

# Electron and Photon Identification

Tetiana Berger-Hryn'ova  
(LAPP/CNRS)

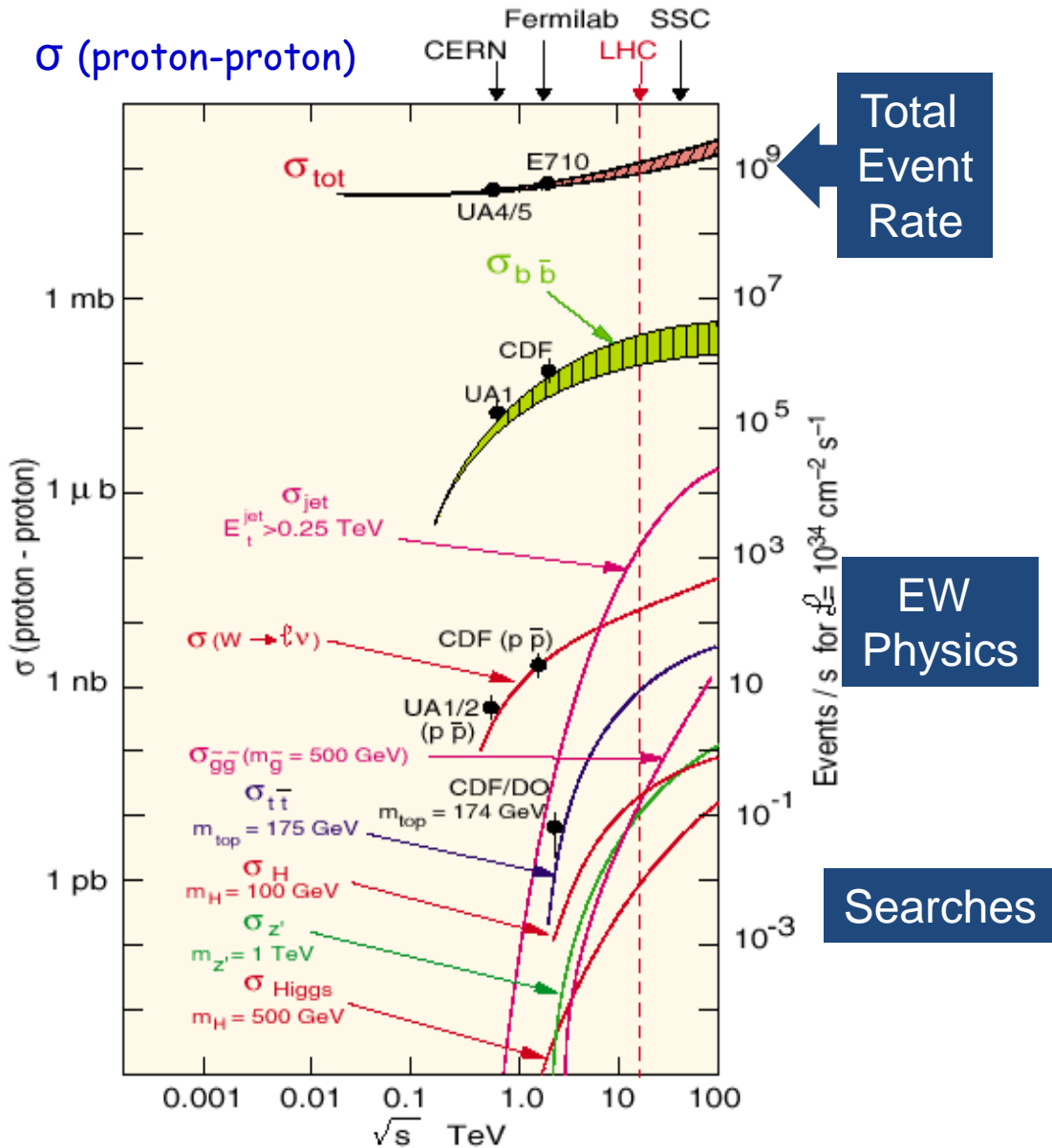
On behalf of the ATLAS Collaboration

ICNFP

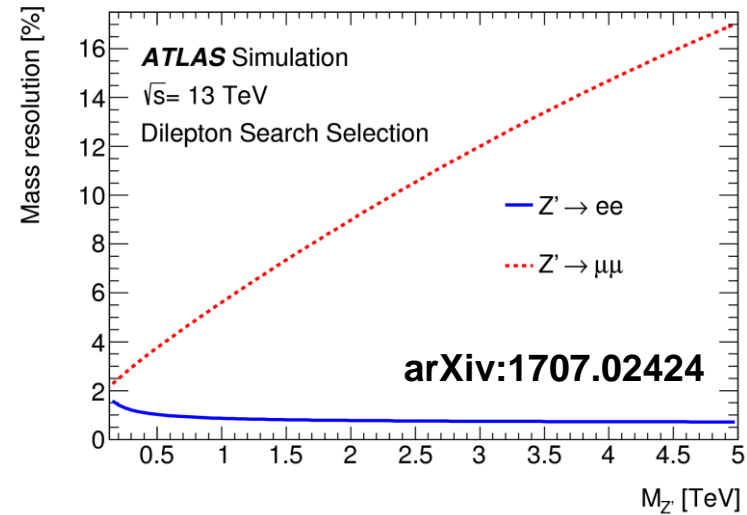
19 August 2017

# Why need Electrons or Photons?

$\sigma$  (proton-proton)

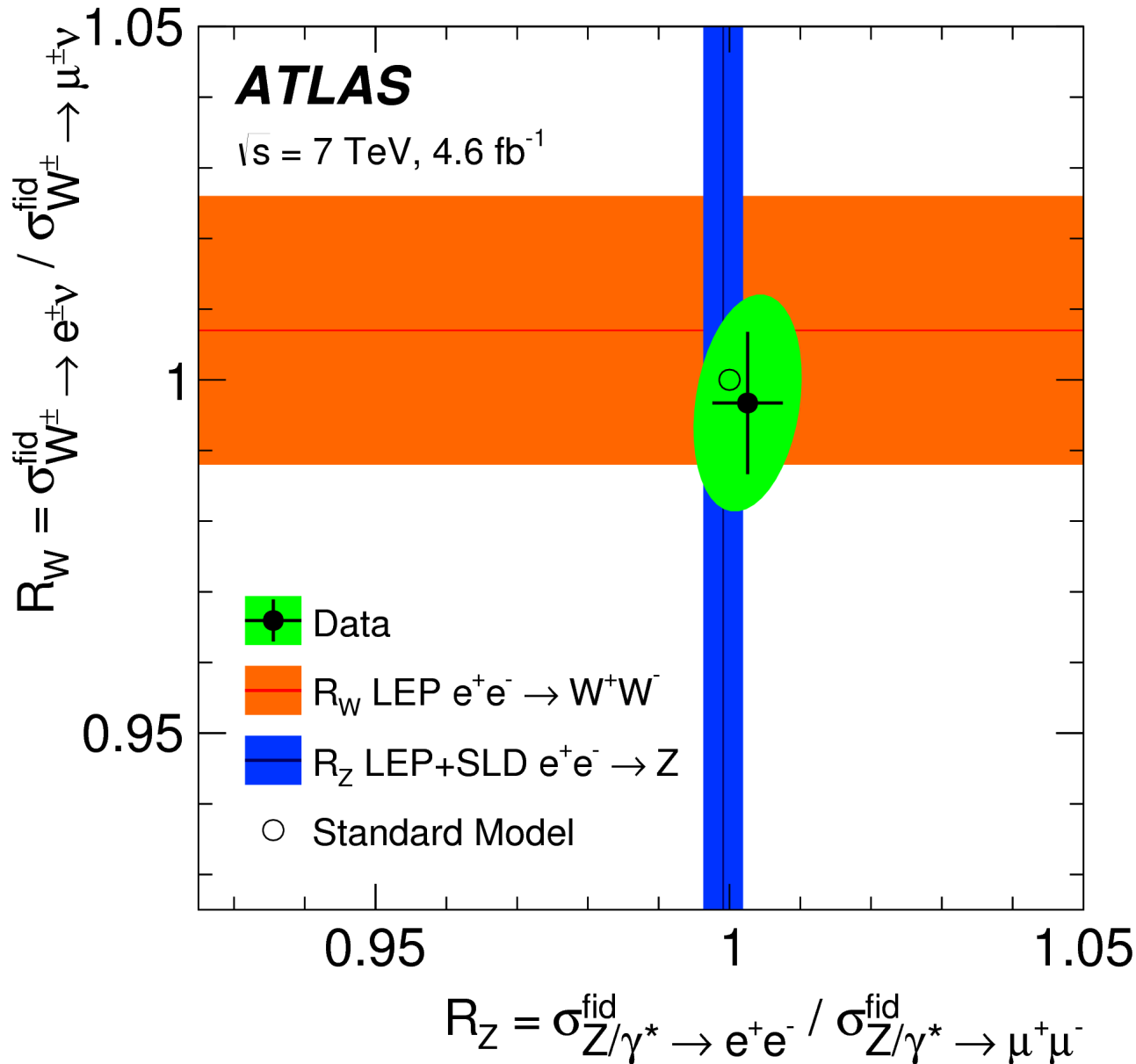


Electron and photon identification is needed to select interesting signal events.



Excellent resolution at high  $p_T$  crucial for high mass new phenomena searches.

# Why need Electrons or Photons?



Excellent understanding of electron and photon performance is crucial for the precision measurements.

# Electron and Photon Reconstruction

## Hadronic Calorimeter:

- 3 layers of scintillating tile/steel to  $|\eta| < 1.7$
- 4 layers copper/LAr for  $1.5 < |\eta| < 3.2$

## Electromagnetic (EM) Calorimeter:

- **Pb/Liquid Argon accordion** ( $|\eta| < 3.2$ )
- 4/3/2 layers  $|\eta| < 1.8/2.5/3.2$

## Inner Detector (ID) $|\eta| < 2.5$ :

- 4 layer Pixel Detector
- 4 layer Semi-Conductor Tracker (SCT)
- 73-layer Transition Radiation Detector (TRT)  $|\eta| < 2.0$  electron ID  $1 < p_T < 150 \text{ GeV}$

third layer hadronic calorimeter

second layer  
 $\Delta\eta \times \Delta\phi = 0.025 \times 0.0245$

electromagnetic calorimeter (EM)

first layer (strips)  
 $\Delta\eta \times \Delta\phi = 0.0031 \times 0.098$

presampler

Transition Radiation Tracker

beam axis

beam spot

$d_0$

pixels

SCT

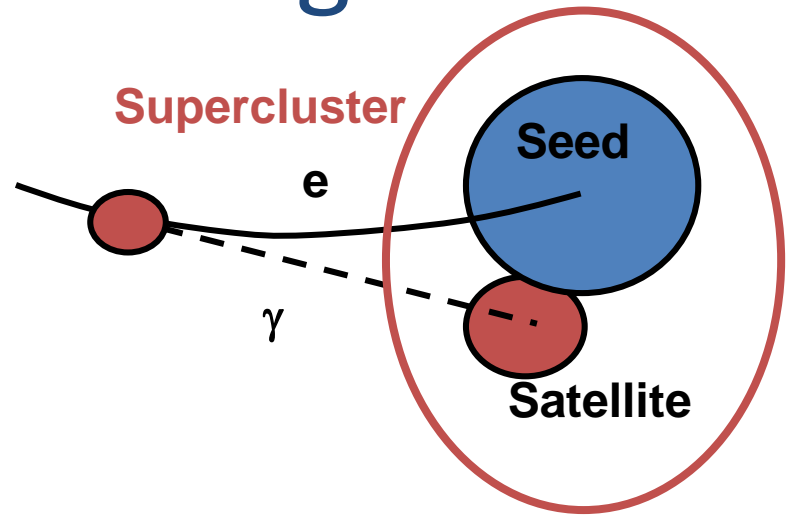
insertable b-layer (IBL)

	EM Cluster	Matched Track	IBL hit
Electron	$ \eta  < 2.47$	yes	yes
Unconverted $\gamma$	$ \eta  < 2.37$	none	n/a
Converted $\gamma$	$ \eta  < 2.37$	1 or 2	no

# Electron & Photon Clustering

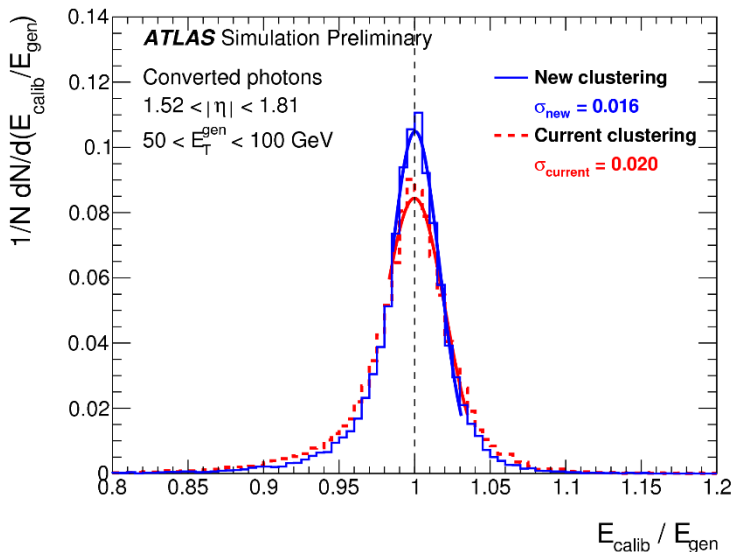
EM “sliding window” fixed-size rectangular clusters, that can be associated to tracks

