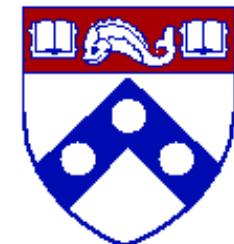




Electrons and photons at ATLAS

Sarah Heim, University of Pennsylvania

ICHEP, August 6th 2016

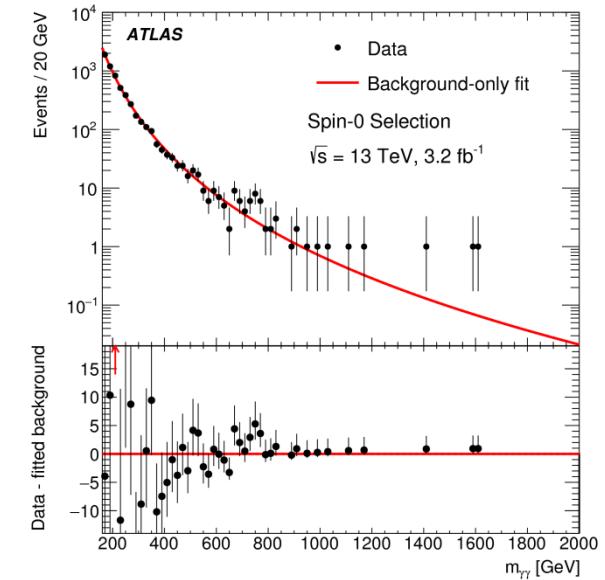
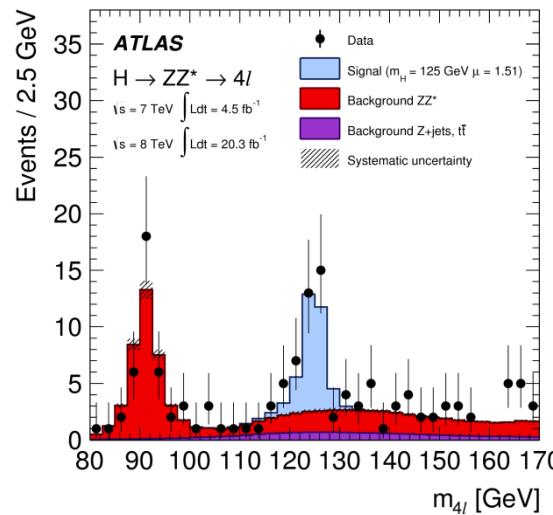
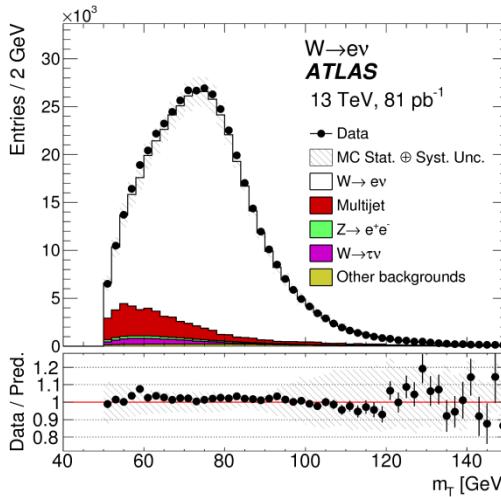


ATLAS



Why this is important

Electrons and photons are excellent probes for interesting signatures in proton-proton collisions



Precision electroweak

Higgs discovery

New physics?

Crucial for all analyses:

- high efficiencies, good background rejection and energy calibration
- precise understanding of performance



Reconstruction and backgrounds

Electrons: Energy cluster and matching track

Photons: Energy cluster without track
or matched to track(s) from conversion vertex

Special track reconstruction for electrons with

Bremsstrahlung: possible energy loss at every surface point

Conversion reconstruction:

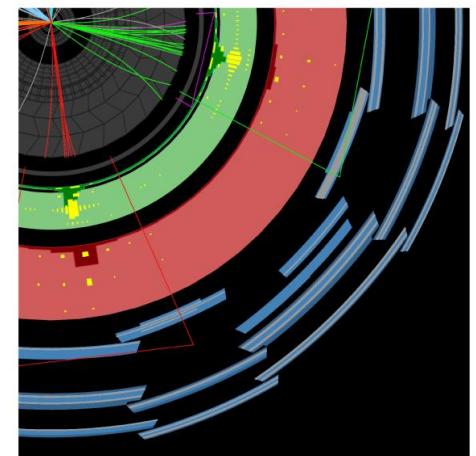
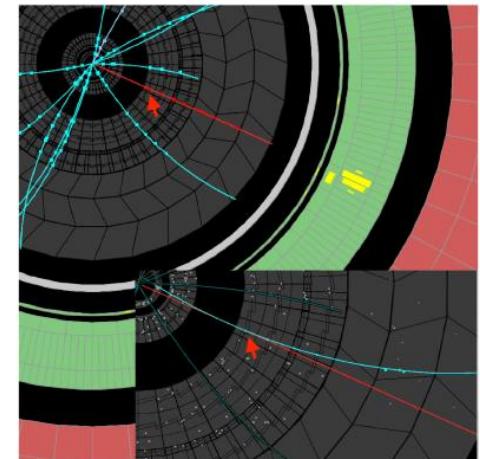
double tracks and single tracks included to improve efficiency

Background objects:

