Electron and photon identification with the ATLAS detector

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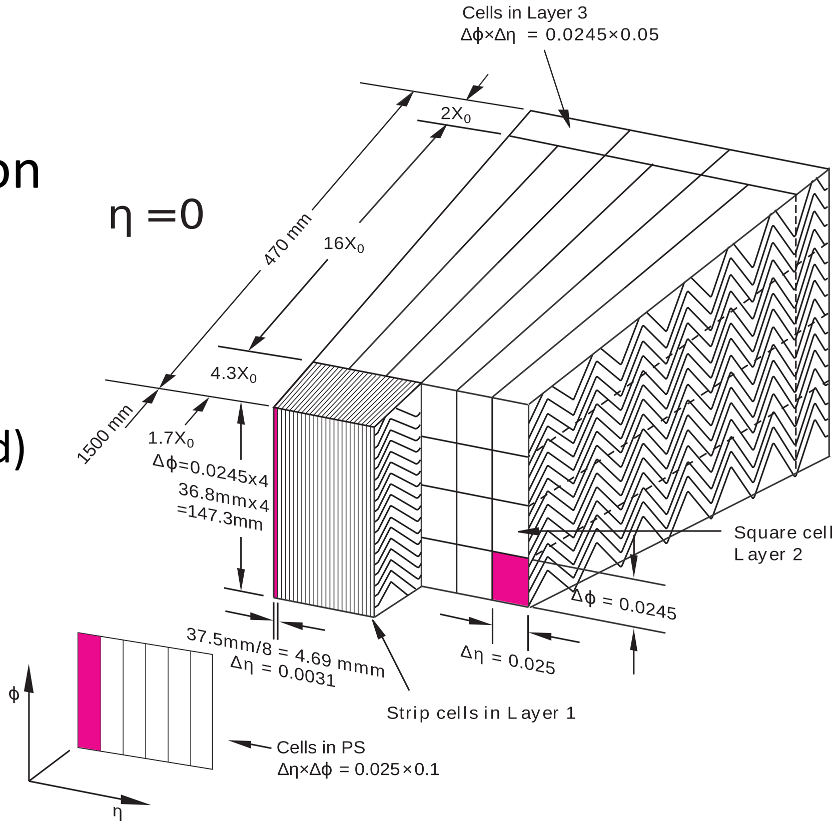
Reconstruction & Identification at ATLAS

high granularity of the ATLAS calorimeter ECAL



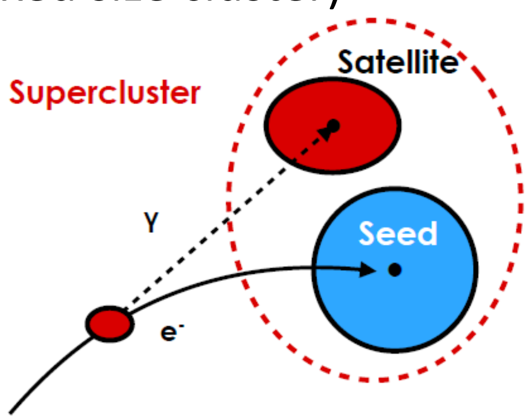
Electrons & Photons: Crucial for most of the analysis (SM, Higgs, BSM?)

- high efficiencies, good background rejection
- precise understanding of performance

Reconstruction:

- **Electrons**: Energy cluster and matching track
- **Photons**: Energy cluster without track (unconverted)
    - or matched to track(s) from conversion vertex (converted)

NEW: use of superclusters (w.r.t rectangular fixed size cluster)



- recover low E photons from bremsstrahlung in the Inner Detector, and connect them to their associated electron or converted photon.

– can contain a wide range of deposited E with good E resolution for both low and high energy particles