- $\Delta\eta \times \Delta\phi$ :  $\gamma = 3 \times 5$ ,  $e = 3 \times 7$  (Barrel) or  $5 \times 5$  (Endcap) cells in the middle layer
- Size is trade-off between energy leakage and noise pickup

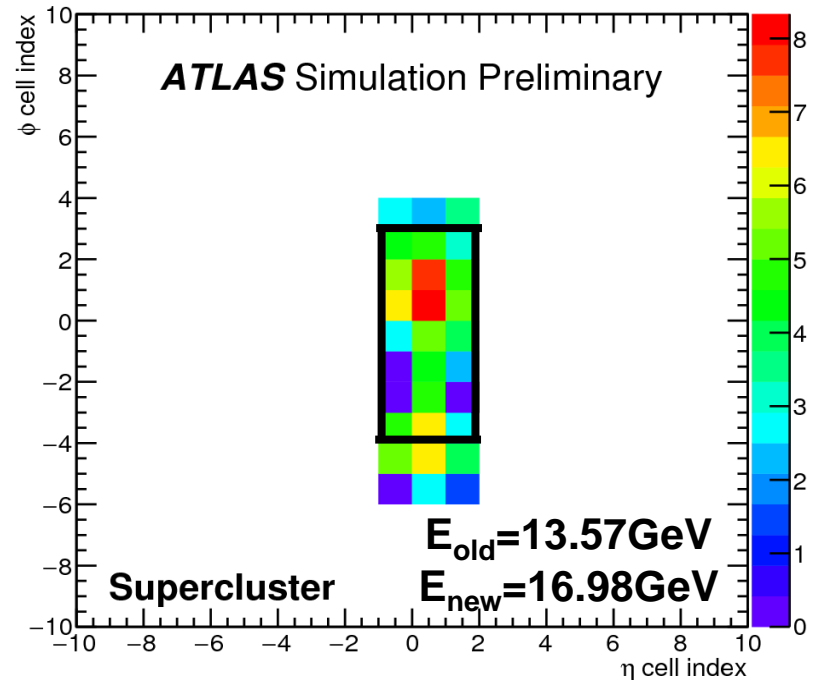


New Supercluster approach (2017):

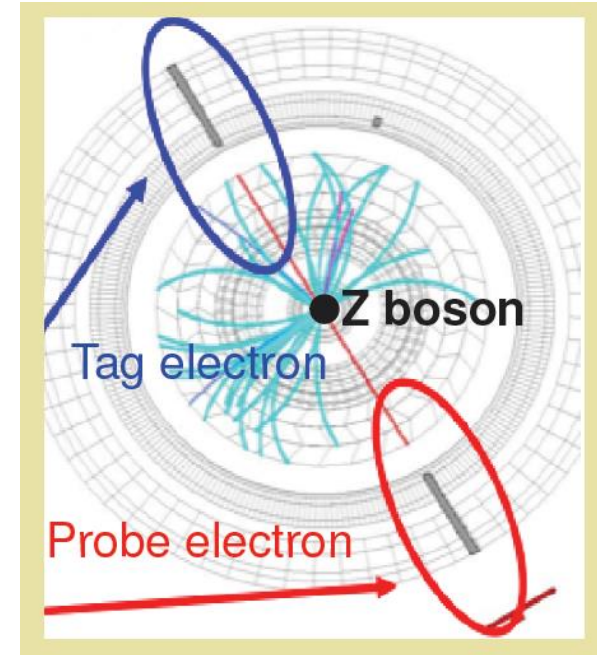
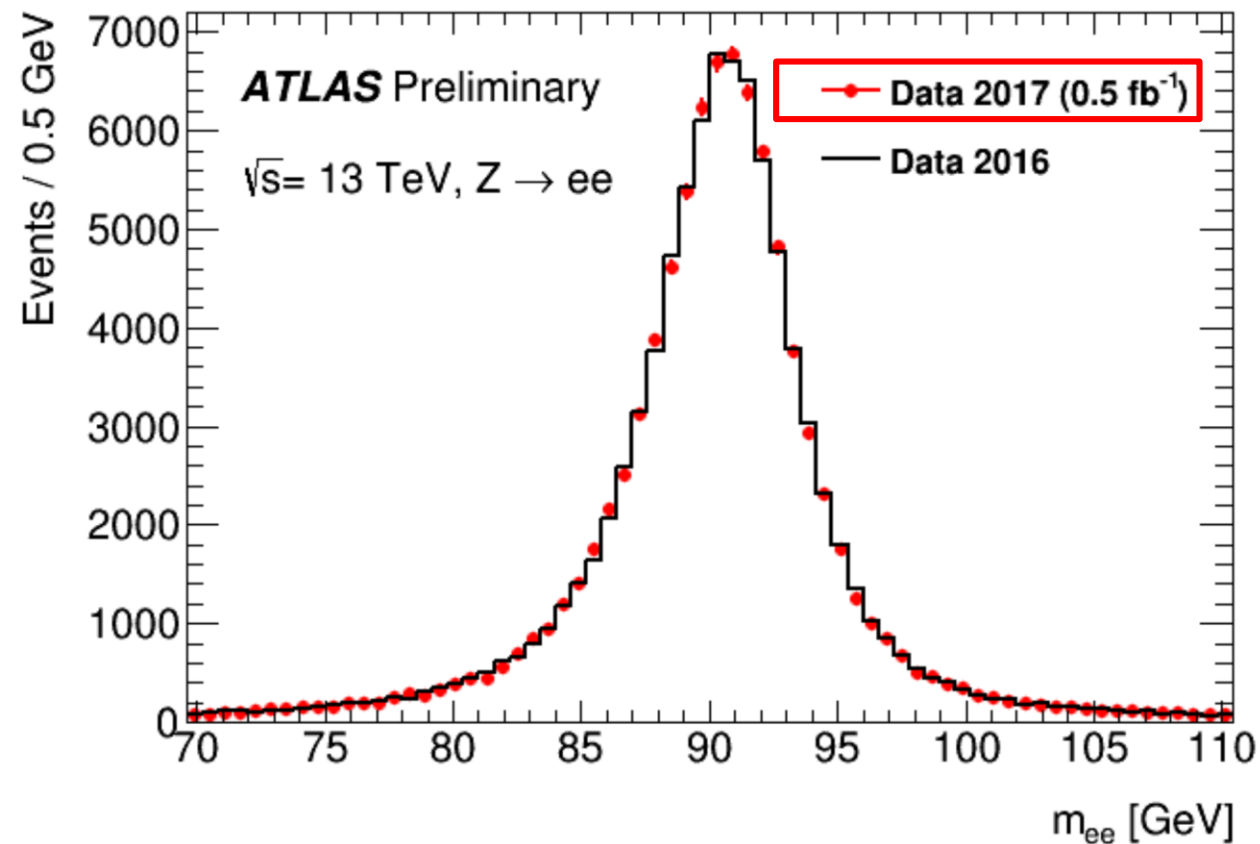
- Improvement of energy resolution low  $E_T$  and high  $|\eta|$  due to inclusion of bremsstrahlung energy depositions



$E_{Raw} = 16.98 \text{ GeV}$ ,  $E_{Gen} = 17.59 \text{ GeV}$ ,  $\eta_{Gen} = -0.50$



# Standard candles



Tag & Probe Method:

Strict selection for one electron (“tag”) and a looser electron (“probe”),  
the di-electron invariant mass in the mass window

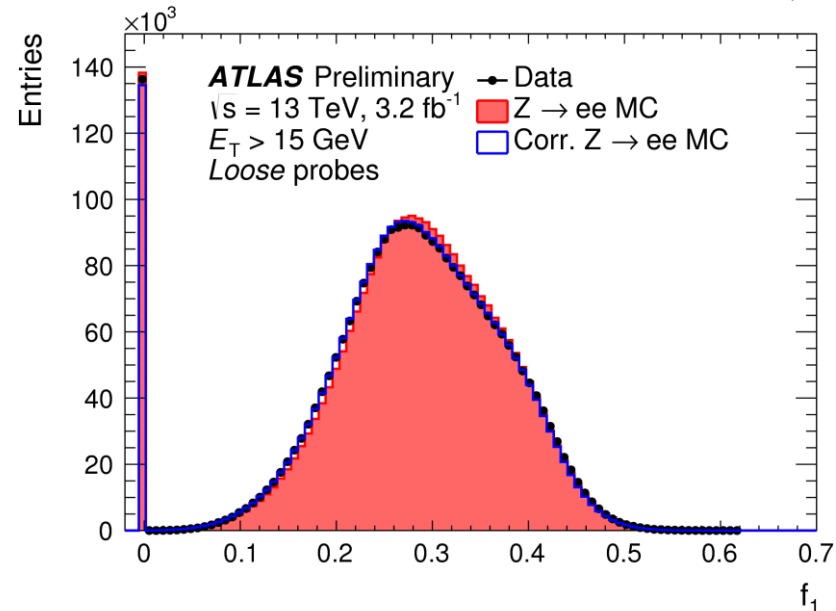
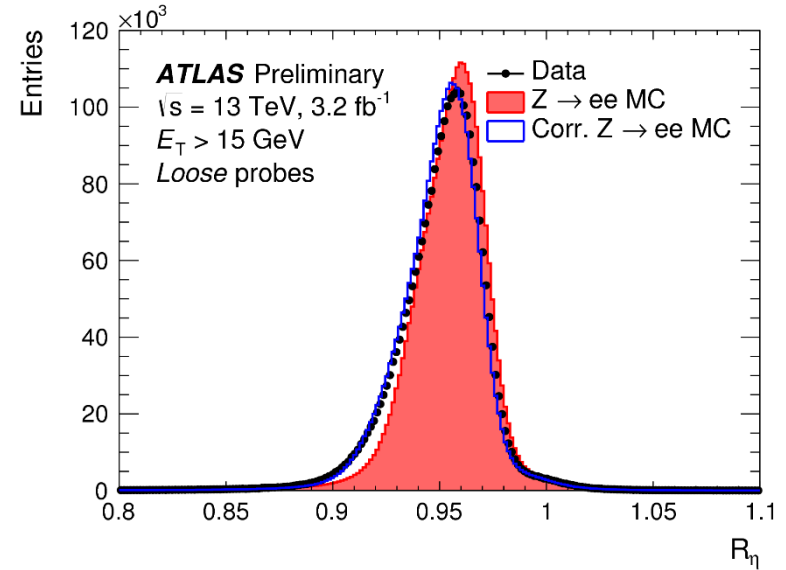
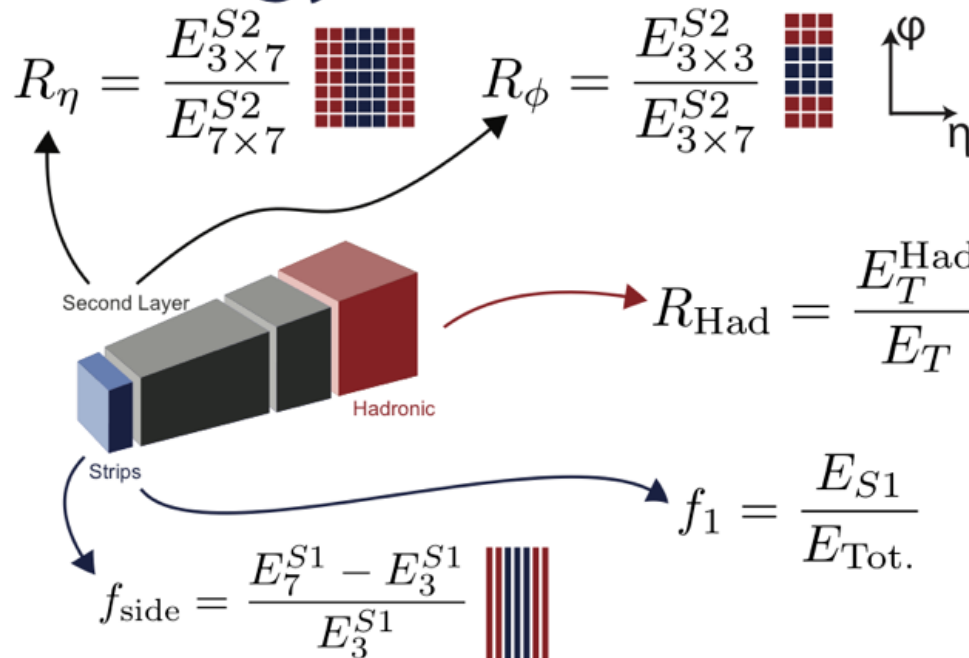
# Shower Shape Variables

ATLAS-CONF-2016-024

## Variables and Position

	Strips	2nd	Had.
Ratios	$f_1, f_{\text{side}}$	$R_\eta^*, R_\phi$	$R_{\text{Had.}}^*$
Widths	$w_{s,3}, w_{s,tot}$	$w_{\eta,2}^*$	-
Shapes	$\Delta E, E_{\text{ratio}}$	* Used in PhotonLoose.	

