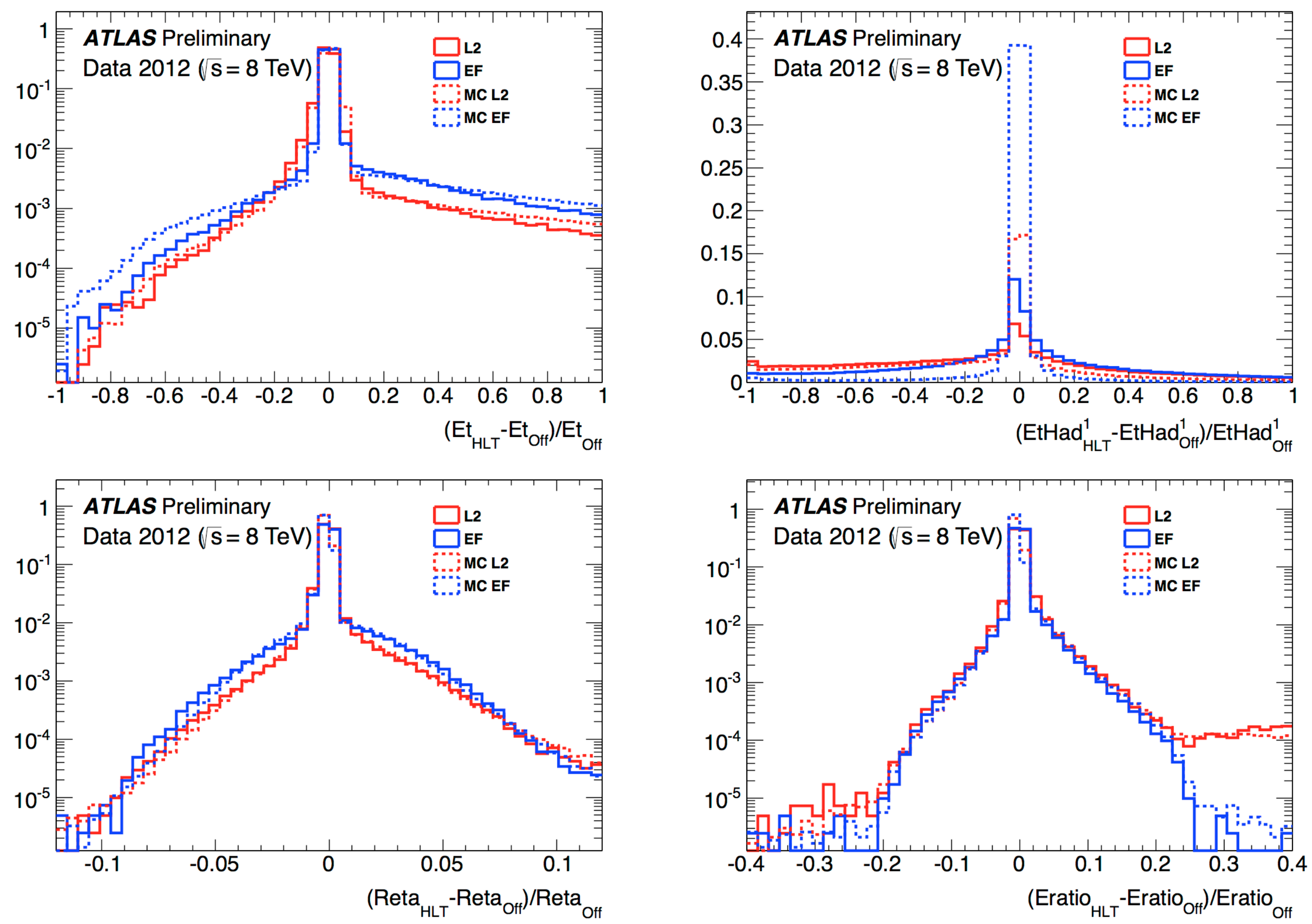


2012 trigger rates



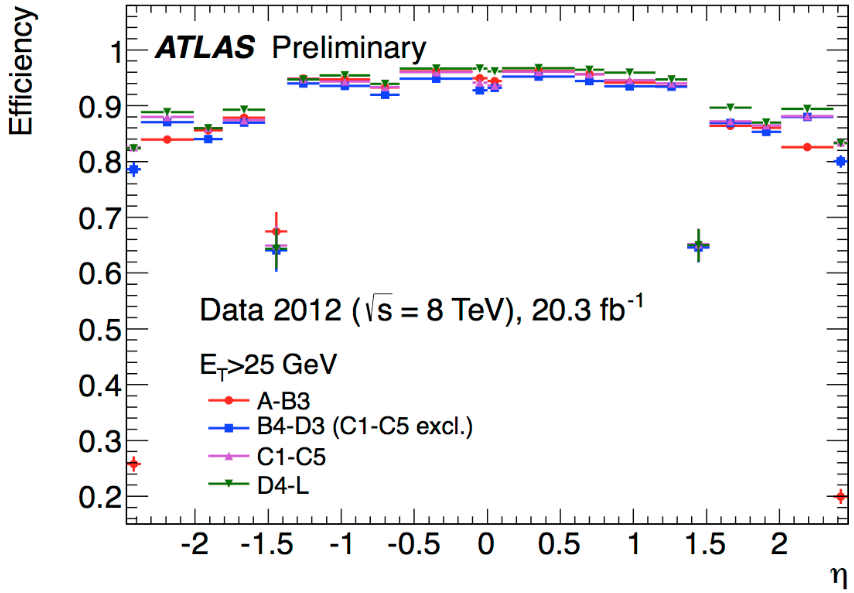


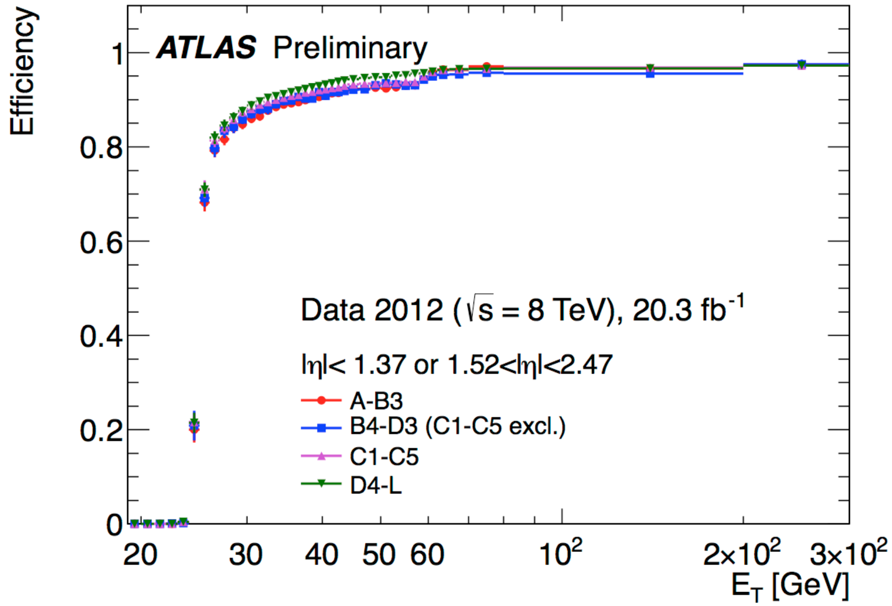
2012 trigger reconstruction resolution