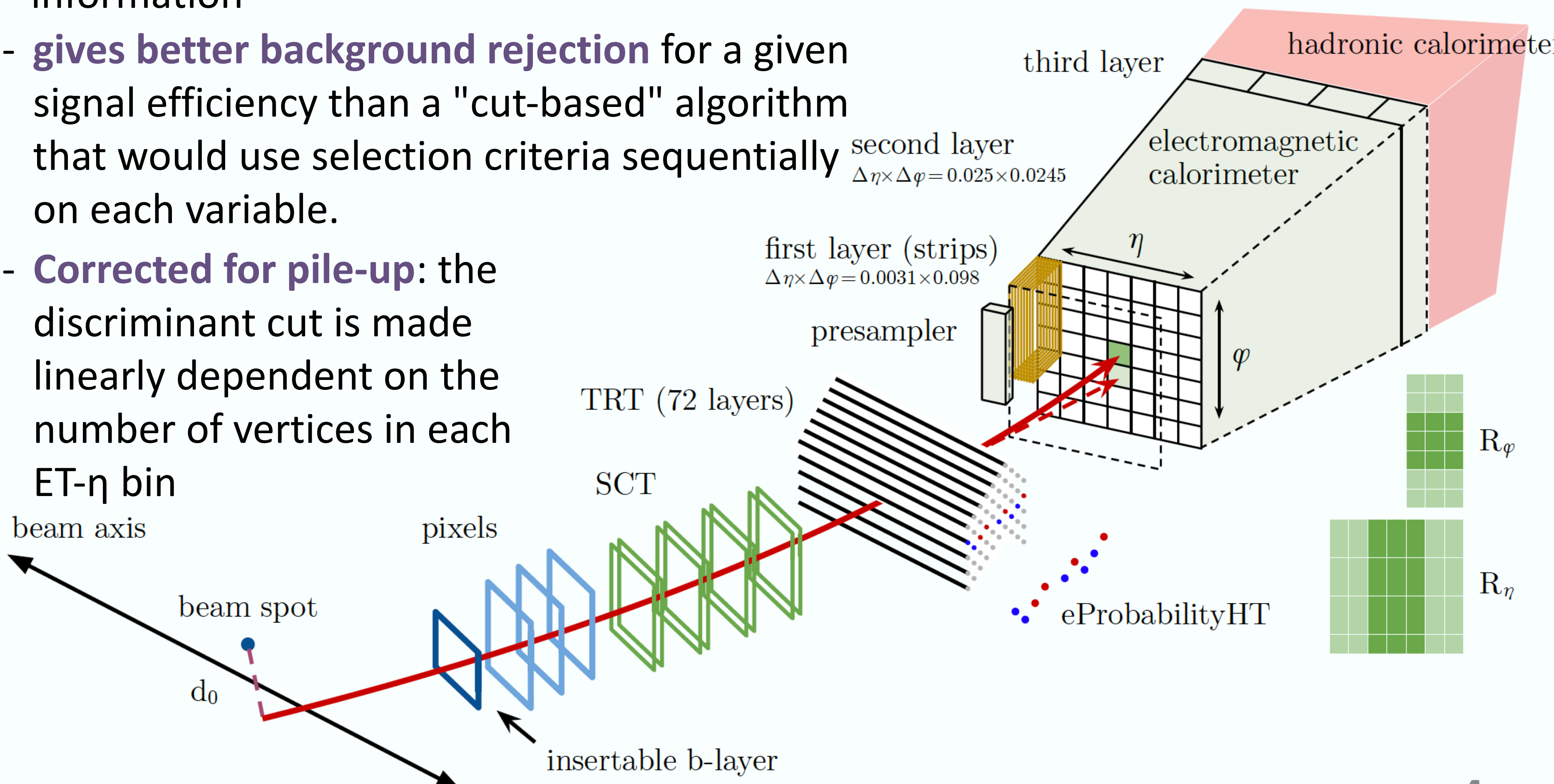
Electrons

ATLAS-CONF-2016-024

Electron identification

Electron identification:

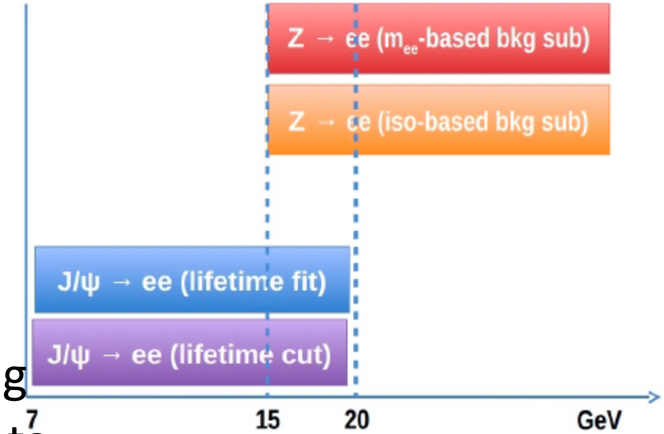
- **based on a likelihood (LH)** discrimination to separate **isolated electrons** from photon conversions, hadron misidentification and heavy flavor decays.
- multivariate: use of shower shape, track information, and track-cluster matching information
- **gives better background rejection** for a given signal efficiency than a "cut-based" algorithm that would use selection criteria sequentially on each variable.
- **Corrected for pile-up**: the discriminant cut is made linearly dependent on the number of vertices in each ET-η bin