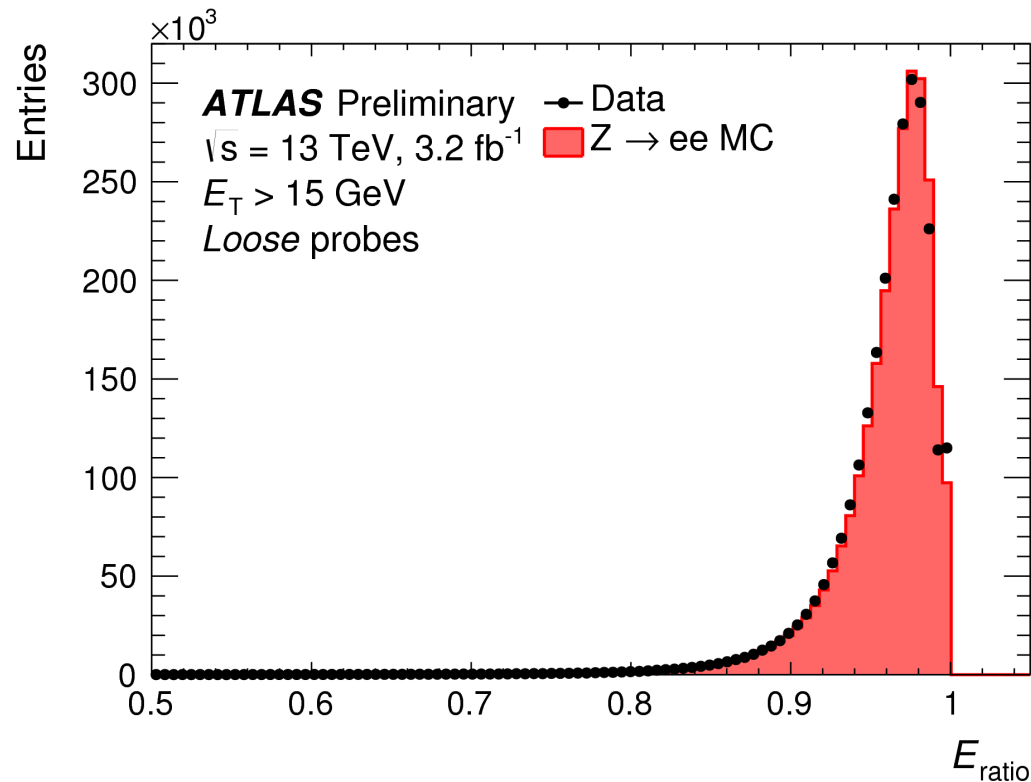
## Energy Ratios



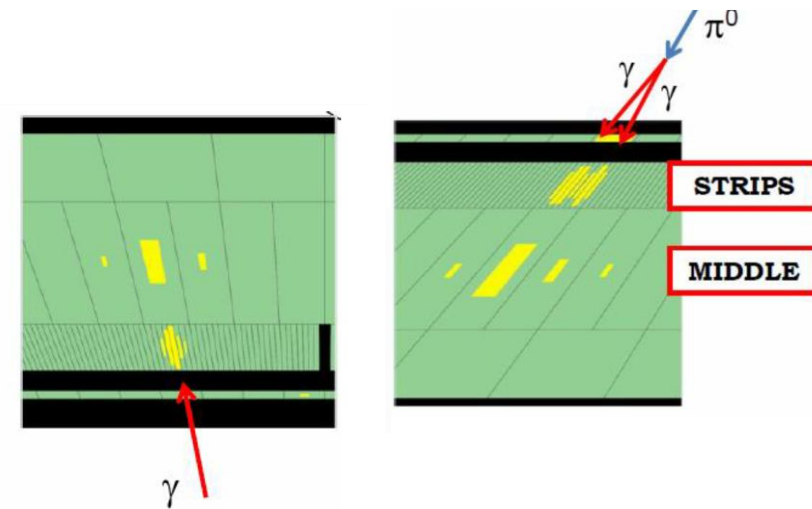
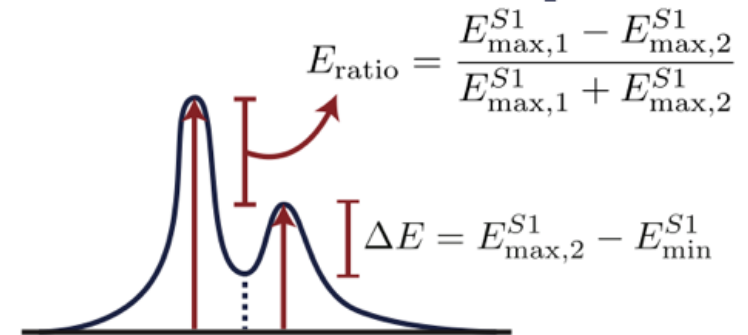
# Shower Shape Variables

## Variables and Position

	Strips	2nd	Had.
Ratios	$f_1, f_{\text{side}}$	$R_\eta^*, R_\phi$	$R_{\text{Had.}}^*$
Widths	$w_{s,3}, w_{s,tot}$	$w_{\eta,2}^*$	-
Shapes	$\Delta E, E_{\text{ratio}}$	* Used in PhotonLoose.	



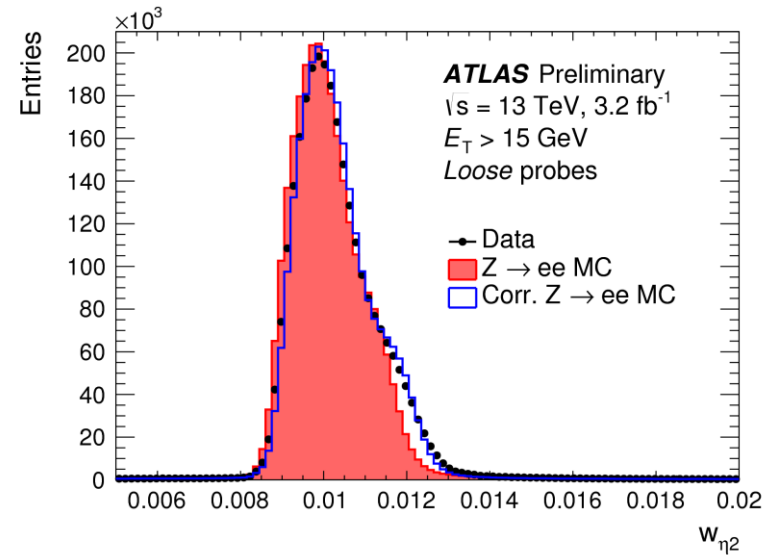
## Shower Shapes



# Shower Shape Variables

## Variables and Position

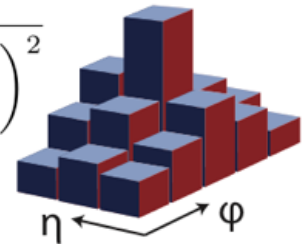
	Strips	2nd	Had.
Ratios	$f_1, f_{\text{side}}$	$R_{\eta}^*, R_{\phi}$	$R_{\text{Had.}}^*$
Widths	$w_{s,3}, w_{s,\text{tot}}$	$w_{\eta,2}^*$	-
Shapes	$\Delta E, E_{\text{ratio}}$	* Used in PhotonLoose.	



## Widths

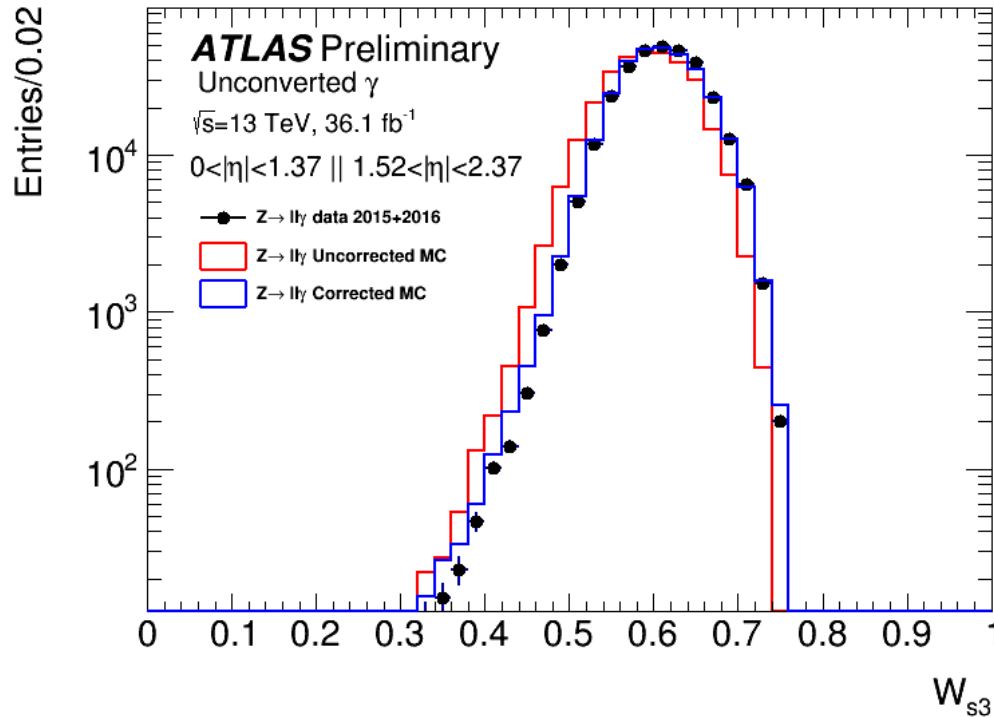
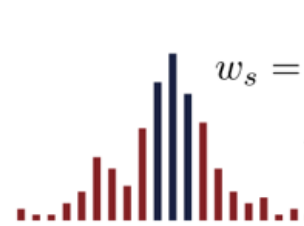
$$w_{\eta,2} = \sqrt{\frac{\sum E_i \eta_i^2}{\sum E_i} - \left(\frac{\sum E_i \eta_i}{\sum E_i}\right)^2}$$

Width in a  $3 \times 5$  ( $\Delta\eta \times \Delta\phi$ ) region of cells in the second layer.

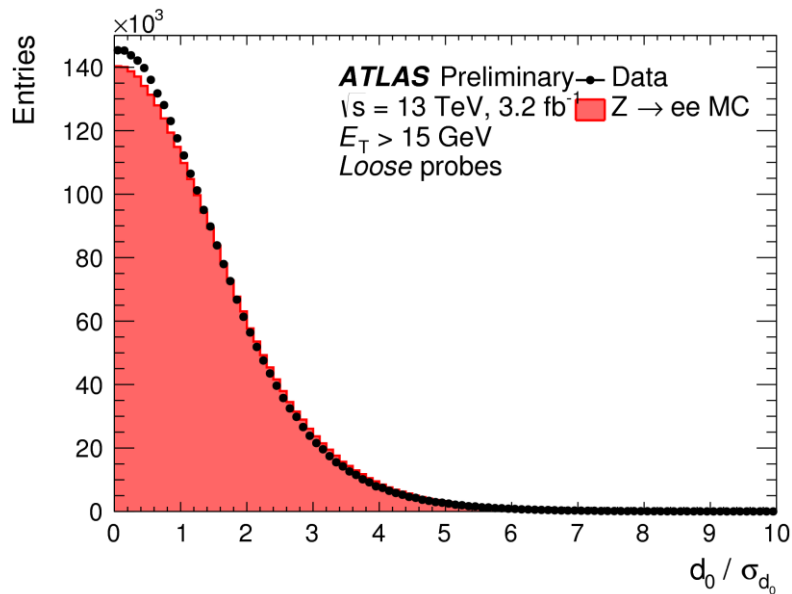
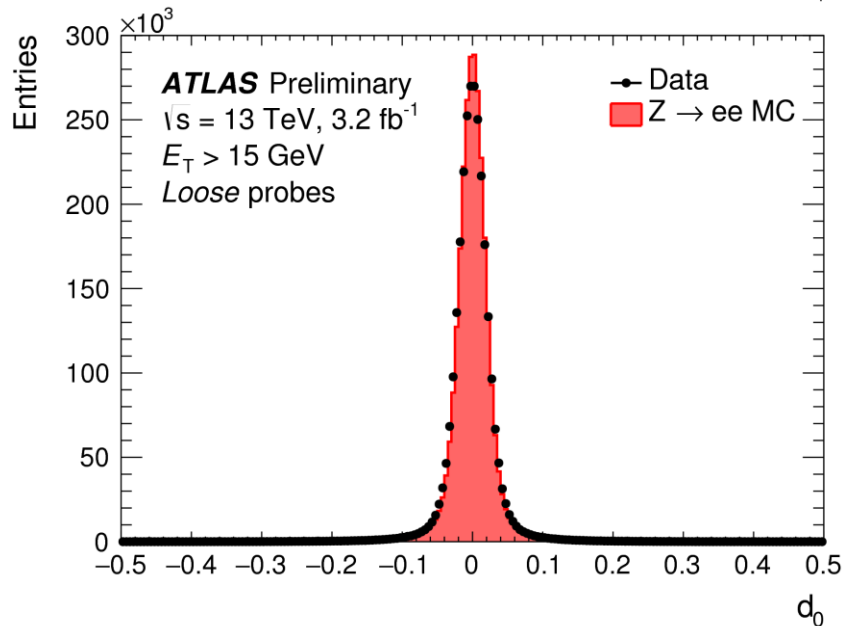
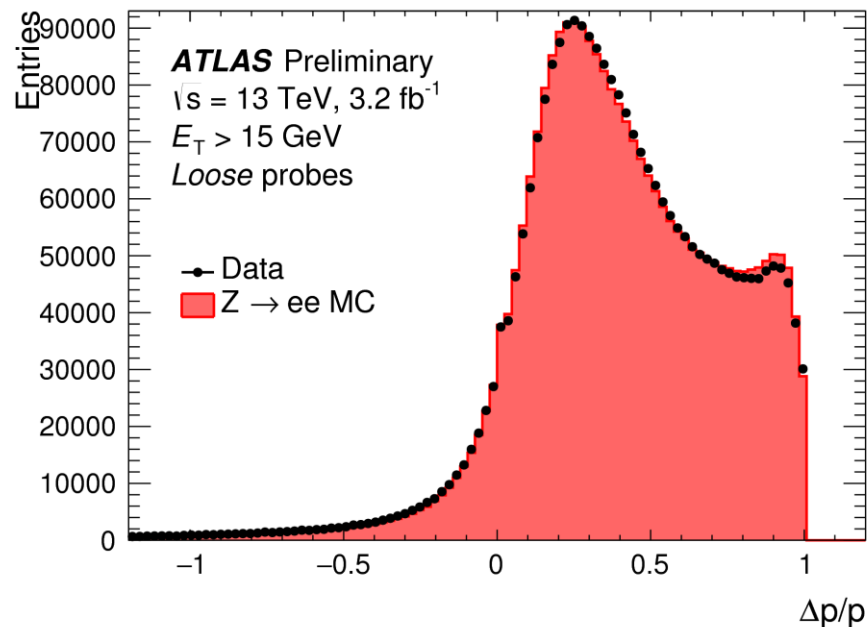
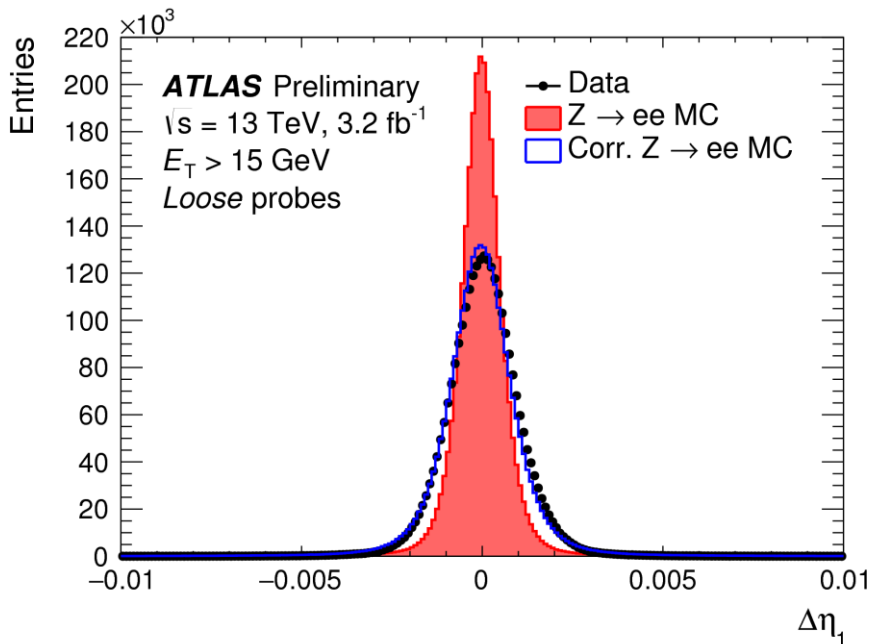