Electrons: hadronic jets, heavy flavor electrons, photon conversions

Photons: hadronic decays with photons, hadronic jets, electrons

→ drastically reduced by applying identification and isolation algorithms



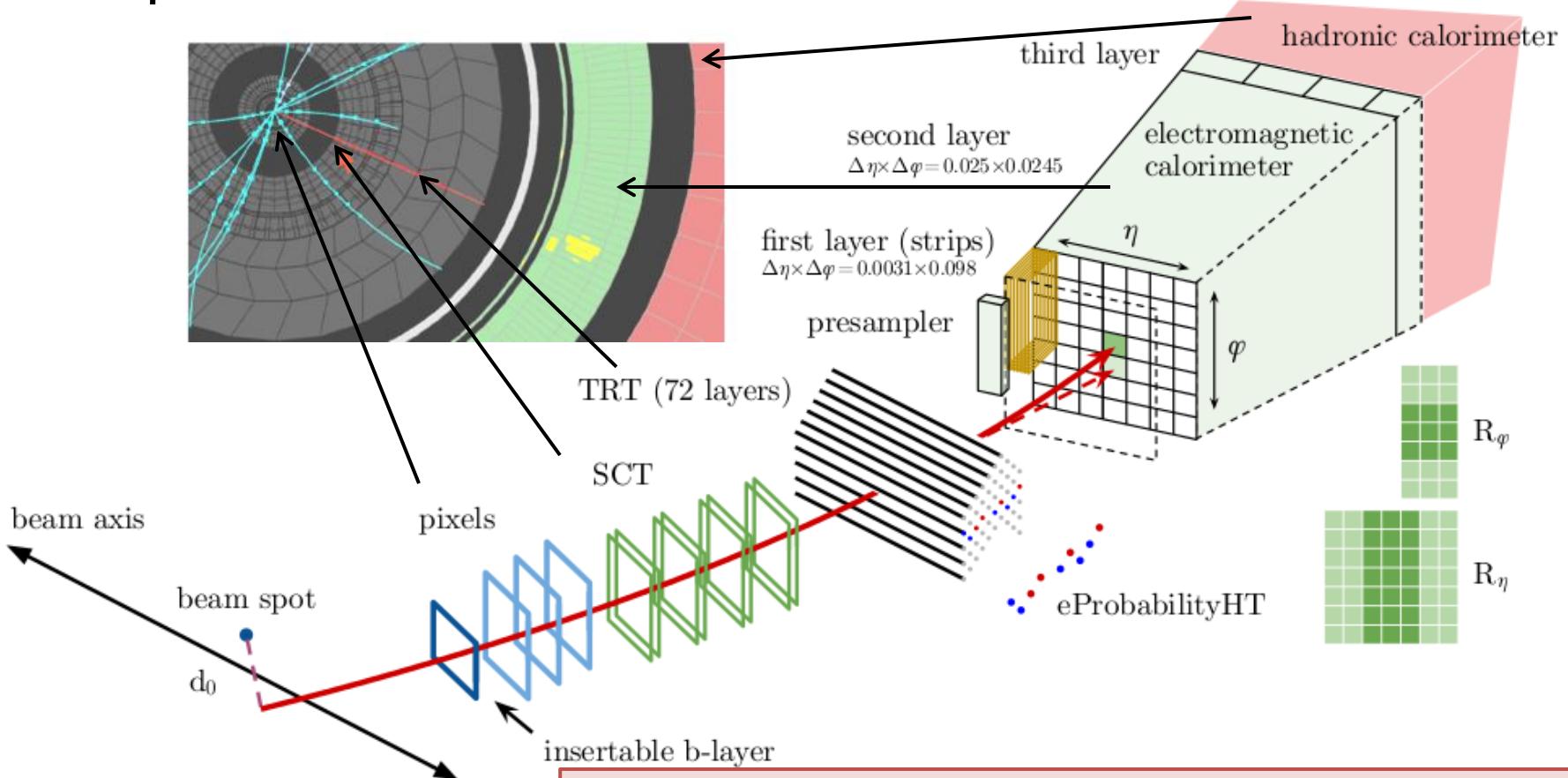


Identification

Based on discriminating variables

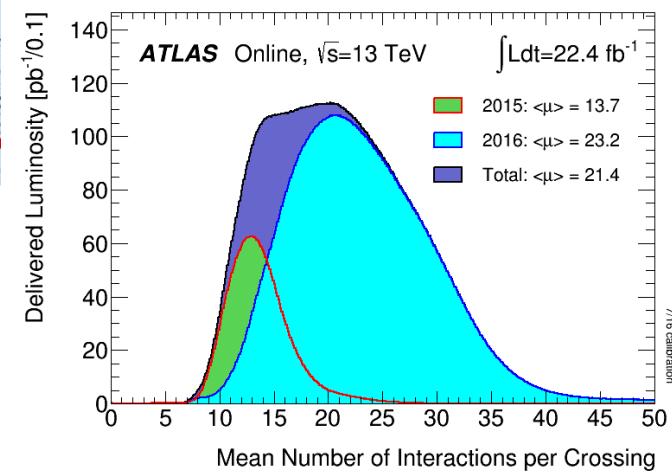
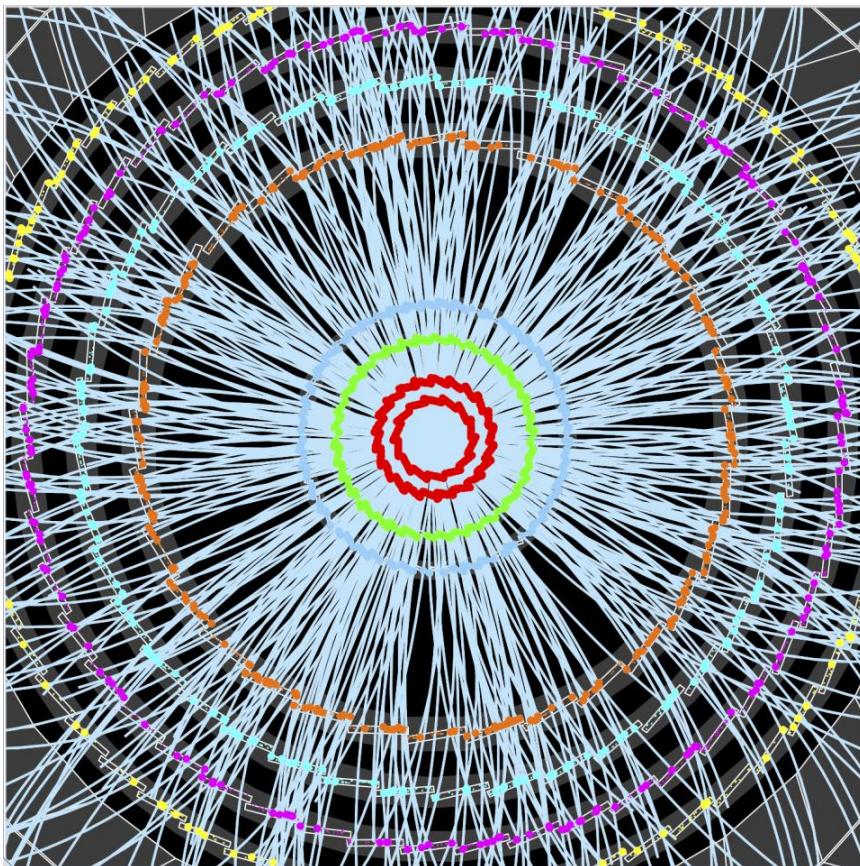
see also poster by Leonor Alberich

Example electron:



Run 2: Argon instead of Xenon in parts of the TRT due to leaks
 → reduces discrimination power between electrons and hadrons, so far fixed by improved strategy

Multiple interactions per LHC bunch crossing (pileup)



Max. number of interactions

2016: ~50

High-Luminosity LHC: 140 – 200

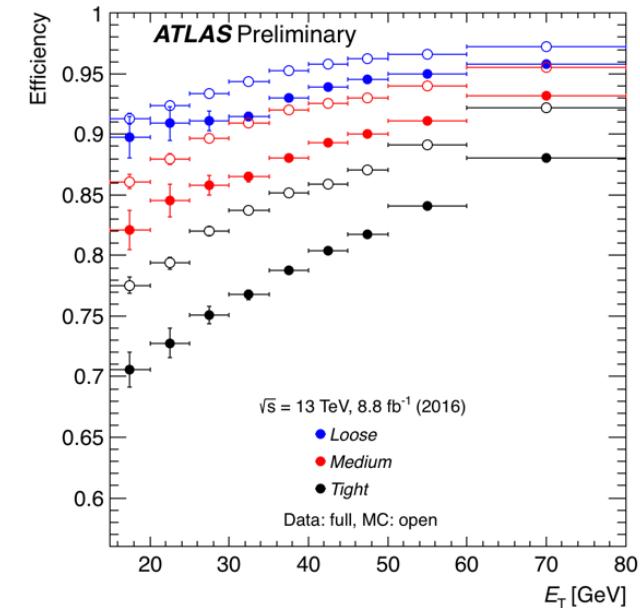
→ big challenge for e/γ identification, degrades discriminating variables



Identification – electrons

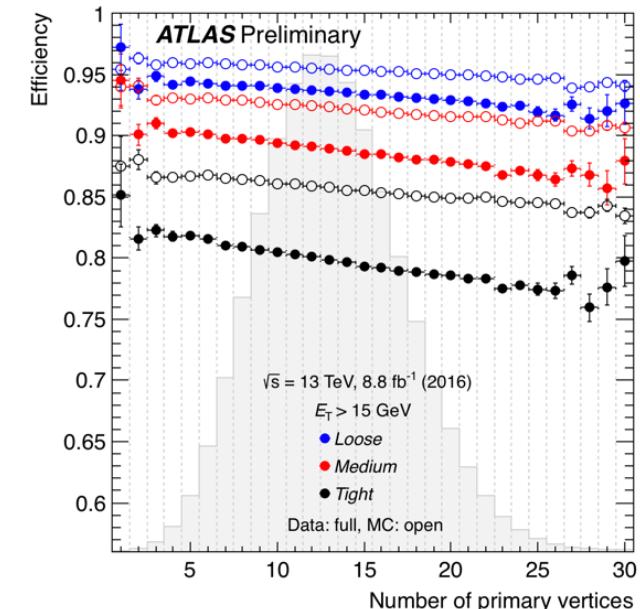
Multivariate (loose, medium, tight)

- based on discriminant variables, like shower shapes, tracking properties, track-cluster match
 - η and E_T dependent cuts on a likelihood discriminant, corrected for pileup
 - mismodelling of shower shapes in simulation
- apply data/MC efficiency correction factors



Run 2 improvements:

- likelihood also used in the trigger!
- smoothed vs. transverse momentum
- improvement of efficiencies at high transverse momentum (for searches for heavy resonances)



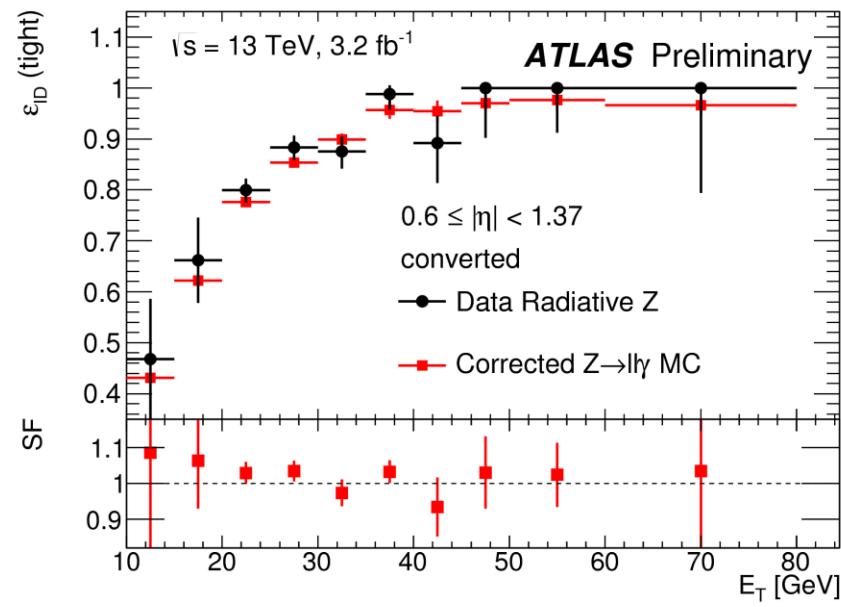
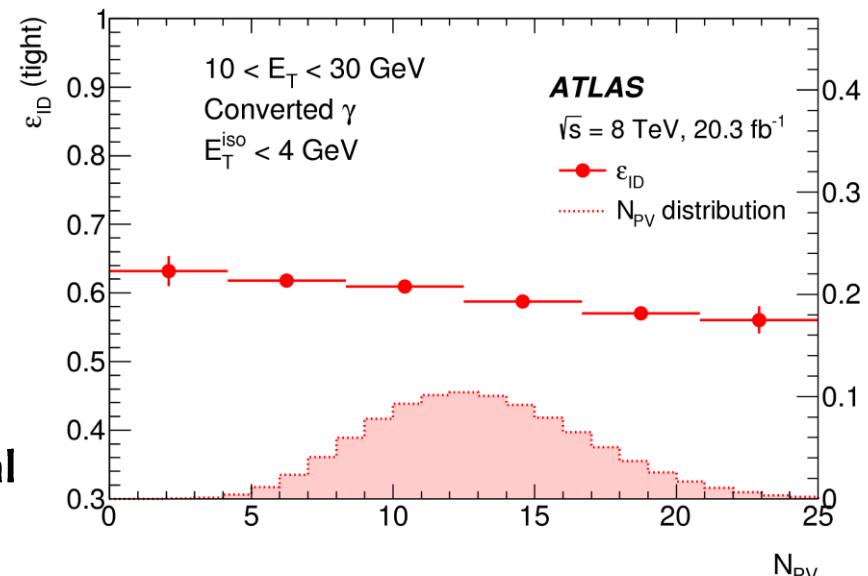
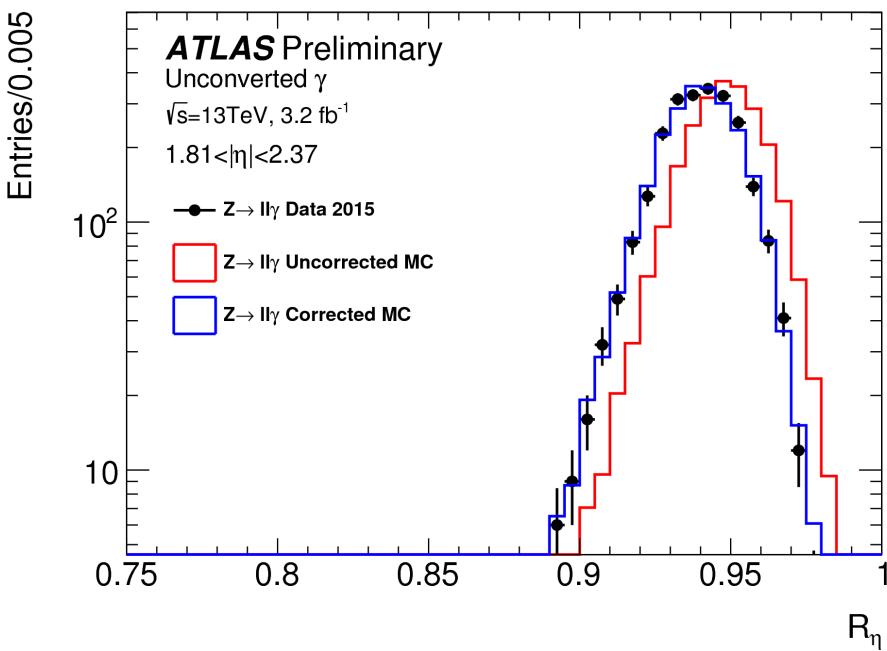


Identification - photons

Cut-based: independent cuts on 9 variables

- in η bins
- tuned separately for converted and unconverted photons
- retuned for expected pileup distribution
- variables corrected in simulation, additional

Data/MC correction factors applied

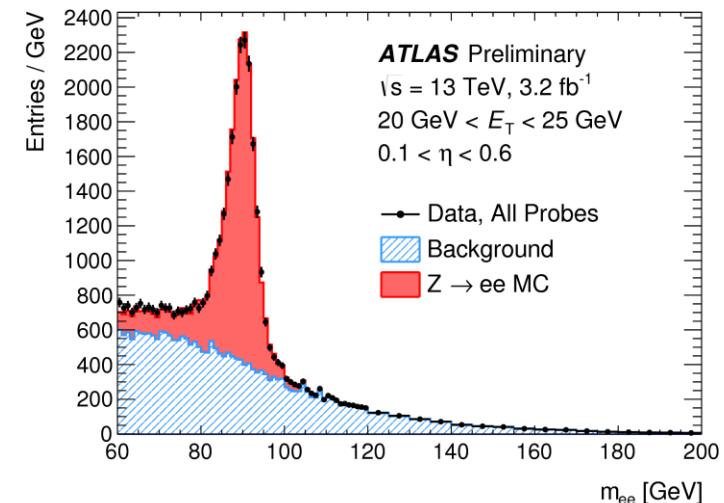




How are efficiencies measured in data?