Electron identification

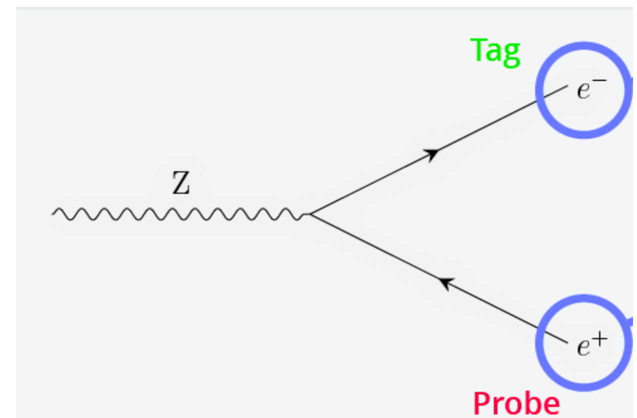
Measured in data with tag&probe method:

- J/Ψ (low ET), Z (high ET) decays to electrons

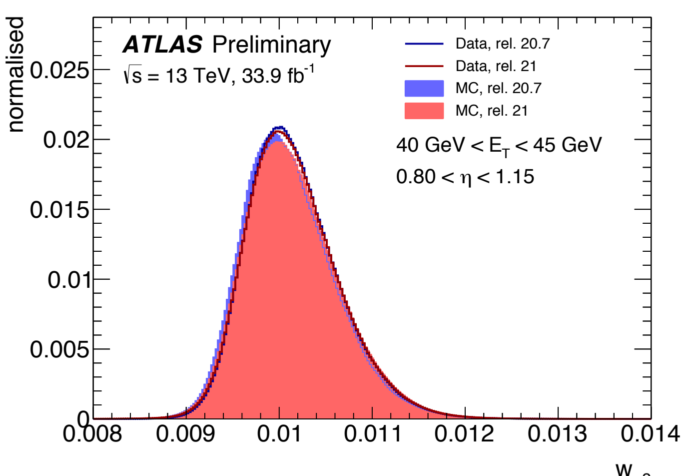


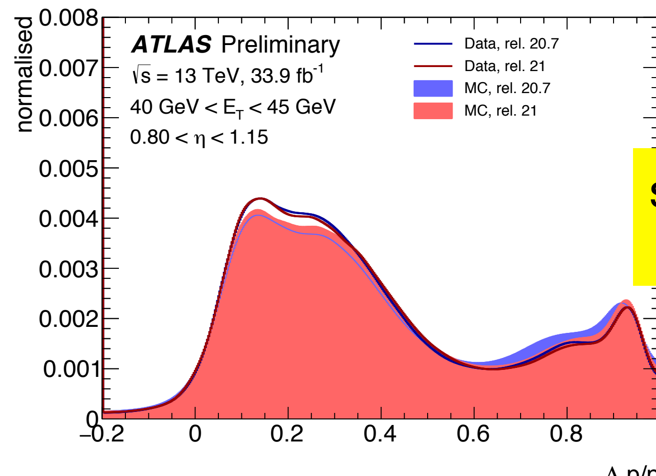
1. **PDFs** (Probability Density Functions) of discriminating variables for signal and background are formed from data distributions