$$w_s = \sqrt{\frac{\sum E_i (i - i_{\text{max}})^2}{\sum E_i}}$$

$w_{s3} = w_1$  uses 3 strips in  $\eta$ ;  
 $w_{s\text{tot}}$  is defined similarly, but uses 20 strips.



# Track & Track-to-Cluster Matching Variables



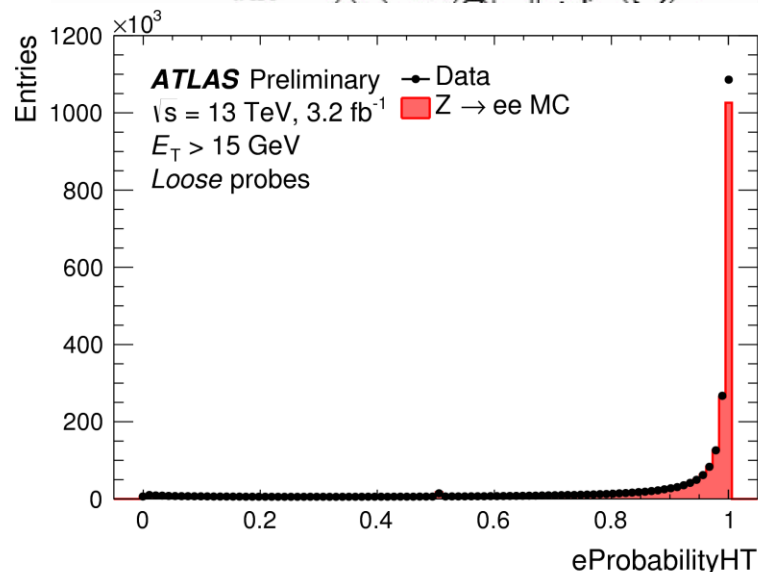
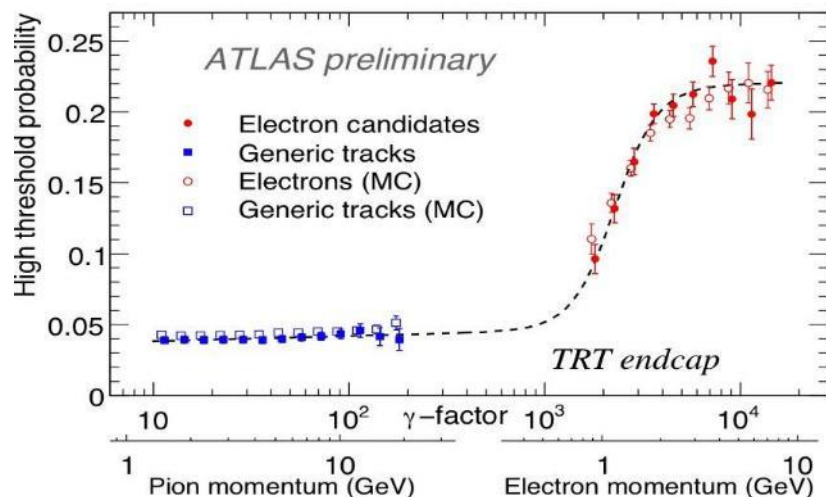
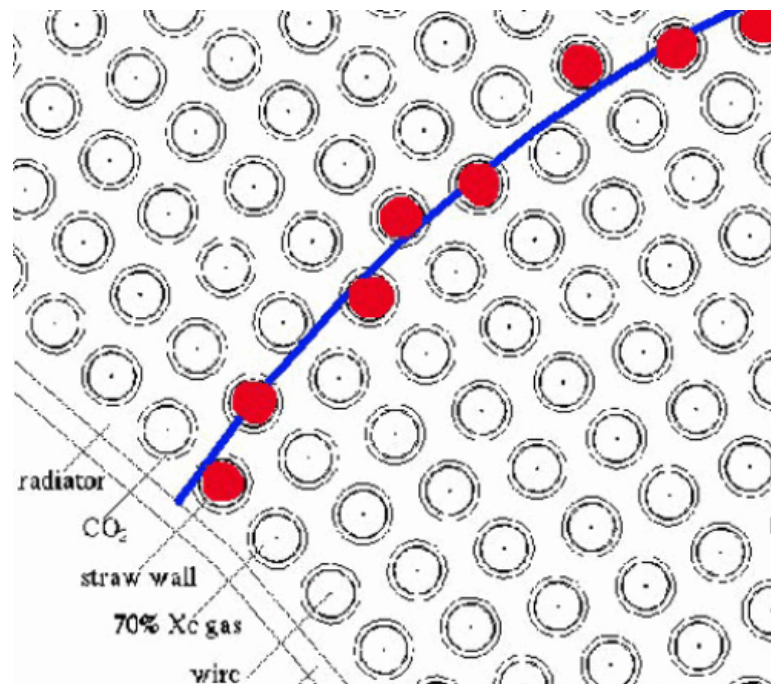
# Transition Radiation

Charged particles can emit photons at material boundaries

Effect depends on  $\gamma = E / m$

Many thin radiator fibres/foils increase X-ray emission probability

Noble gas (Xe, Ar) acts as absorber

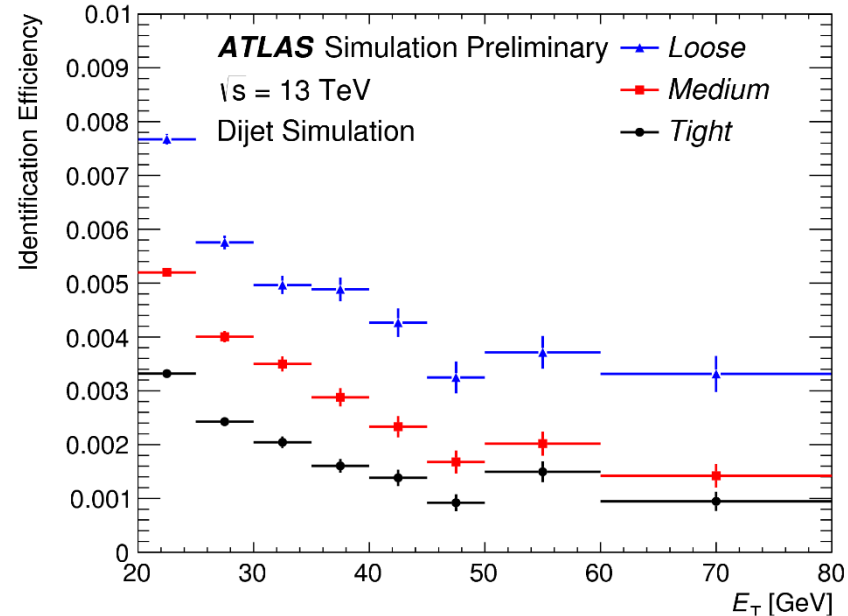
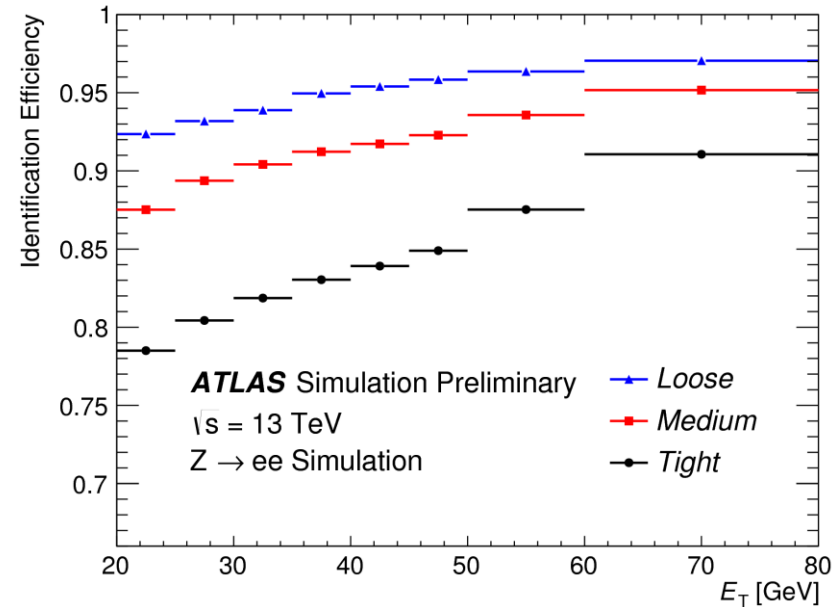


# Electron Identification

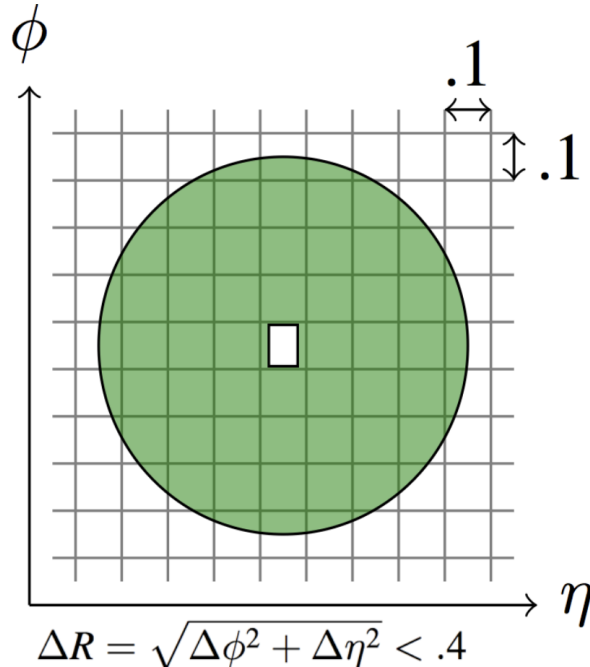
**Electrons:** Likelihood discriminant ( $\mathcal{L}$ ) using Probability Density Functions (PDFs) constructed from the shower shape, track and track-to-cluster matching variables

$$d_{\mathcal{L}} = \mathcal{L}_s / (\mathcal{L}_s + \mathcal{L}_b)$$

- $d_{\mathcal{L}}$  cut depends on  $E_T$ ,  $\eta$  and number primary vertices; input PDFs are corrected for known mis-modelings
- Input set variables vary with  $E_T$  (e.g.  $f_3$  is not used above 100 GeV)
- Three operating points **loose/medium/tight** (subset of each other)