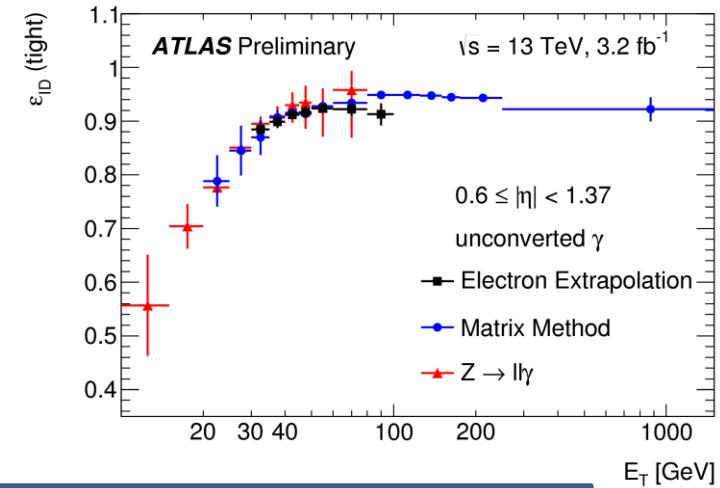
Electrons: Tag & Probe

- Z, J/ Ψ decays to electrons
- strong criteria on event selection, and on one of the electrons
- other electron is the unbiased probe
- non-electron background is subtracted



Photons: More tricks needed

1. Tag & Probe with $Z \rightarrow ll\gamma$ ($l = e, \mu$)
2. Matrix method
3. Electron-photon extrapolation ($Z \rightarrow ee$)



Precision of efficiency measurements in data (Run 1, Run 2)

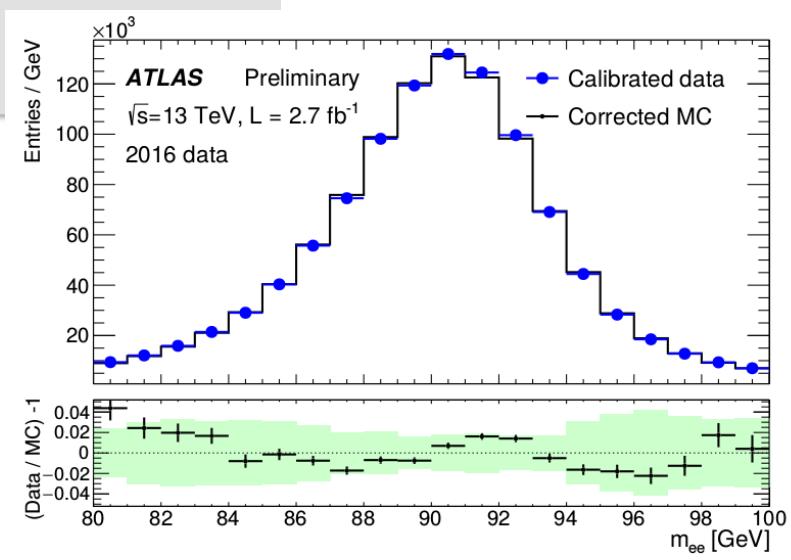
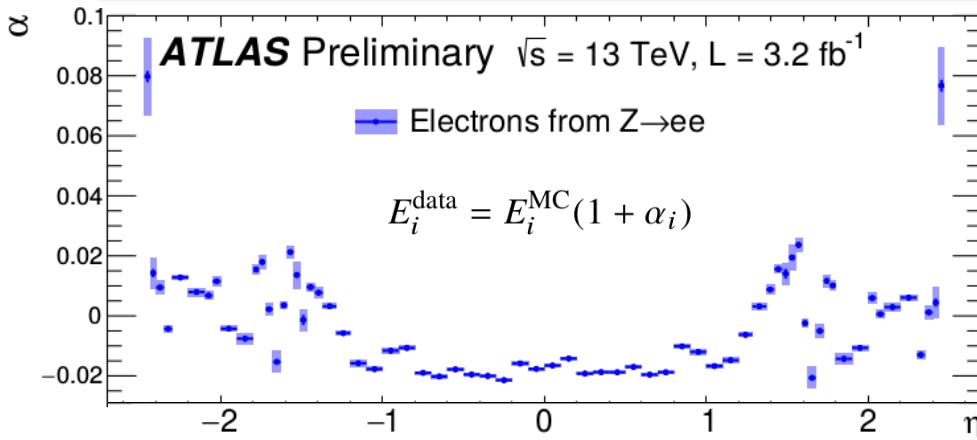
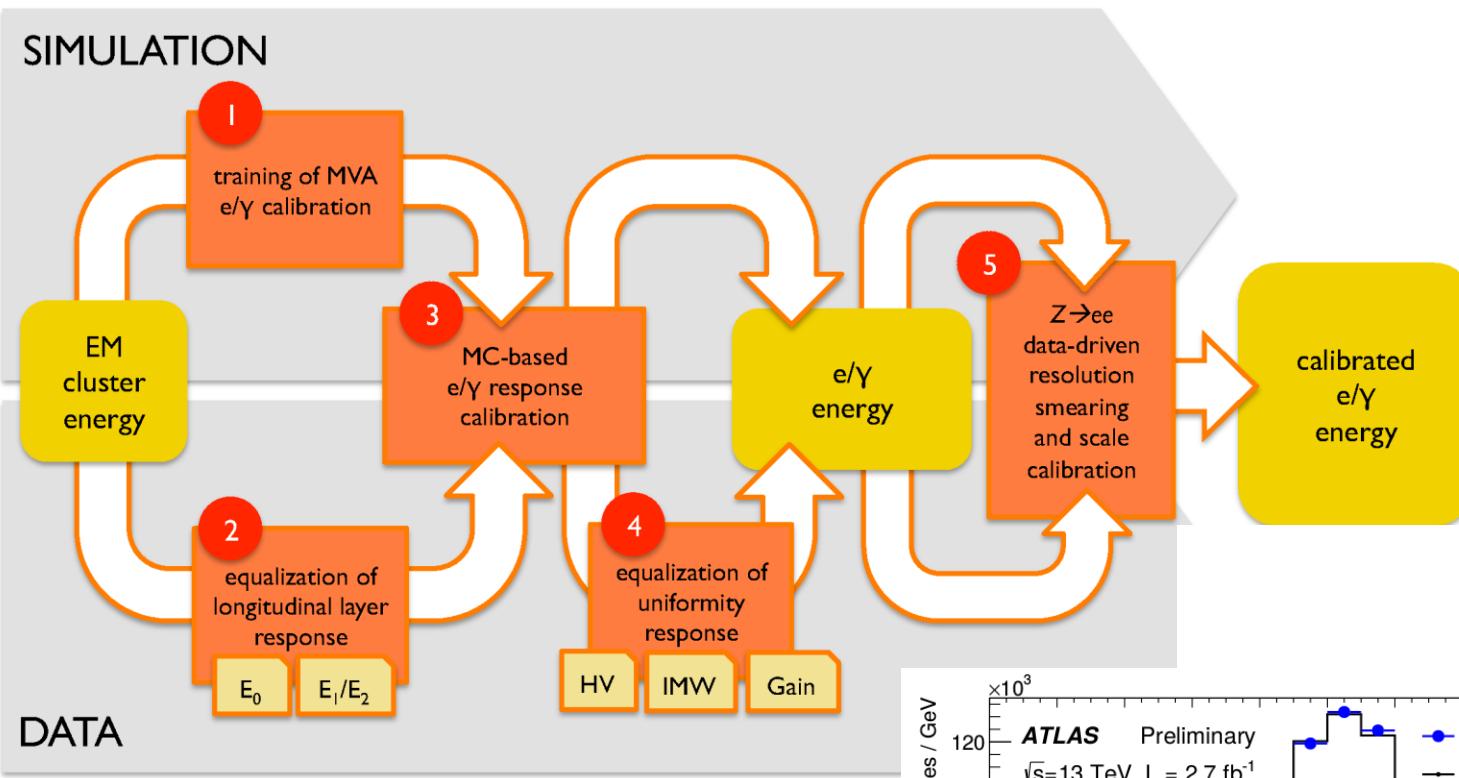
Electrons (35 – 40 GeV)	0.2%
Photons (35 – 40 GeV)	1-2%