Improving the trigger performance

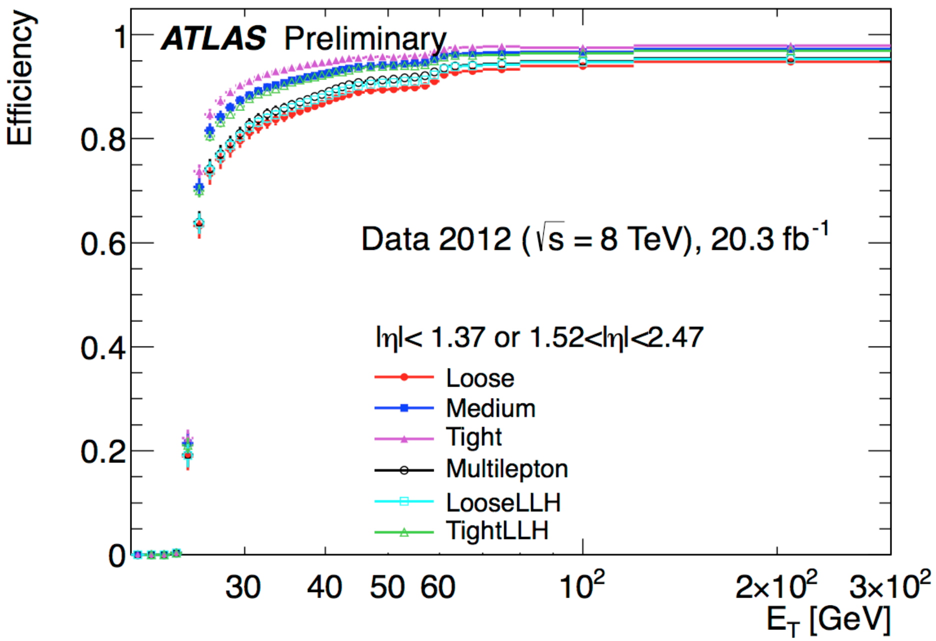
- Through out data taking, trigger performance improved in 2012

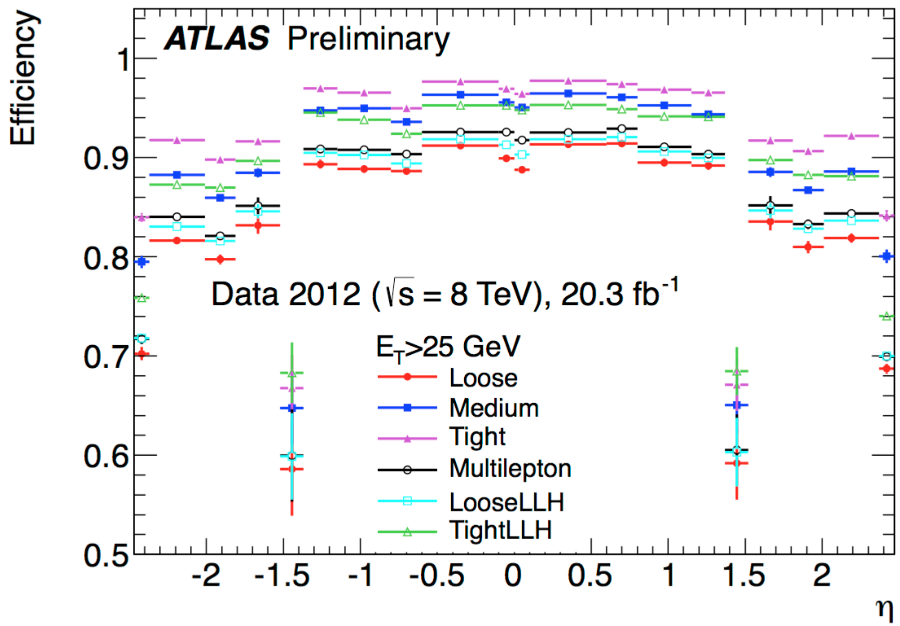




- Main focus now: understand and fix inefficiencies
- First improvements in 2015 already available
  - Improved Inner Detector – Calorimeter inter-alignment
  - New LH tune with improved input variable probability distribution functions