# Isolation



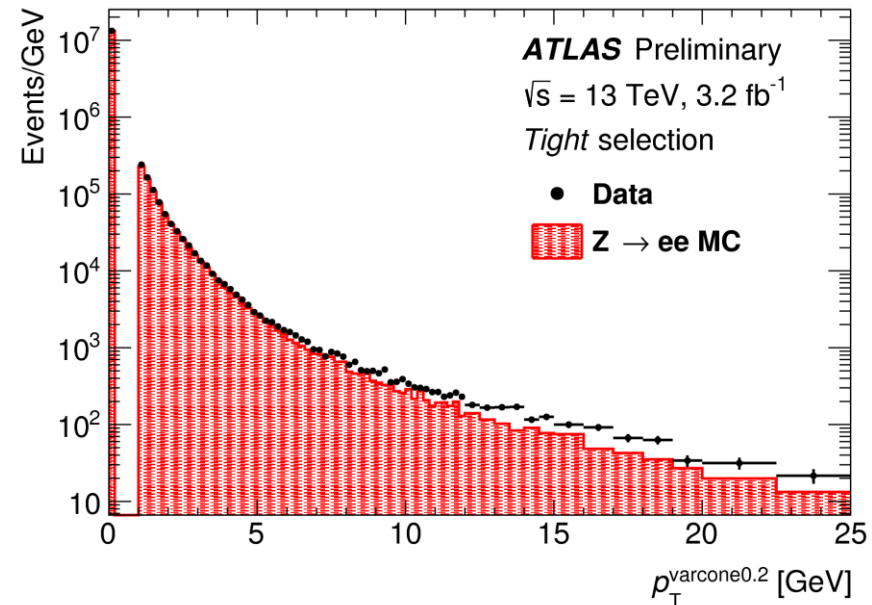
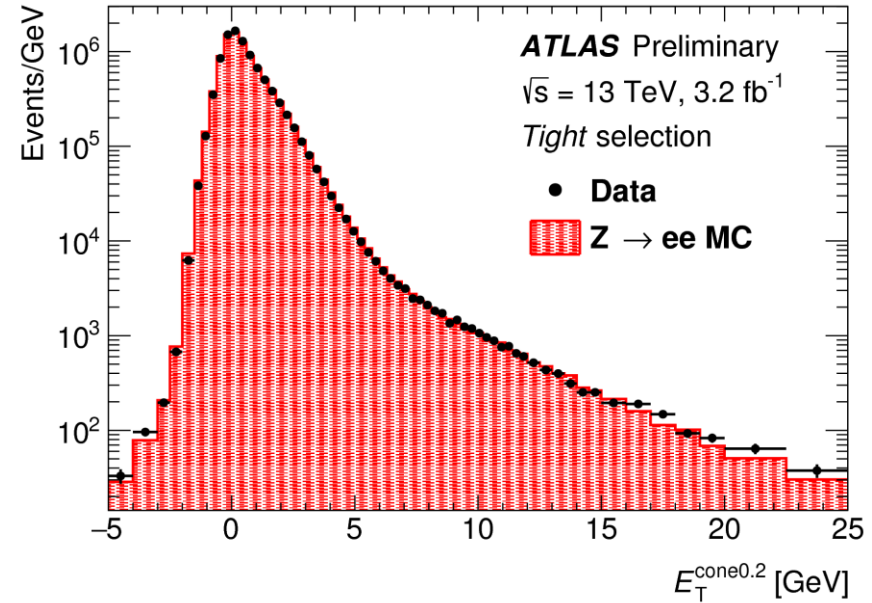
$E_T^{\text{iso}}$  is corrected for the energy leakage and pile-up event-by-event. Excluded:

$$\Delta\eta \times \Delta\phi = 0.125 \times 0.175$$

$p_T^{\text{iso}}(\text{var})$  sums tracks ( $>1\text{GeV}$ ) within  $\Delta R = 10 \text{ GeV}/p_T^e$

Two main configurations:

- Fixed efficiency (for higher  $p_T$  analyses)
- Fixed selection (for lower  $p_T$  analyses)



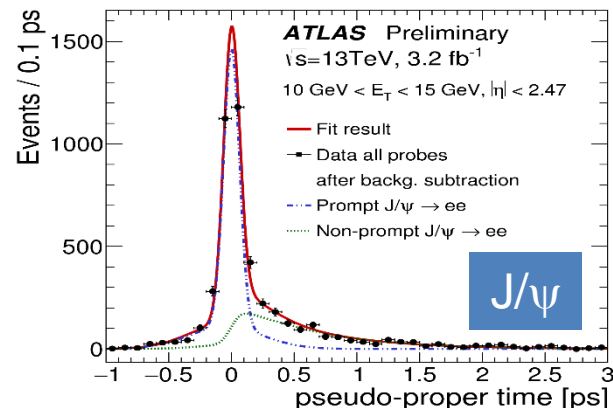
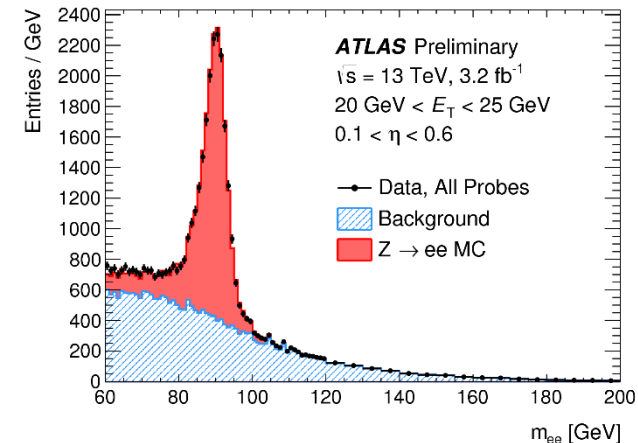
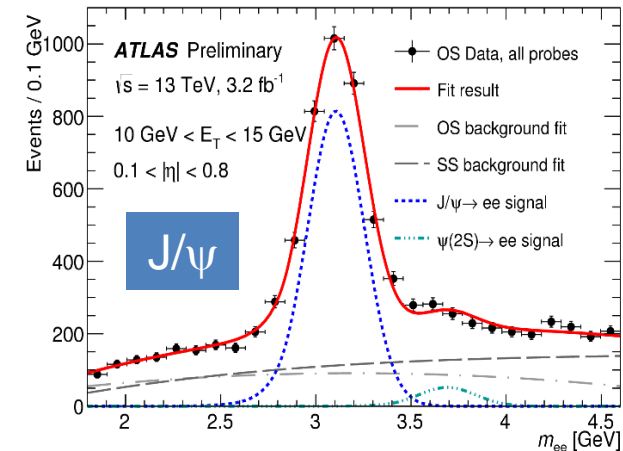
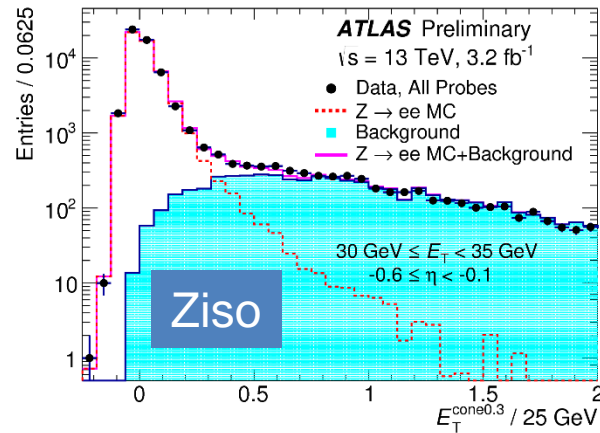
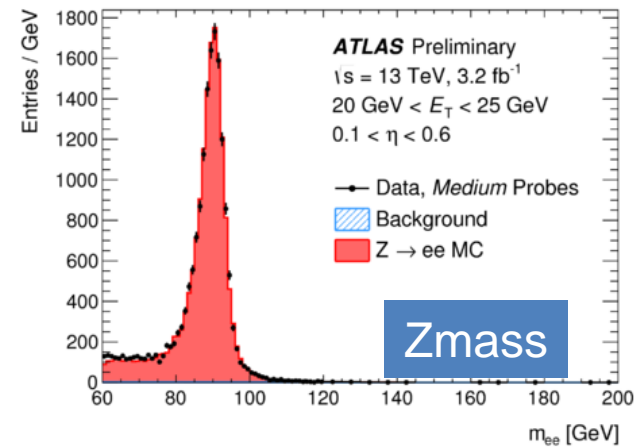
# Electron Efficiencies: Tag & Probe

Efficiencies measured in data ( $\epsilon_{\text{data}}$ ) and Monte Carlo simulation ( $\epsilon_{\text{MC}}$ ) following the same procedure

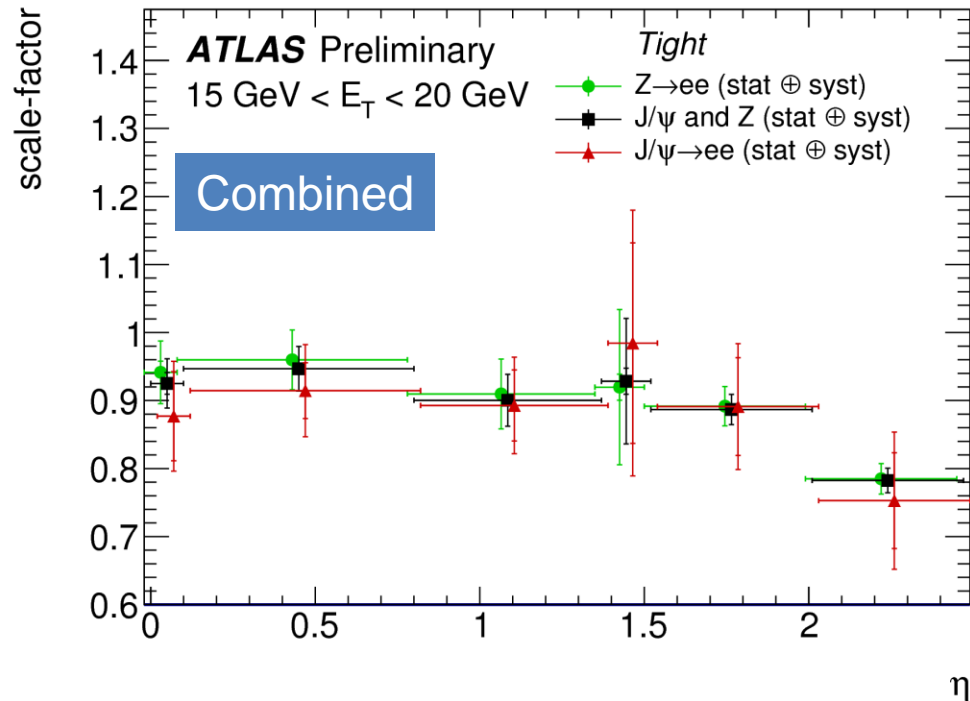
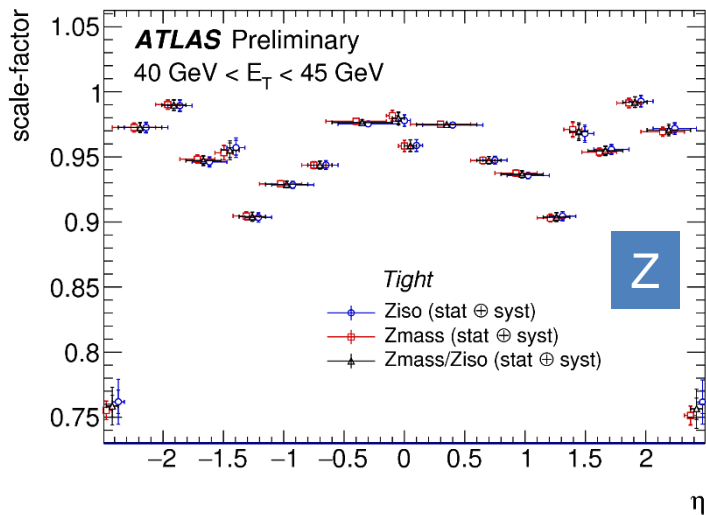
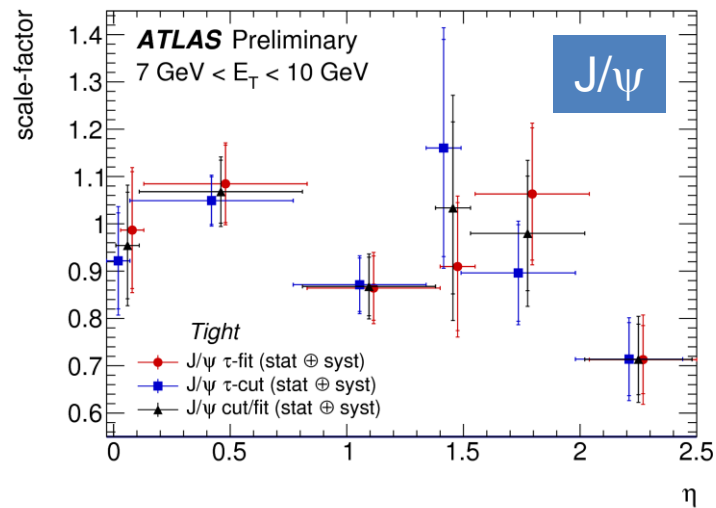
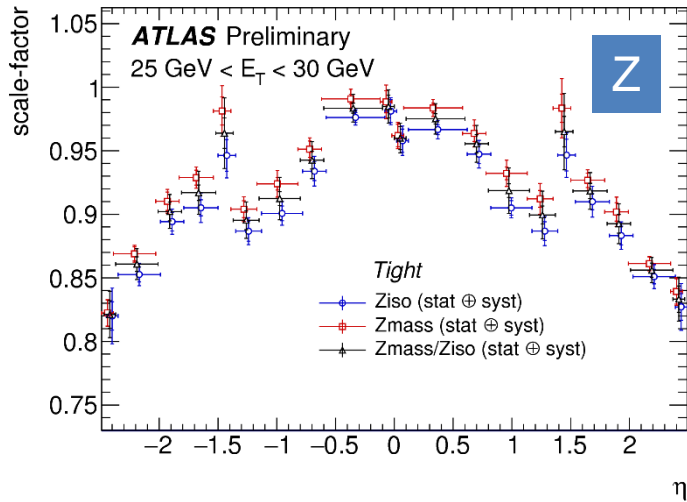
Tag & probe  $Z \rightarrow ee$  for  $p_T > 15 \text{ GeV}$  and  $J/\psi \rightarrow ee$  for  $p_T < 20 \text{ GeV}$