2016 prelim. results are extrapolated and have larger uncertainties



Energy calibration

see also poster by Stefano Manzoni

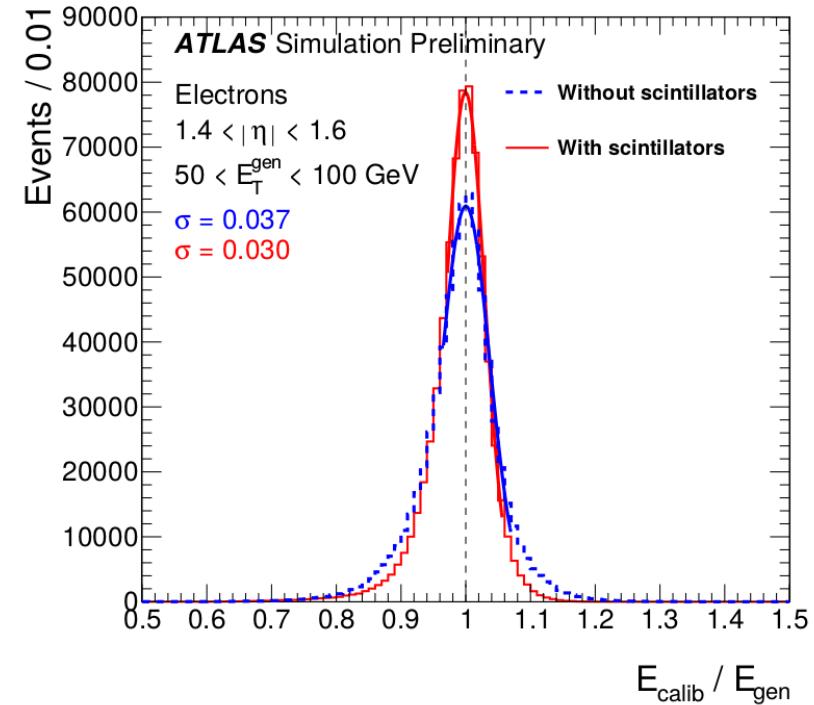
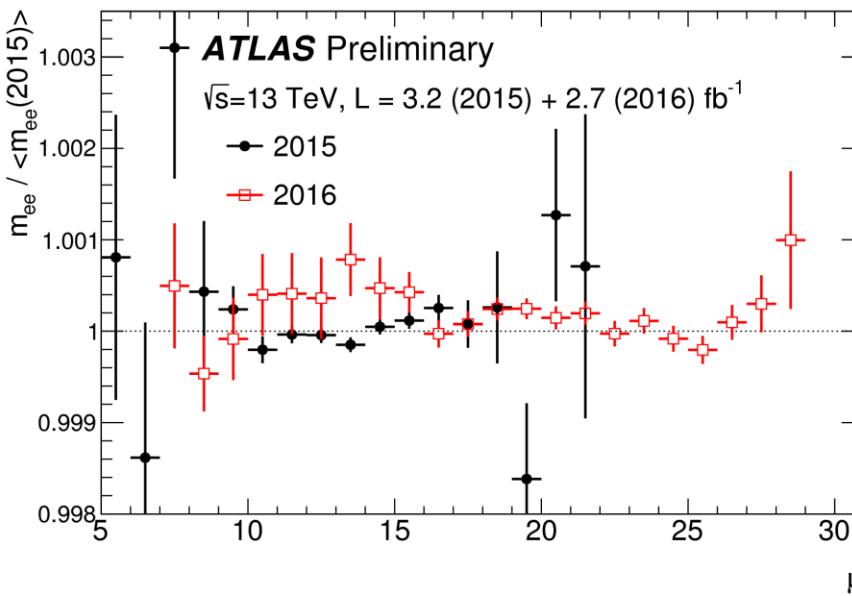




Energy calibration

Run 2:

- new detector description
(including new inner most B-layer)
- improved calibration in calorimeter gap
- Run 2 full evaluation of uncertainties
ongoing



Resolution

$4e$ (125 GeV): 2.4 GeV 2γ (750 GeV): 7.5 GeV

Scale uncertainties (Run 1)

e (25 GeV): 0.05-0.2% γ (60 GeV): 0.3%

(slightly increased for Run 2)



Conclusions

Electron and photon performance is crucial for many analyses in ATLAS

Improved strategies for electron and photon identification

→ special care for higher pileup and new gas mixture in TRT

Electron and photon efficiency uncertainty already at similar level as in Run 1

Calibration improved in the calorimeter gap, same (excellent) level of uncertainties as in Run 1 expected soon



Documentation

Run 2

- Electron efficiency: [Conference Note](#)
- Photon efficiency: [Public Note](#)
- Calibration: [Public Note](#)

Run 1

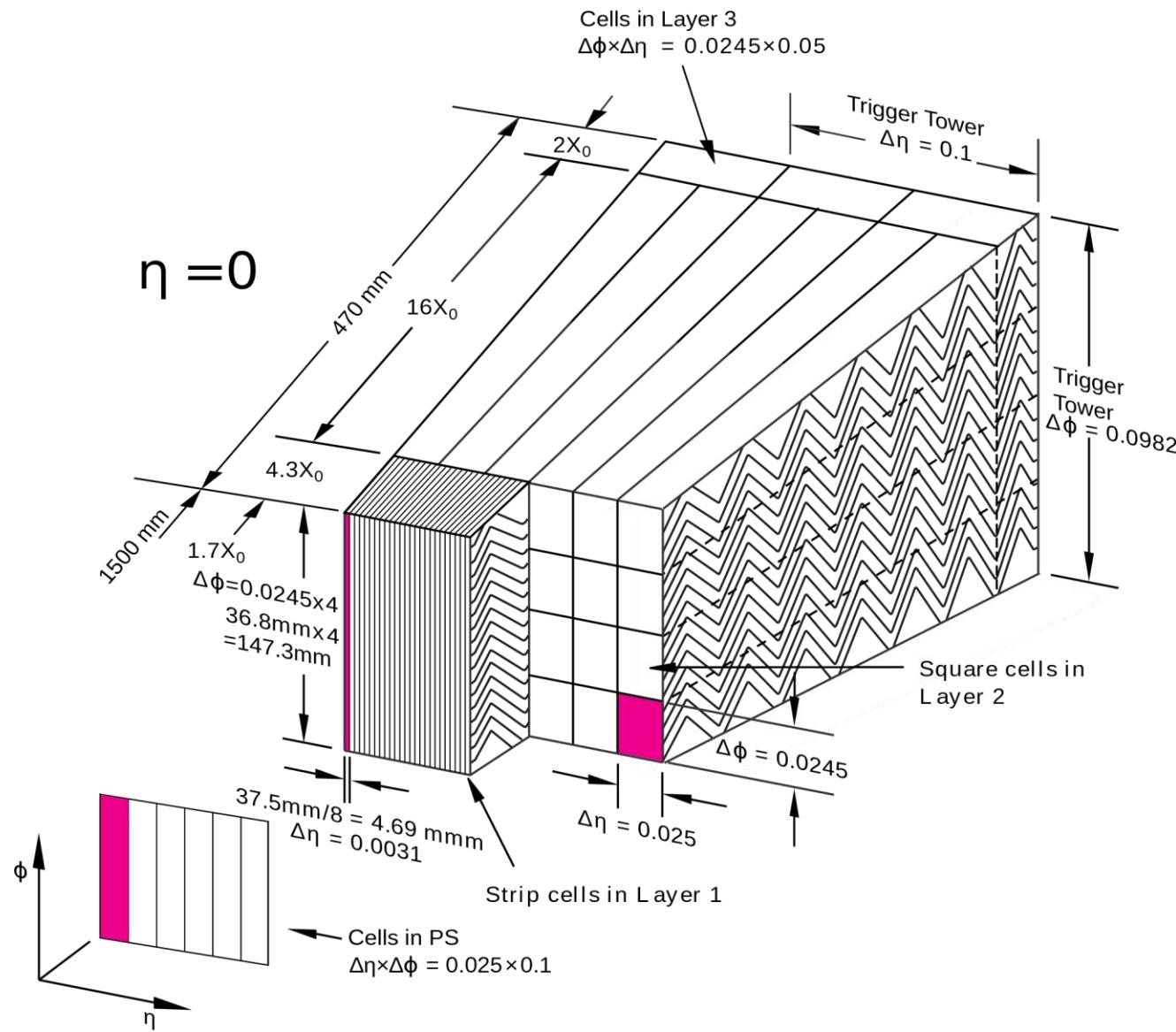
- Electron efficiency: [Conference Note](#)
- Photon efficiency: [Paper](#)
- Calibration: [Paper](#)