Trigger efficiency vs. offline selection

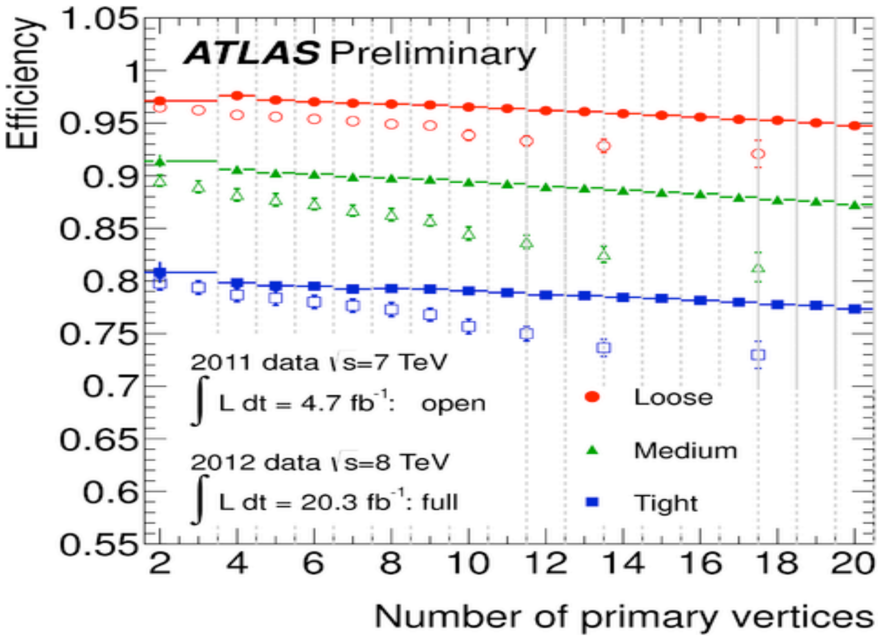




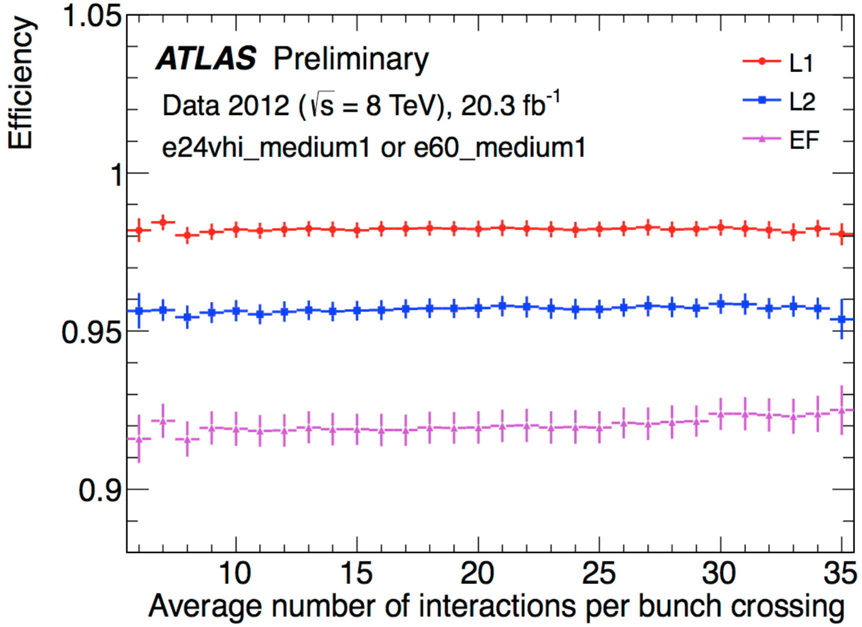
Pile-up dependence

- Offline efficiency shows slight pile-up dependence
- Trigger efficiency wrt offline is stable

Offline ID with respect to reconstruction



Trigger wrt offline identified objects



- Electron LH identification applies pile-up correction in 2015

Relative EM ring isolation