Only selected probes are used for the efficiency measurement after proper background subtraction

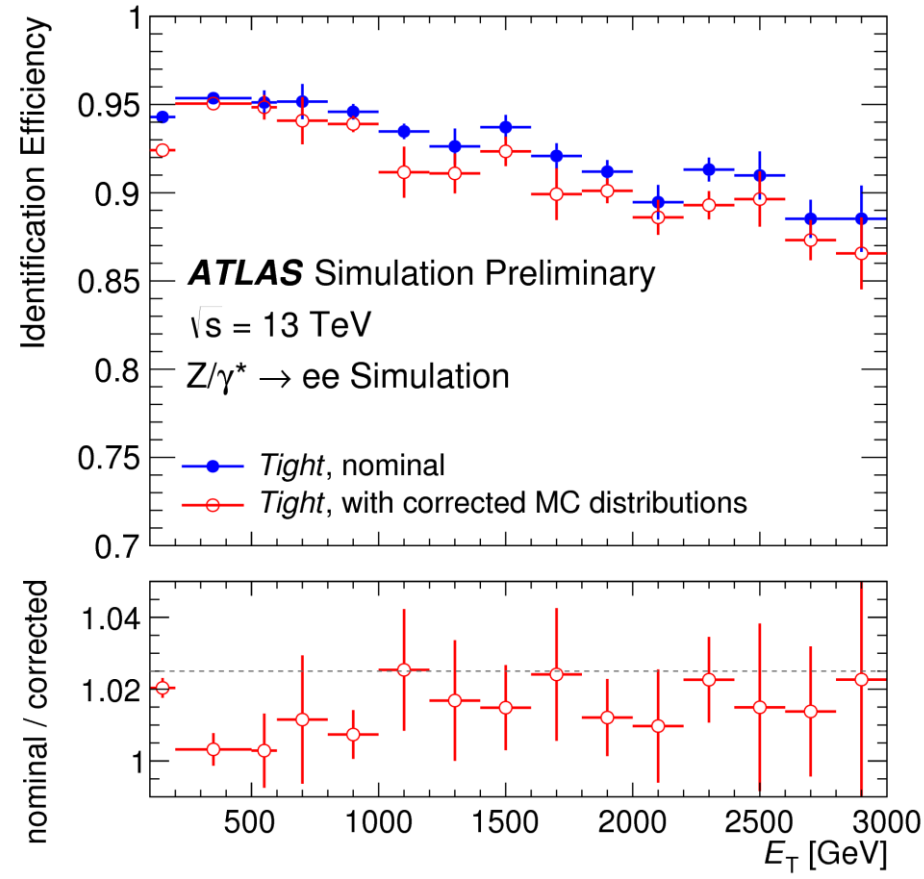
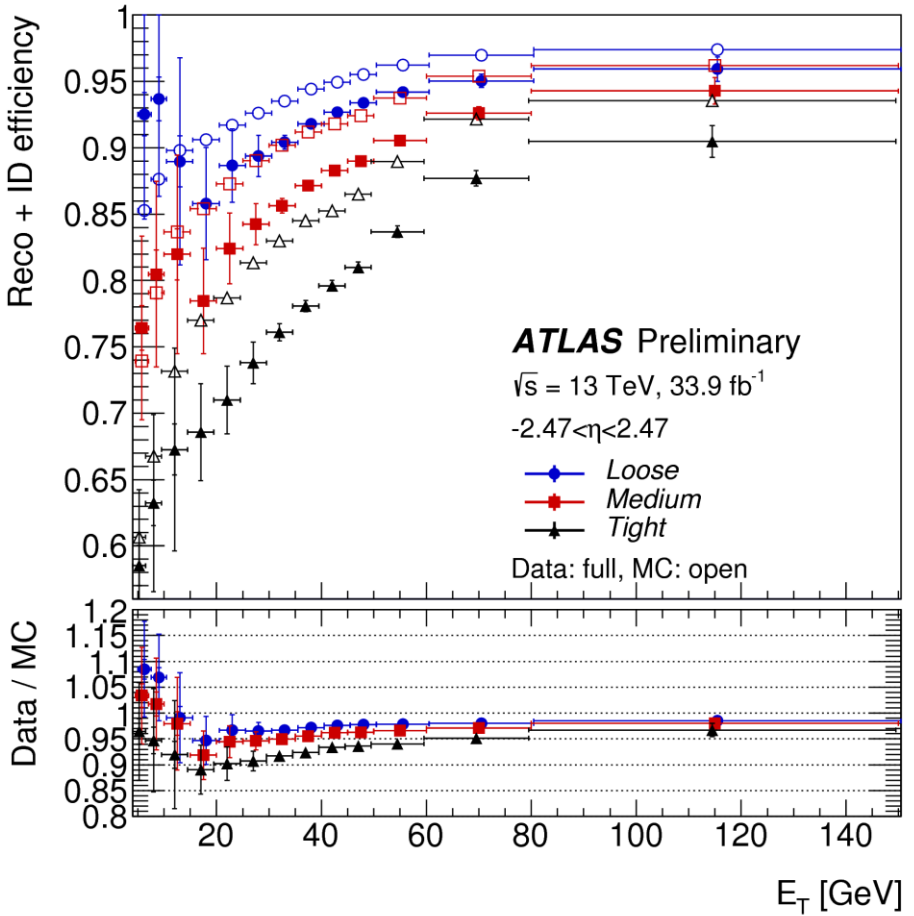
ATLAS-CONF-2016-024



# Combined Electron Efficiencies



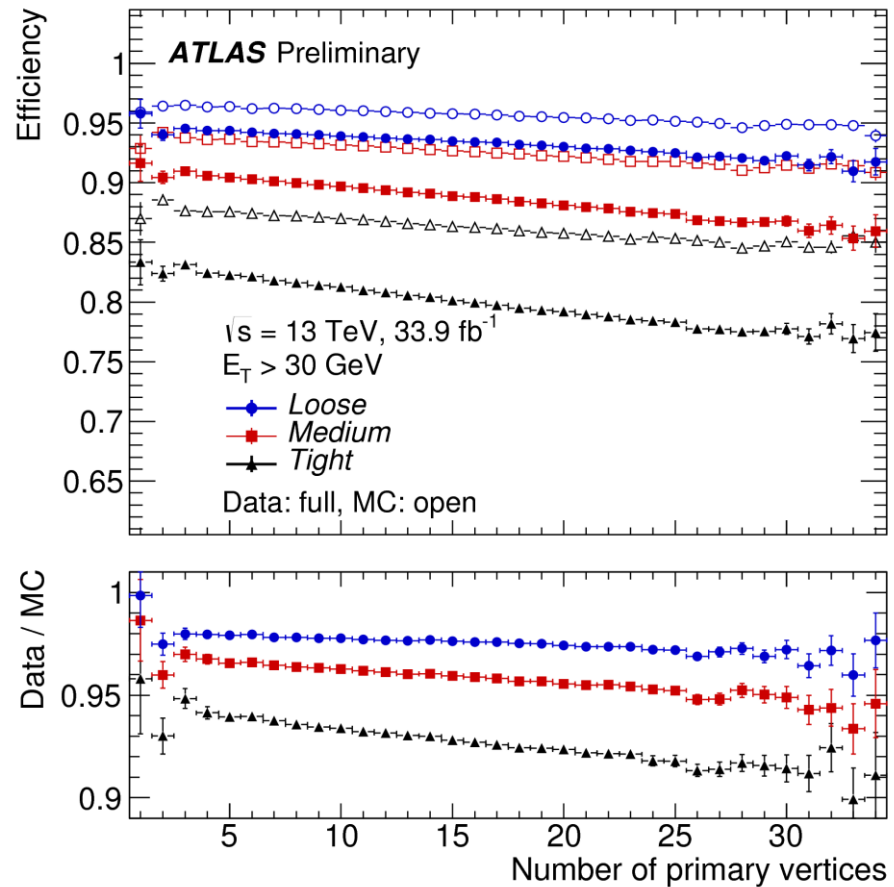
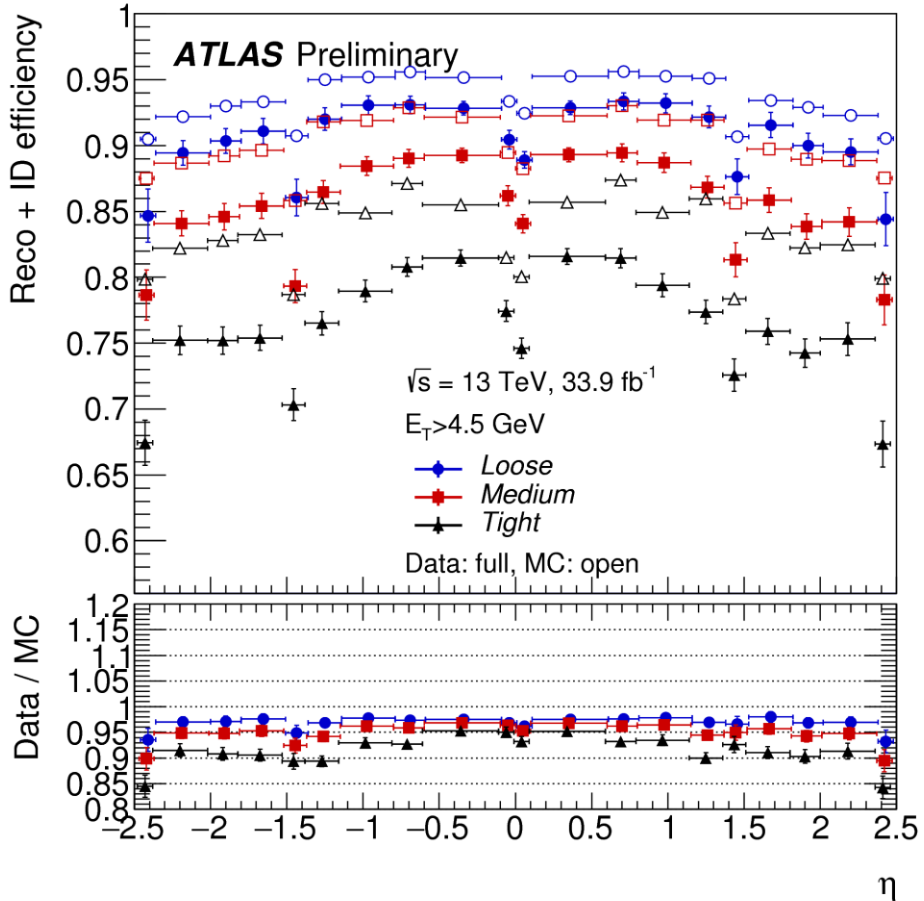
# Electron ID Efficiencies (1)



MC simulations needs to be corrected by Scale Factors (SF):  $SF = \epsilon_{\text{data}} / \epsilon_{\text{MC}}$

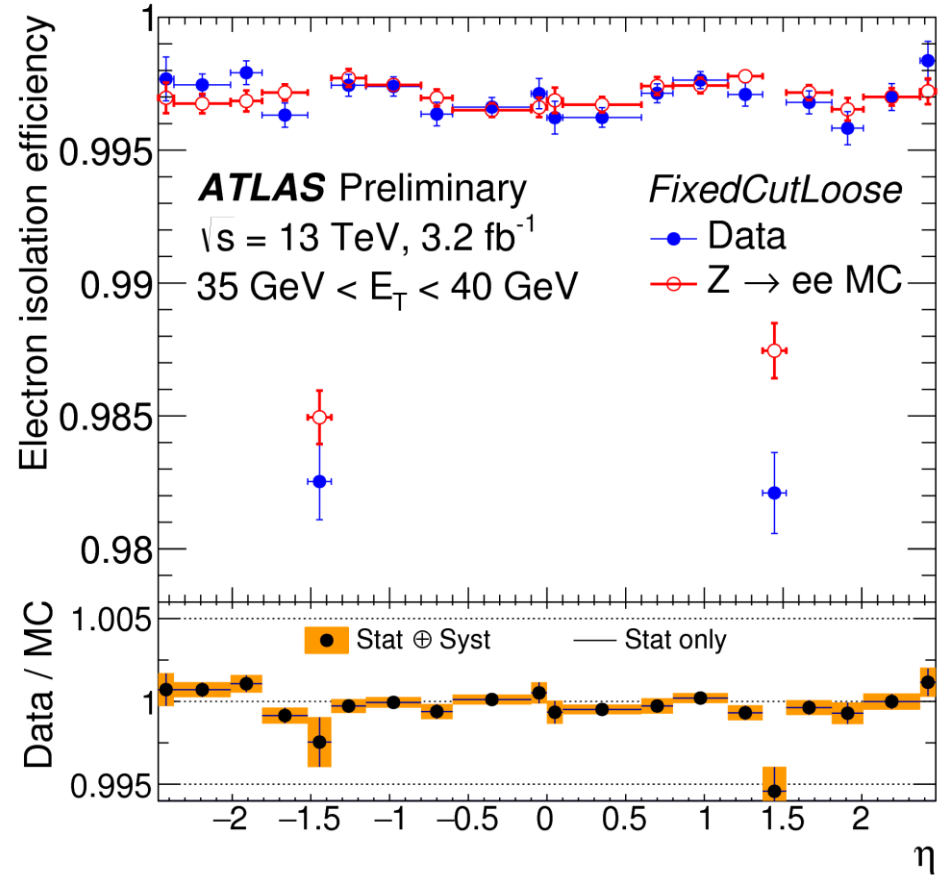
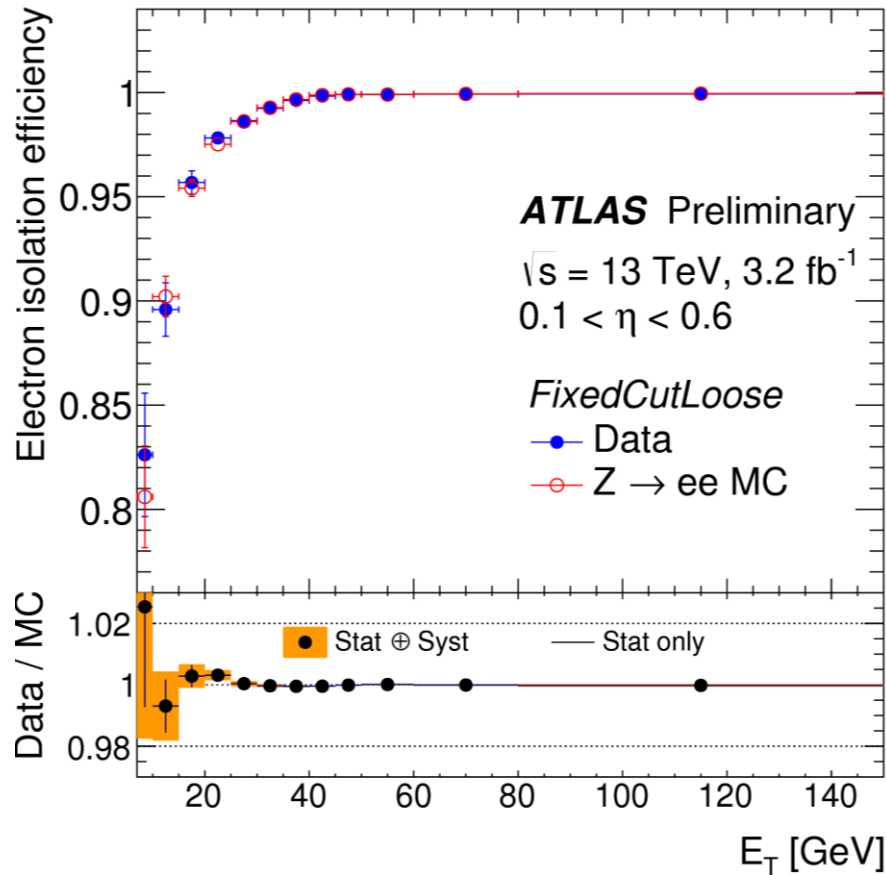
No PDF corrections (shift/width) are applied for the SF calculation.