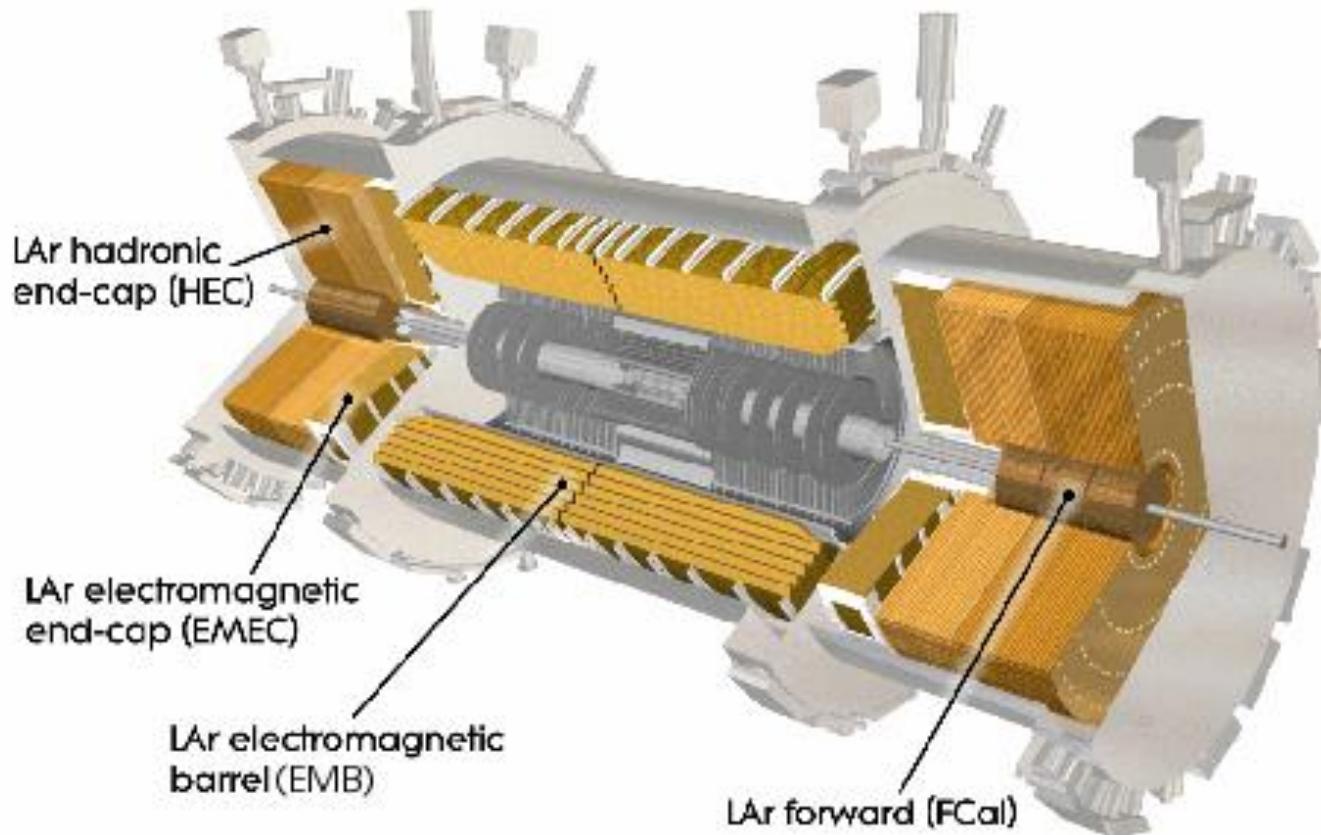
Backup



Backup: Electromagnetic calorimeter

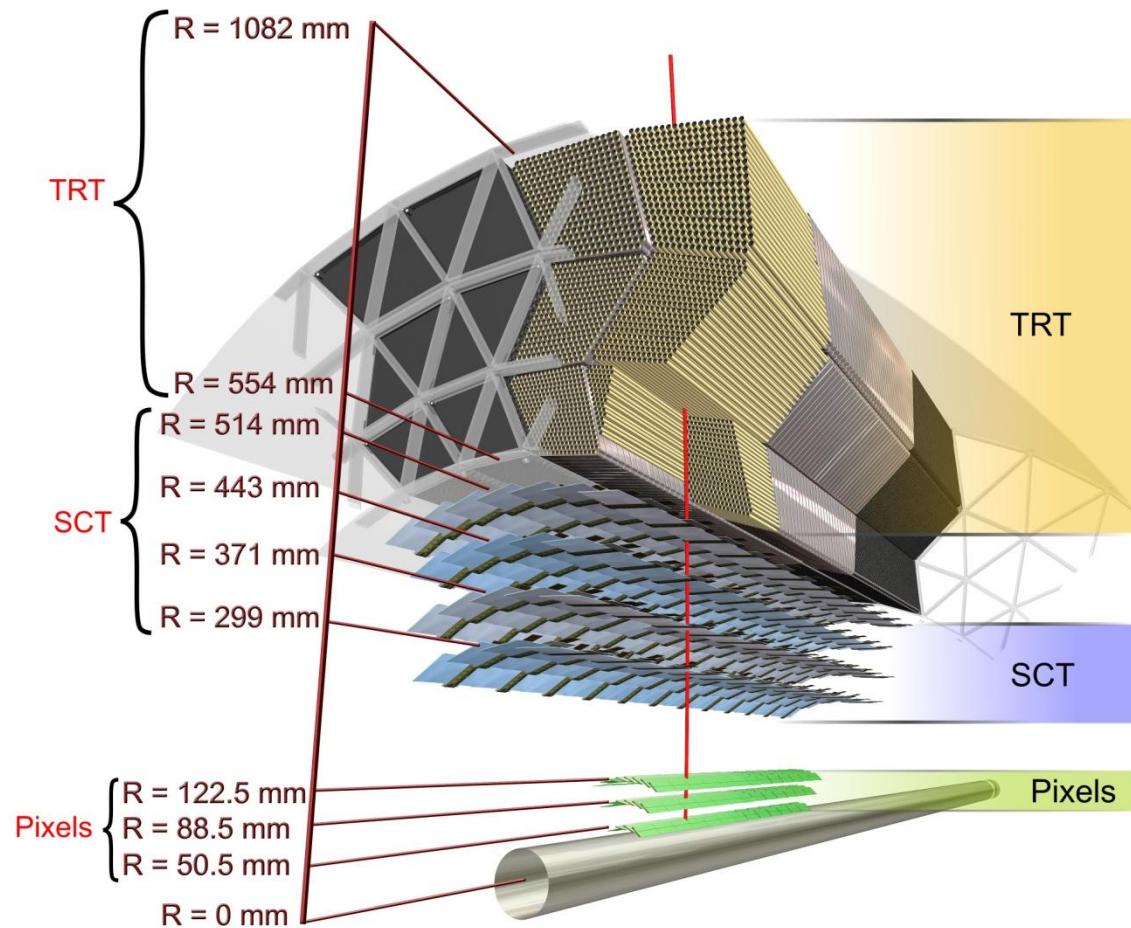


Backup: Electromagnetic calorimeter





Backup: Inner tracker





Backup: Isolation

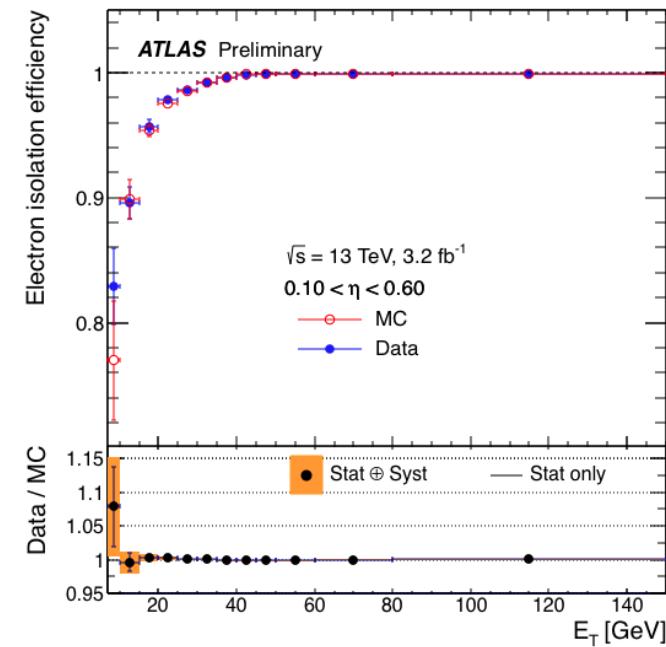
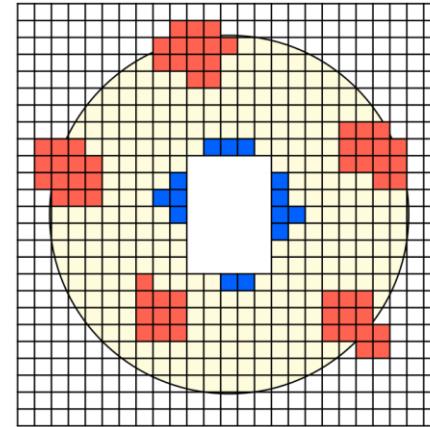
On top of identification:

Effective rejection of real electrons/photons
in hadronic jets (p.ex. from heavy flavor)

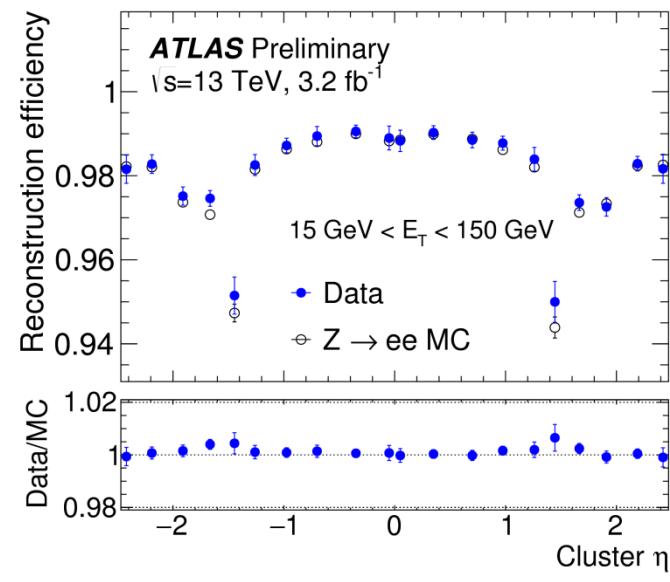
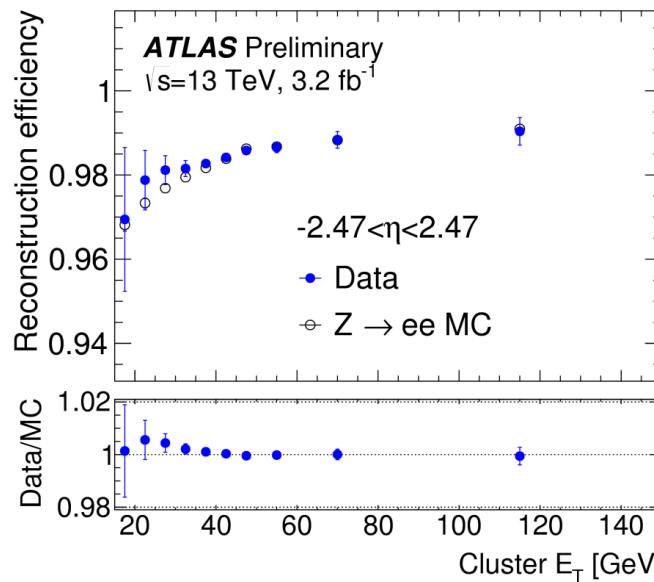
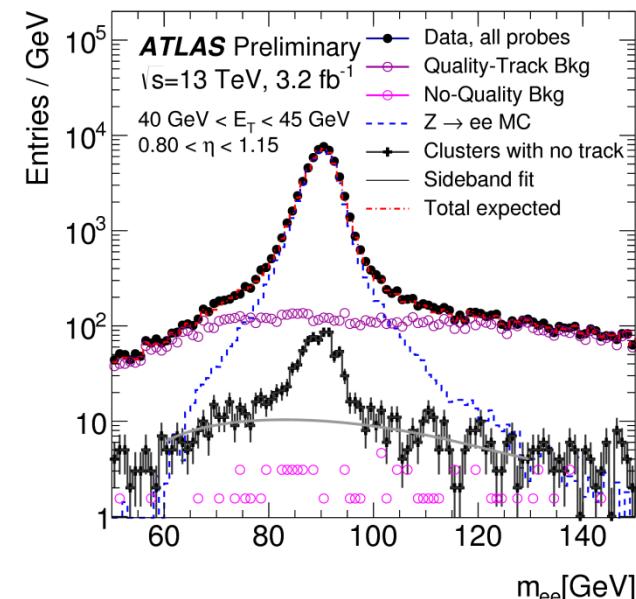
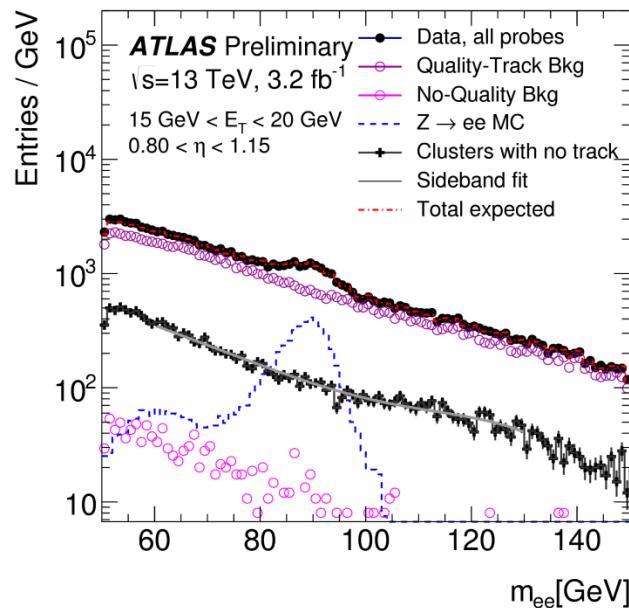
1. Calorimeter based
 - using topoclusters
2. Track- isolation
 - including variable cone sizes decreasing with p_T

Applied corrections

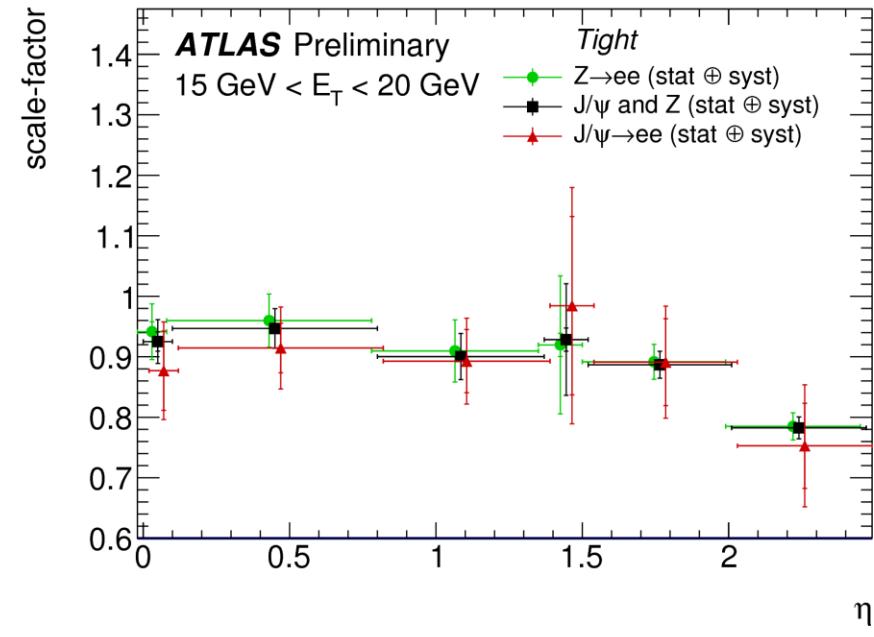
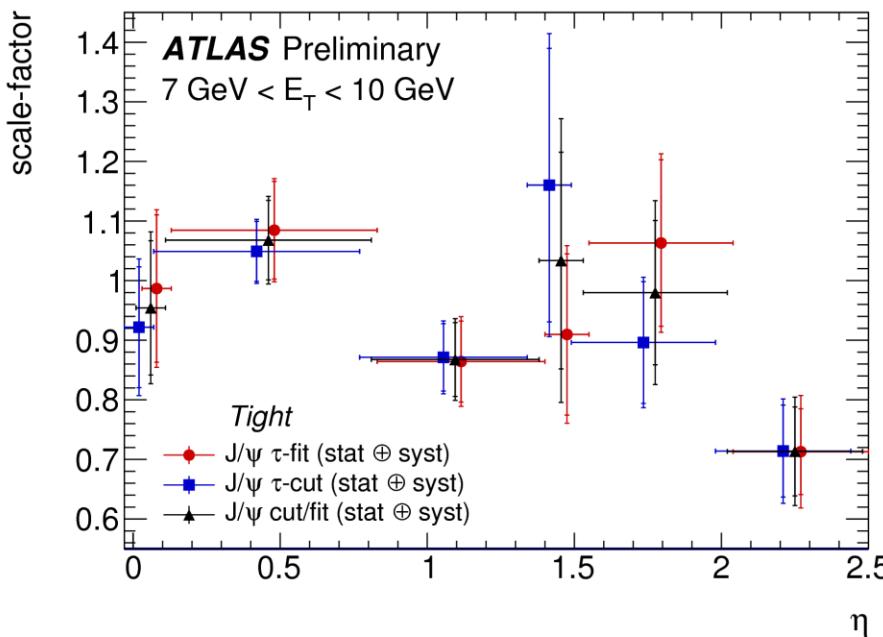
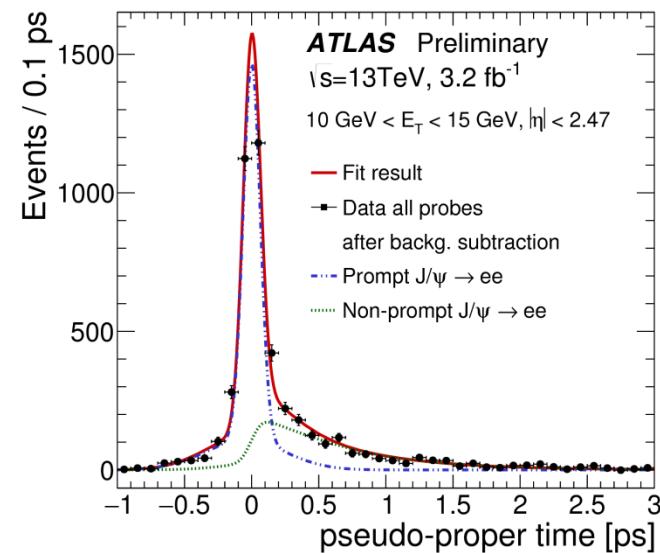
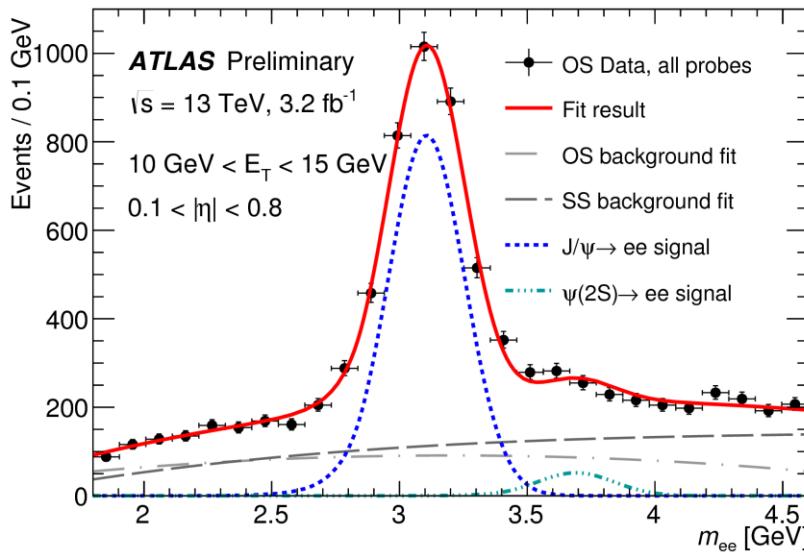
- leakage (topo subtraction for the future)
- pileup, underlying event
- overlap removal



Backup: Electron efficiency plots - reconstruction

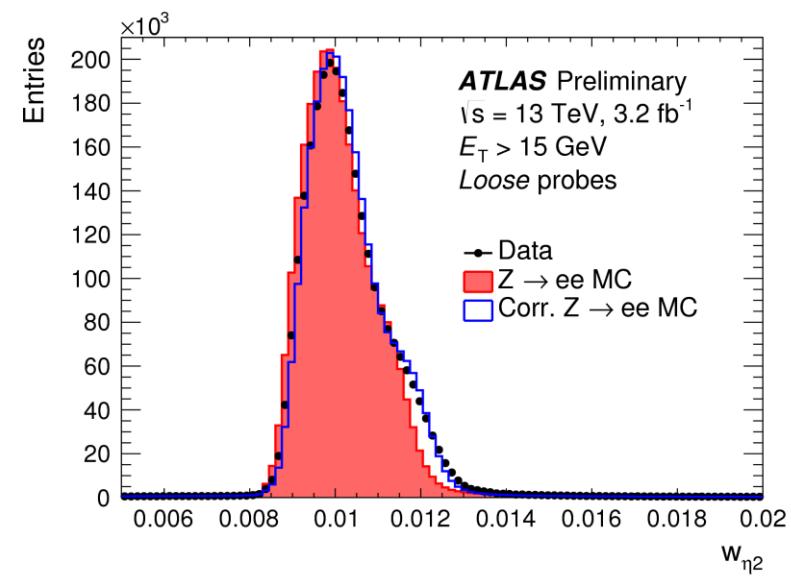
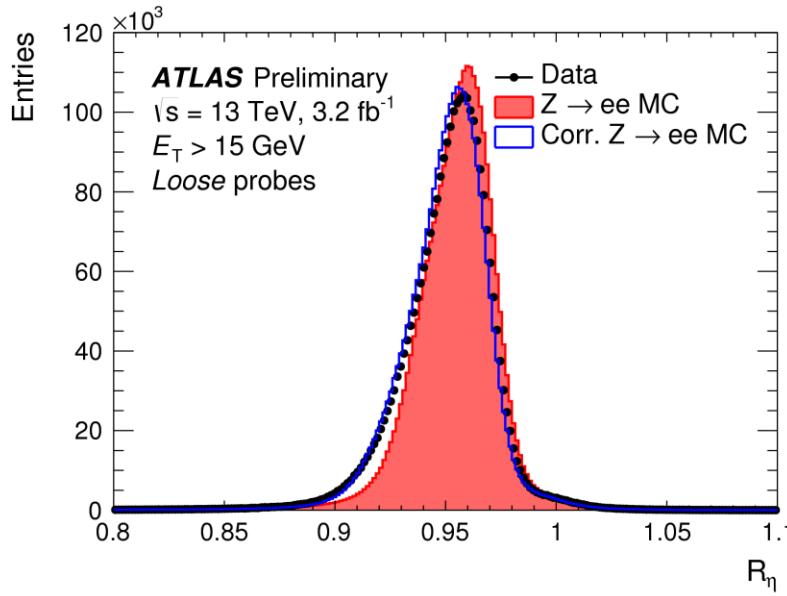
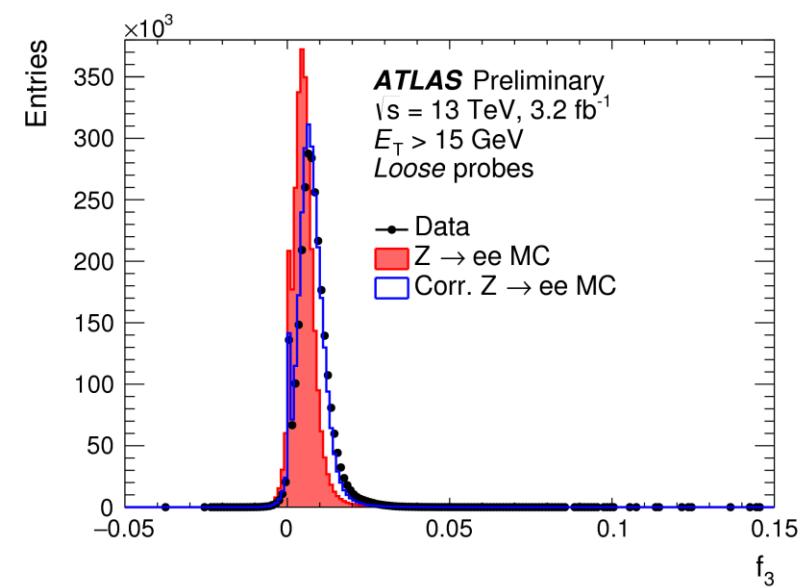
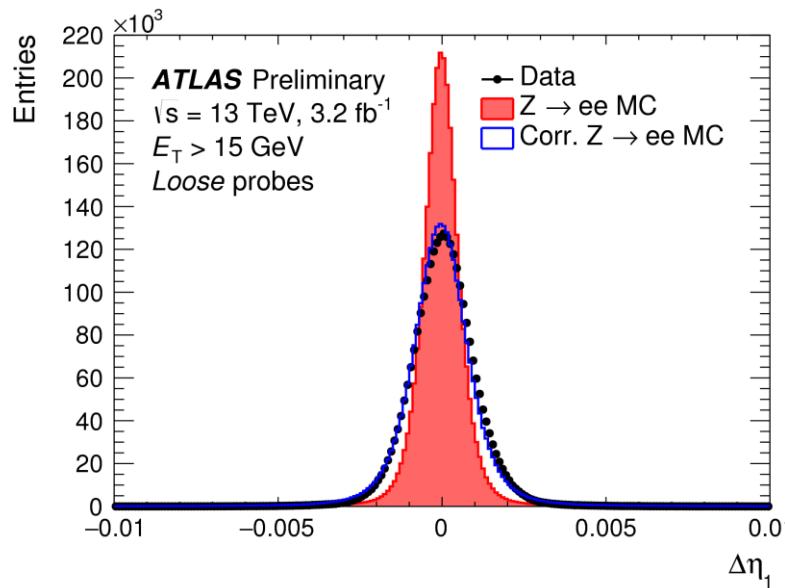