# Electron ID efficiencies (2)



# Isolation Efficiency

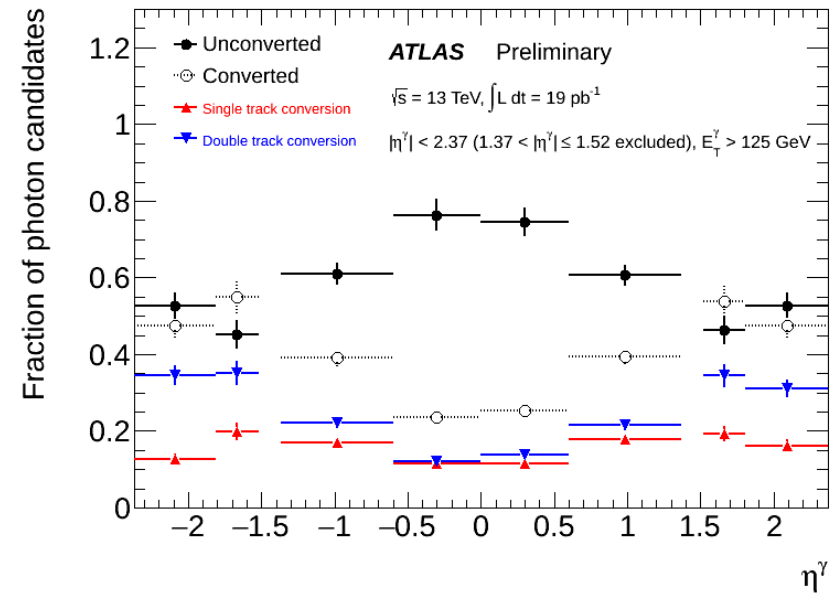
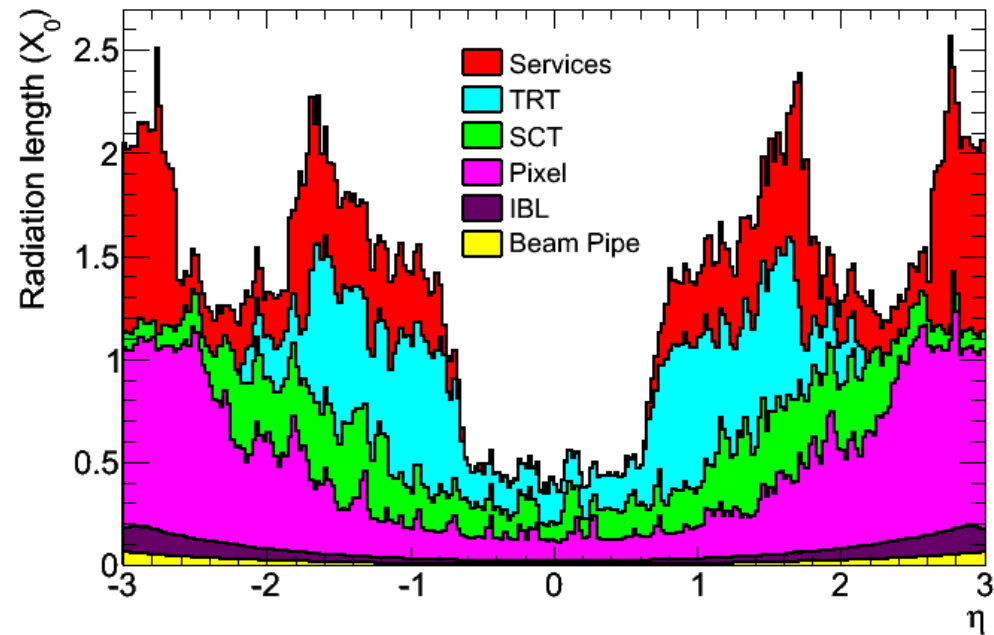
FixedCutLoose isolation requirement ( $E_T^{\text{cone } 0.2}/E_T < 0.2$  and  $p_T^{\text{varcone } 0.2}/E_T < 0.15$ )



# Photons

## Cut-based selection

- depend on  $E_T$  and  $\eta$
- shower-shape variables for unconverted photons;
- add tracking and track-cluster matching for converted photons
- Input variables are corrected for data/MC discrepancies
- Background rejections: loose  $\sim 1000$ , tight  $\sim 5000$



Radiative Z decay

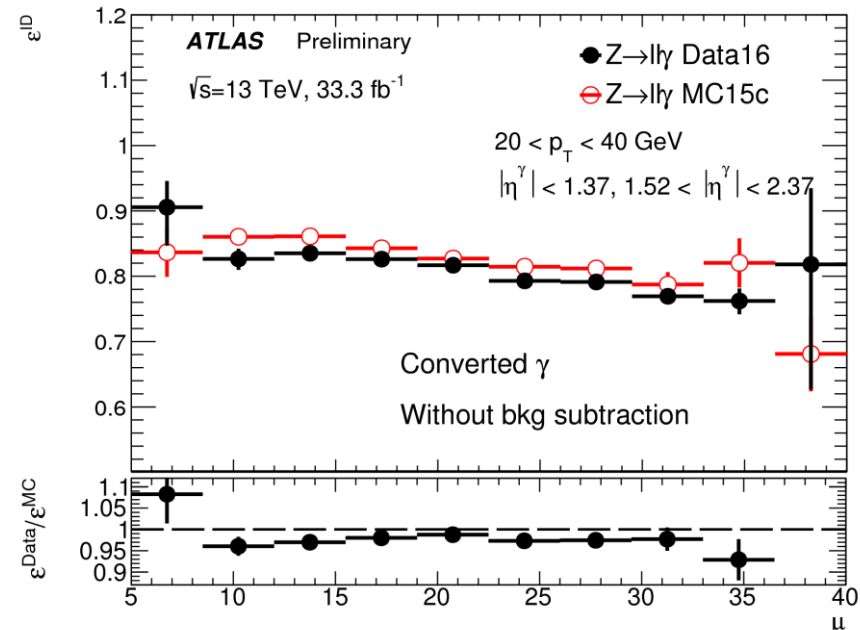
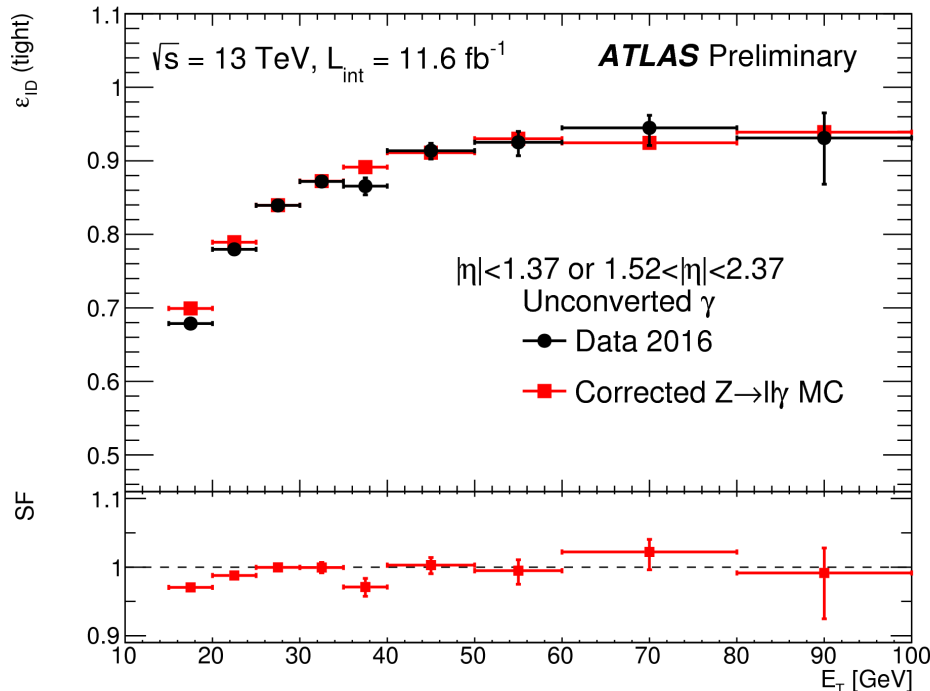
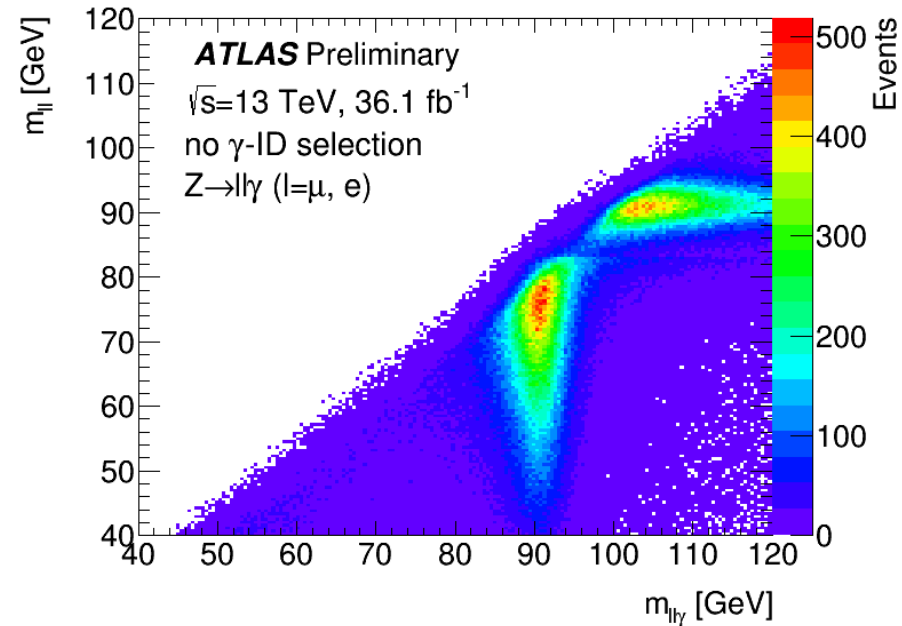
Electron Extrapolation

Matrix Method

10 25 100 150 1500  $E_T$ [GeV]