Backup: Electron efficiency plots – J/Psi





Backup: Electron shower shapes



Backup: 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$)	$R_{\text{had}1}$
	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, $\sqrt{(\sum E_i \eta_i^2)/(\sum E_i) - ((\sum E_i \eta_i)/(\sum E_i))^2}$, 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, $\sqrt{(\sum E_i (i - i_{\max})^2)/(\sum E_i)}$, 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	$\Delta\phi_{\text{res}}$
	Ratio of the cluster energy to the track momentum	E/p

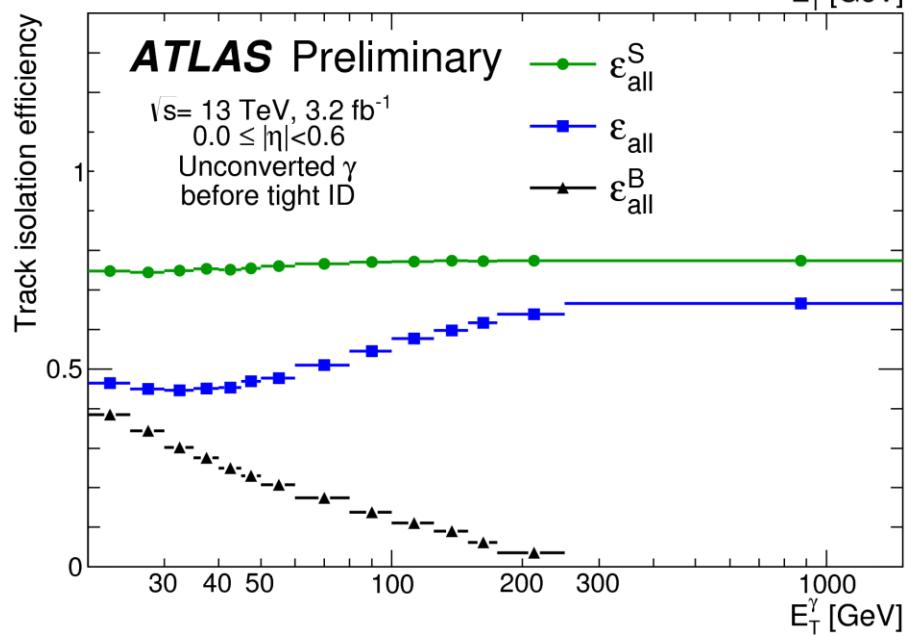
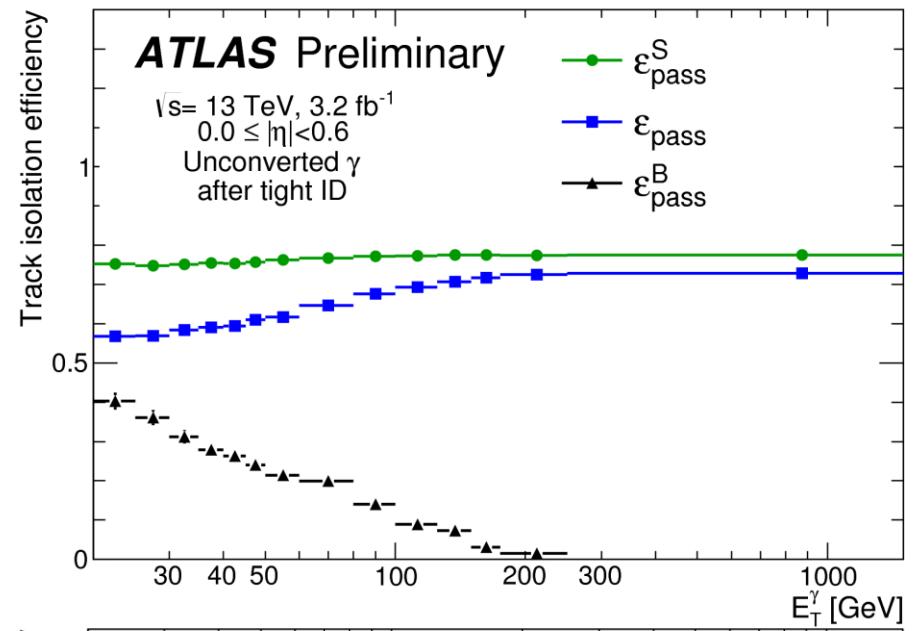
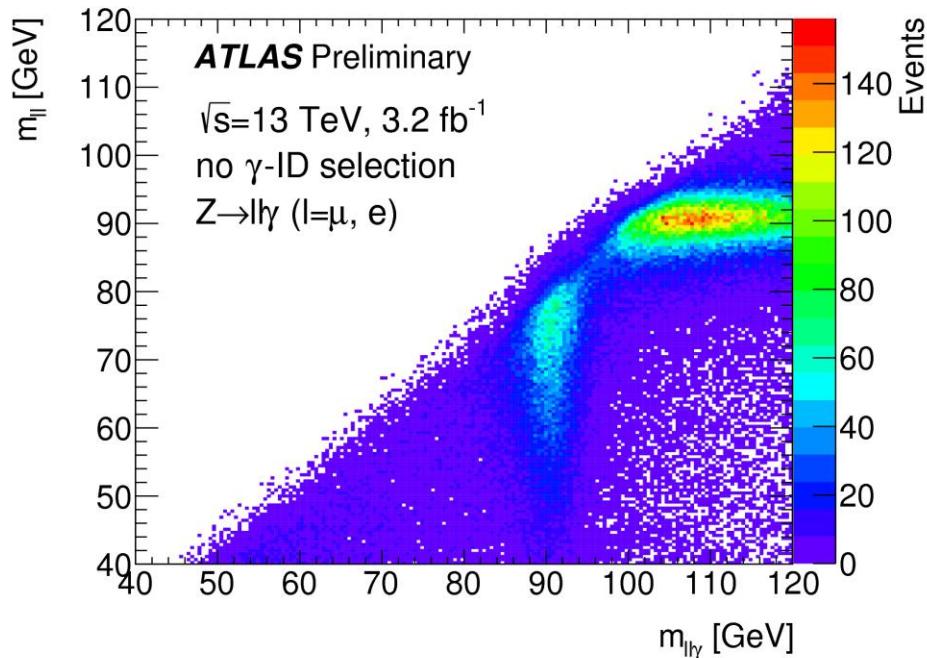


Backup: Photon discriminating variables

Category	Description	Name	loose	tight
Acceptance	$ \eta < 2.37$, with $1.37 < \eta < 1.52$ excluded	—	✓	✓
Hadronic leakage	Ratio of E_T in the first sampling layer of the hadronic calorimeter to E_T of the EM cluster (used over the range $ \eta < 0.8$ or $ \eta > 1.37$)	R_{had_1}	✓	✓
	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}	✓	✓
EM Middle layer	Ratio of $3 \times 7 \eta \times \phi$ to 7×7 cell energies	R_η	✓	✓
	Lateral width of the shower	w_{η_2}	✓	✓
	Ratio of $3 \times 3 \eta \times \phi$ to 3×7 cell energies	R_ϕ		✓
EM Strip layer	Shower width calculated from three strips around the strip with maximum energy deposit	$w_{s,3}$		✓
	Total lateral shower width	$w_{s,\text{tot}}$		✓
	Energy outside the core of the 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 minimum value found between the first and second maxima	ΔE		✓
	Ratio of the energy difference associated with the largest and second largest energy deposits to the sum of these energies	E_{ratio}		✓

Table 1: Discriminating variables used for *loose* and *tight* photon identification.