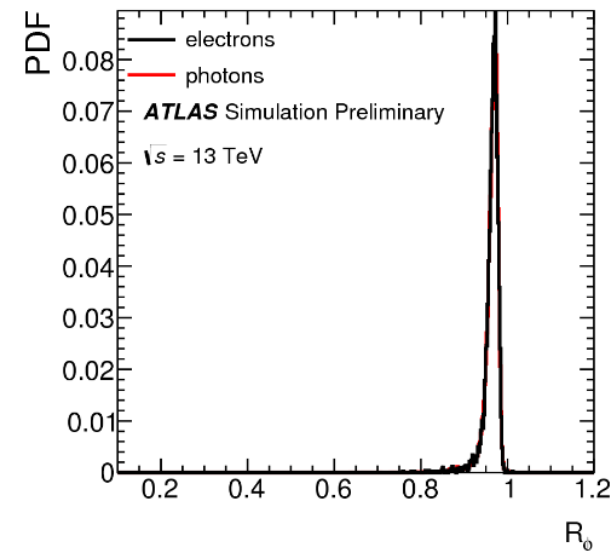
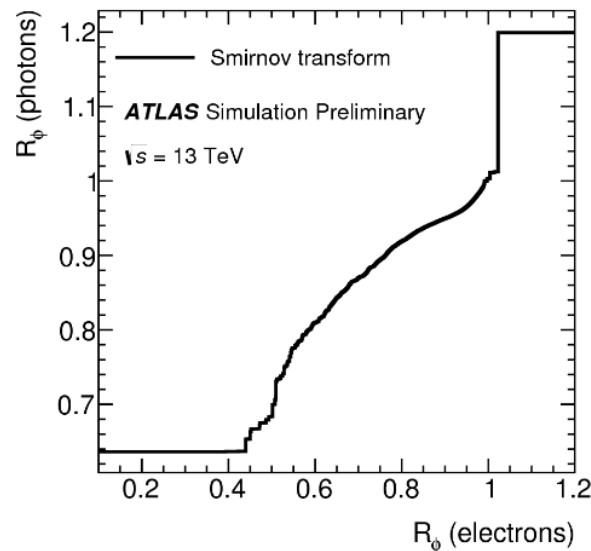
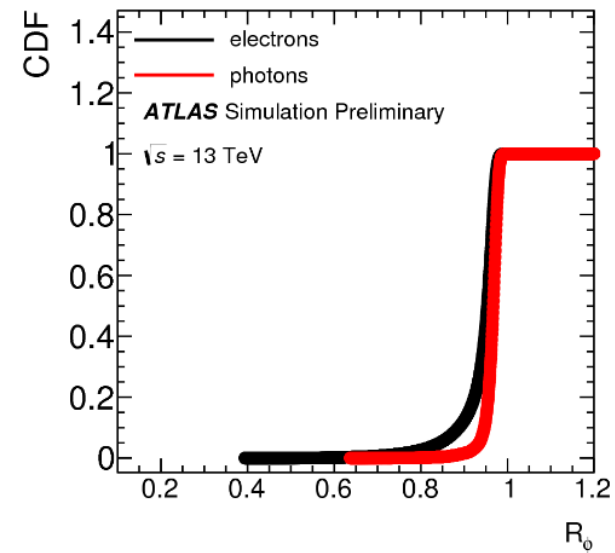
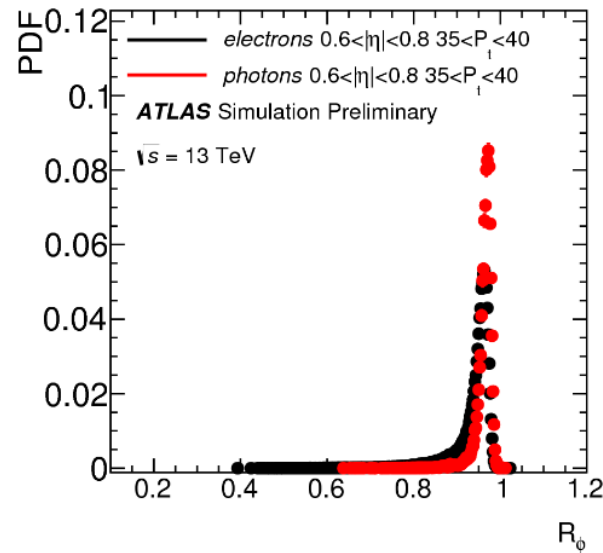
# Radiative Z decays

- Selection:  $\Delta R(e/\mu, \gamma) > 0.4/0.2$ ,  $E_T^\gamma > 10\text{GeV}$  + tight isolation (no ID!),  $p_T^l > 10\text{GeV}$ , e tight ID, combined  $\mu$ ...
- Pure sample of photons: Z+jets  $\sim 7.3$  (8.4)% in  $ee\gamma(\mu\mu\gamma)$  for  $10\text{GeV} < E_T^\gamma < 20\text{GeV}$
- Allows efficiency measurements between 10GeV and 100GeV



# Electron Extrapolation Method

- Derive CDF-based Smirnov-Transform from MC to modify e-shower shapes to reproduce  $\gamma$
- Apply the correction to electrons shower shapes obtained from  $Z \rightarrow ee$  Tag & Probe analysis
- Advantage: higher statistics of electrons wrt photons

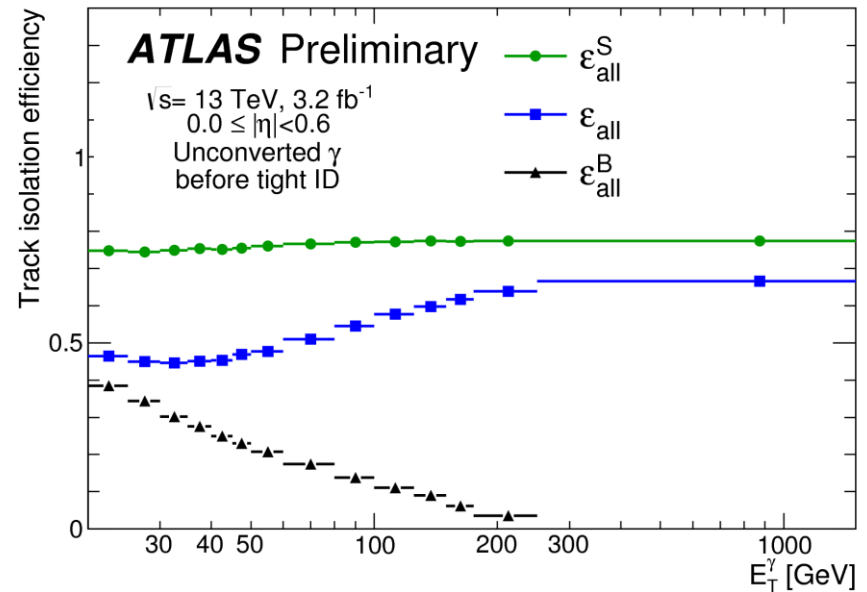
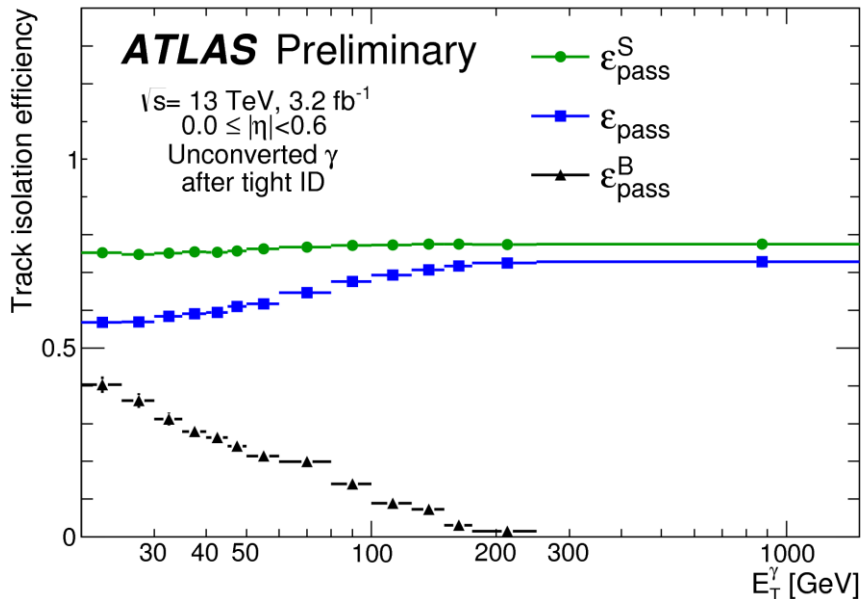


# Matrix Method

- Collect photon-enriched sample with loose photon triggers
- Track isolation efficiencies:

Identification $\Rightarrow$	No Cut	tight
Data	all	pass
Signal MC	S, all	S, pass
Background	B, all	B, pass

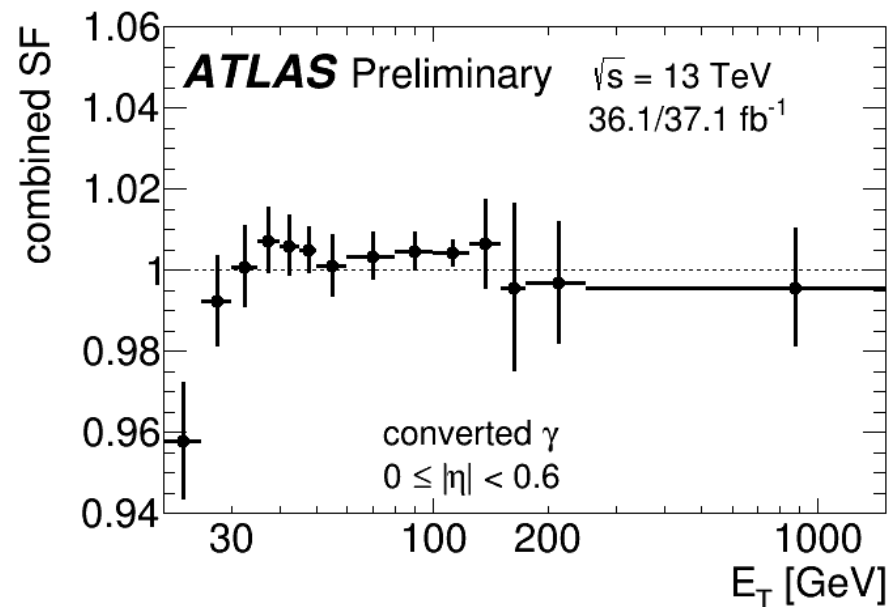
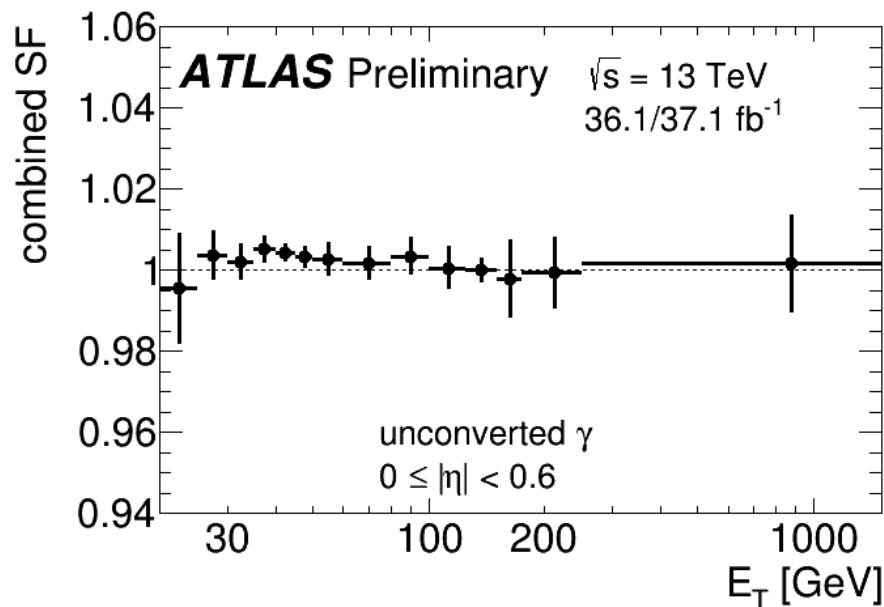
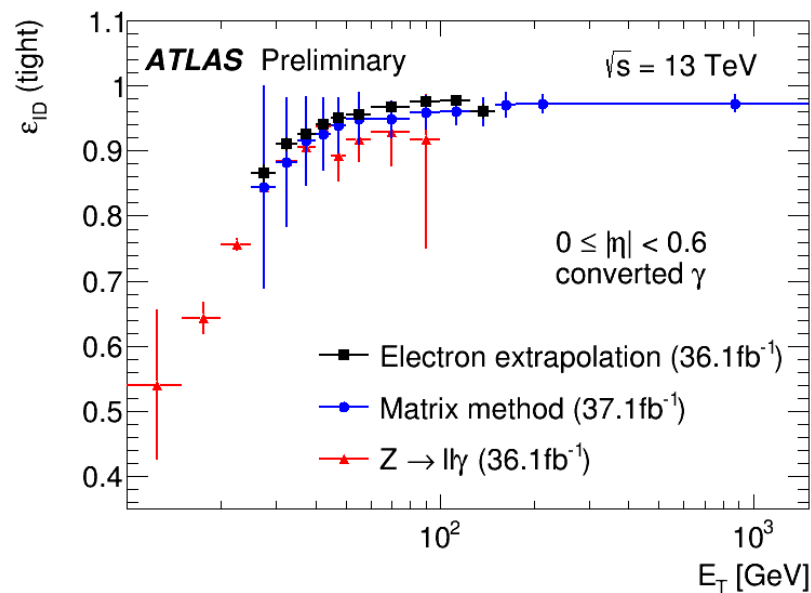
$$\epsilon_{ID} = \frac{\frac{\epsilon_{pass} - \epsilon_{pass}^B}{\epsilon_{pass}^S - \epsilon_{pass}^B} \cdot N_{pass}}{\frac{\epsilon_{all} - \epsilon_{all}^B}{\epsilon_{all}^S - \epsilon_{all}^B} \cdot N_{all}}$$



# Combined Photon Efficiencies

SF from three methods are combined independently in each  $p_T/\eta$  bin using BLUE technique

Input variables for SF calculation are corrected for data/MC discrepancies



# Summary

---

- ATLAS  $e/\gamma$  reconstruction and ID presented
- Data driven measurements for  $e/\gamma$  efficiencies compared to MC predictions
  - Electron Efficiency known to  $<1\%$  for  $E_T > 30\text{GeV}$
  - Good MC modeling, residual differences corrected by SF
  - Ten fold increase in collected data (2016 vs 2015) allowed to extending the measurement to higher and lower energies
- More  $e/\gamma$  performance results are available at <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ElectronGammaPublicCollisionResults>