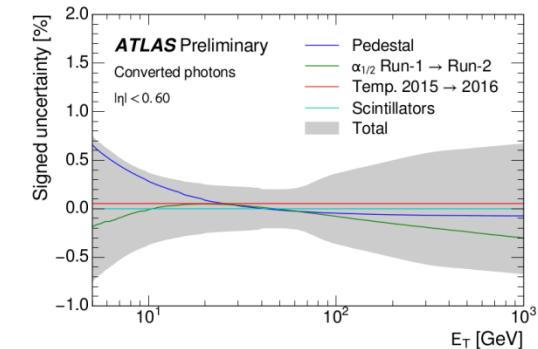
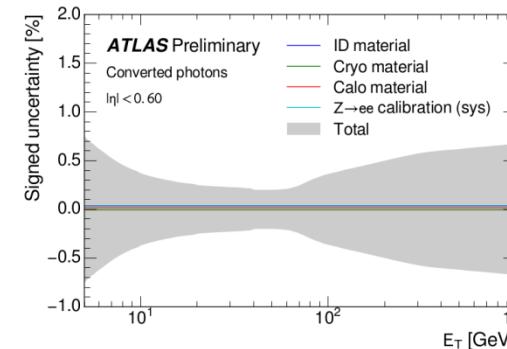
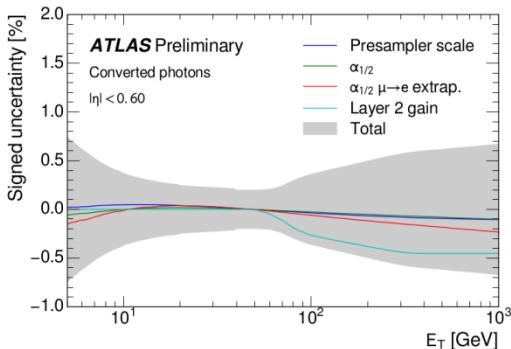
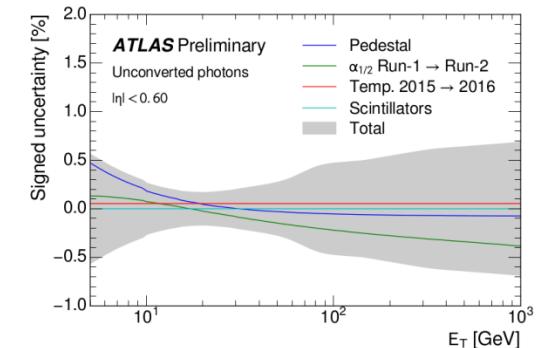
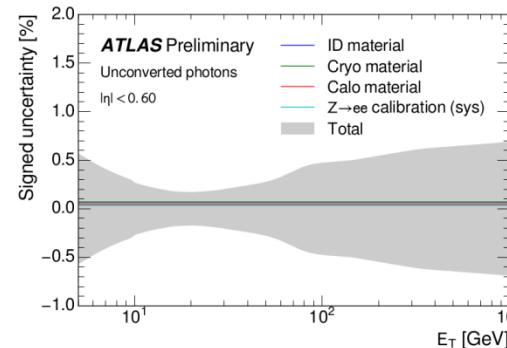
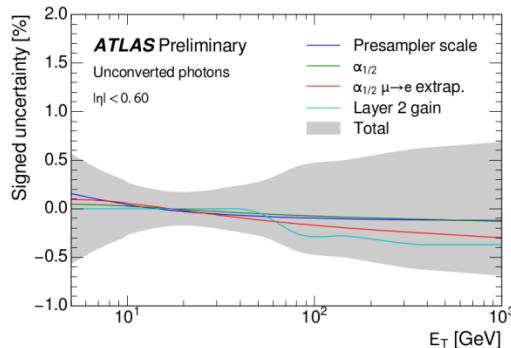
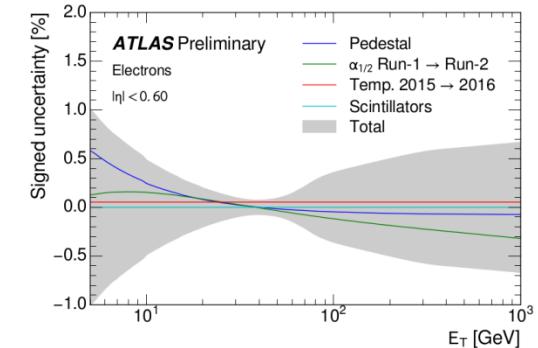
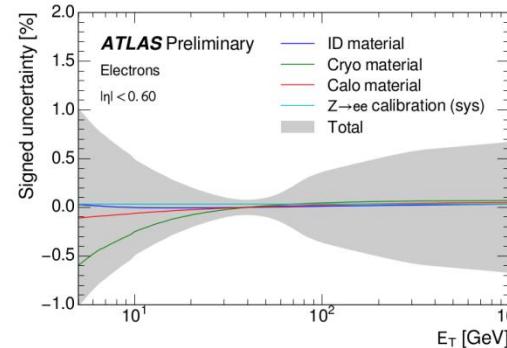
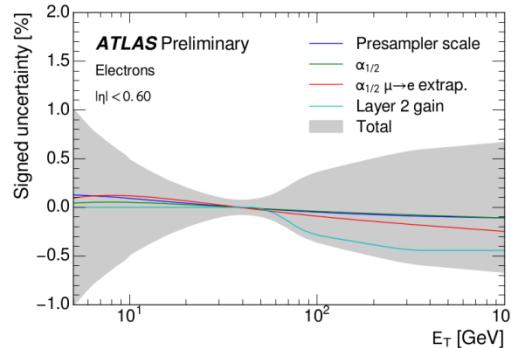
Backup: Photon efficiency plots



Backup: Scale uncertainties in Run 2



- A bit larger than in Run 1, as the full methodology has not been applied yet to Run 2 data, and extrapolations had to be done.





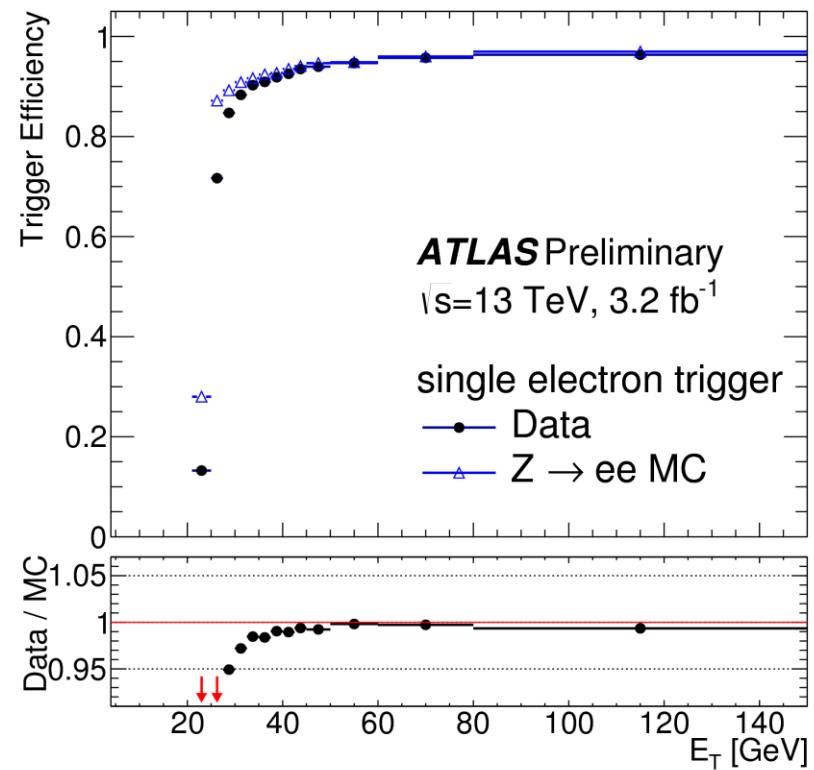
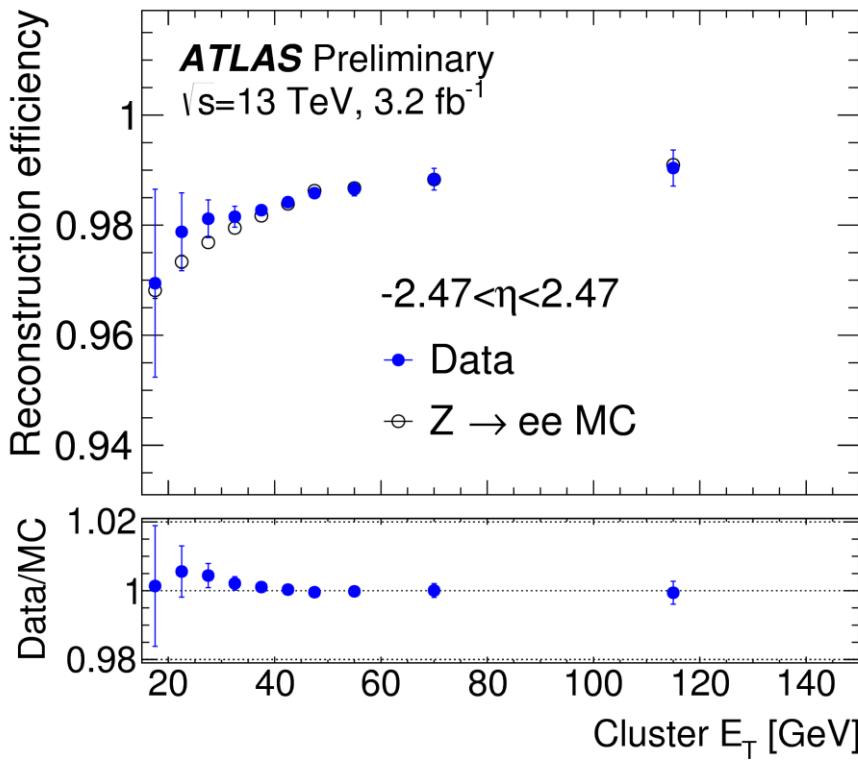
Backup: TRT likelihood

Likelihood probability (based on transition radiation)

Input variables

- Momentum, as higher gamma -factor increases TR production
- Pile up, as more tracks increases the probability both for e and pions
- Straw Layer, as amount of radiator affects amount of TR
- z/r position, as track length in straw and geometry affects TR
- Distance of closest approach to anode, as track length in straw and material affects TR
- High-Threshold bit pattern, as this is affected by process and timing
- If last hit was HT, as hadronic interactions/cascades can create large signals

Backup: More electron efficiencies



Backup: Photon Efficiencies



Photon reconstruction efficiency ~96% (4% of photons reconstructed as electrons)

- 90% at 1 TeV (decrease in conversion reconstruction efficiency)

Efficiency for true conversions to be reconstructed as conversions ~70%

Photon trigger efficiency