$$d_L = \frac{L_S}{L_S + L_B} \qquad L_s(x) = \prod_{i=1}^{n} P_{s,i}(x_i)$$



2. LH discriminant calculated
3. Discriminant cut selected to match desired efficiency





some of discriminating variables

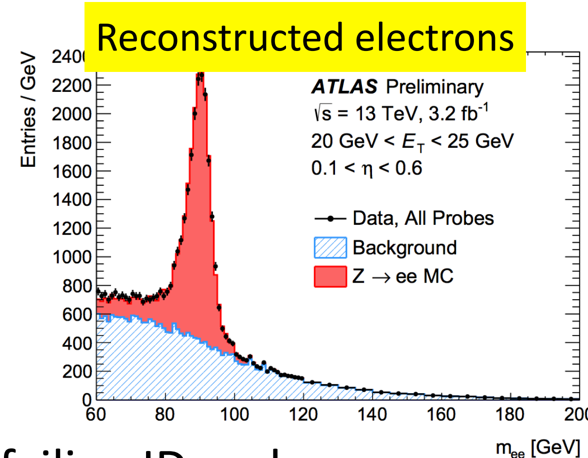
Identification efficiency

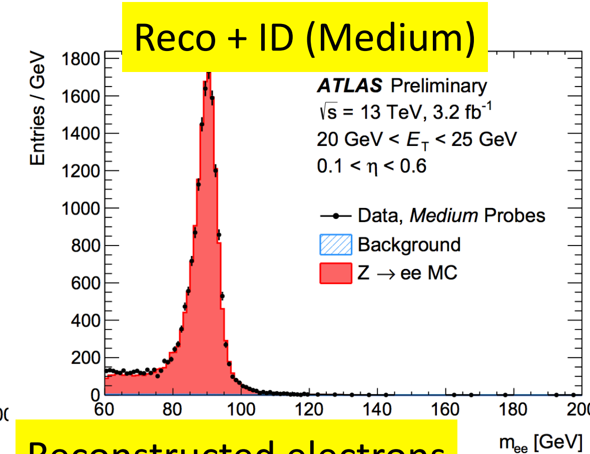
Z mass method

Background subtraction is performed using **the mass distribution** as the discriminating variable.

– **Background templates**: probes failing ID and isolation criteria

– The background model is normalised to the side-bands (high-invariant mass tail or low invariant mass)





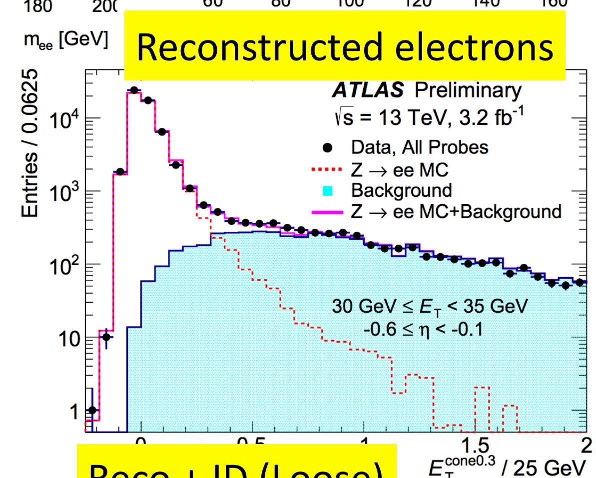
Z iso method

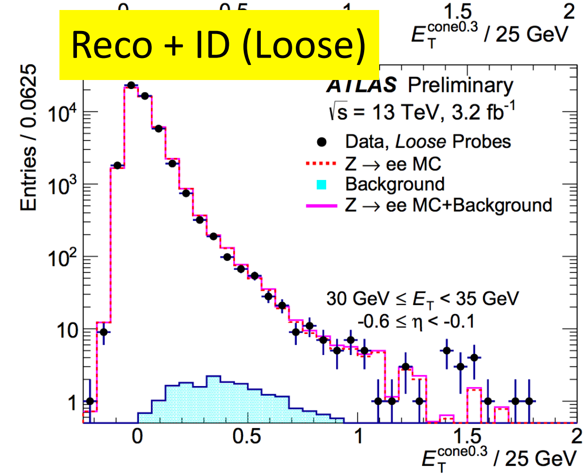
use **the probe isolation** (calo iso) as a discriminator between signal and background

– **Background templates**: created by inverting cuts on shower shape and ID variables

– From MC: Subtract real electrons passing the background selection

– Scale background model to data using entries in tail of probe isolation distribution





Identification efficiency

J/Ψ method

pseudo-proper time

$$\tau = \frac{L_{xy}\, m^{J/\psi}}{p_T^{J/\psi}}$$

1. **2 main backgrounds**:

– **jets, photons from conversions, etc**

- Estimated from fit of m_{e+e-} distribution

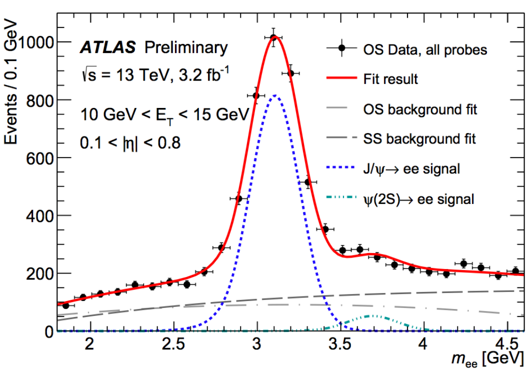
– random combinations of e not from J/Ψ

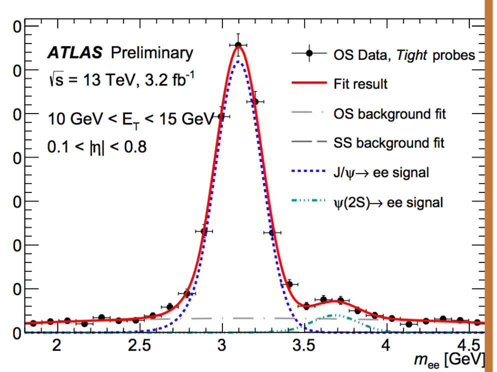
- Estimated from same sign sample m_{e+e+} or m_{e-e-}

2. Separation between prompt and non-prompt with use of pseudo-proper time τ

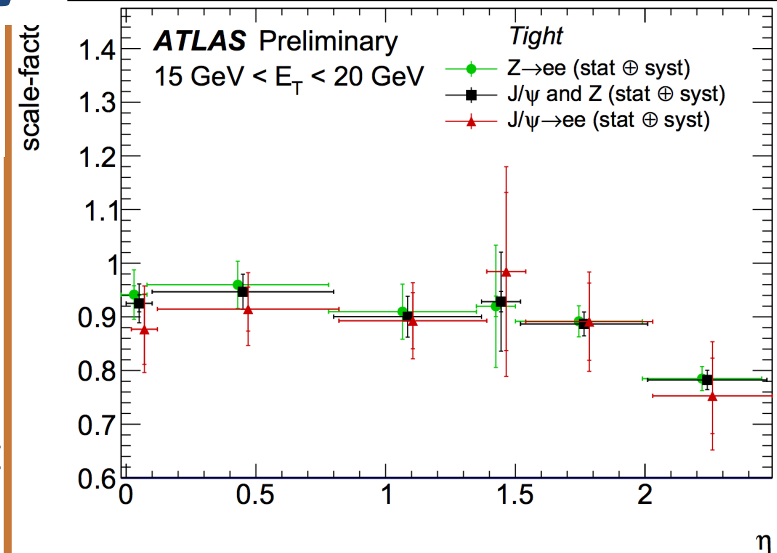
3. Unbinned fit of m_{e+e-} distribution is performed in the region 1.8 GeV - 4.6 GeV:

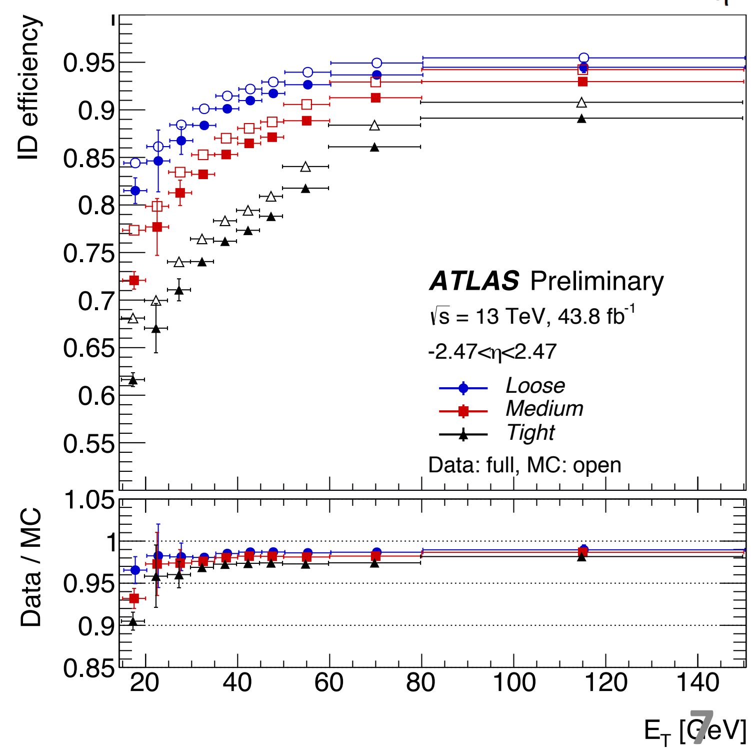
– two Crystal-Ball+Gaussian for J/Ψ and Ψ(2S) signals + Chebychev polynomial of the 2nd order for opposite sign background





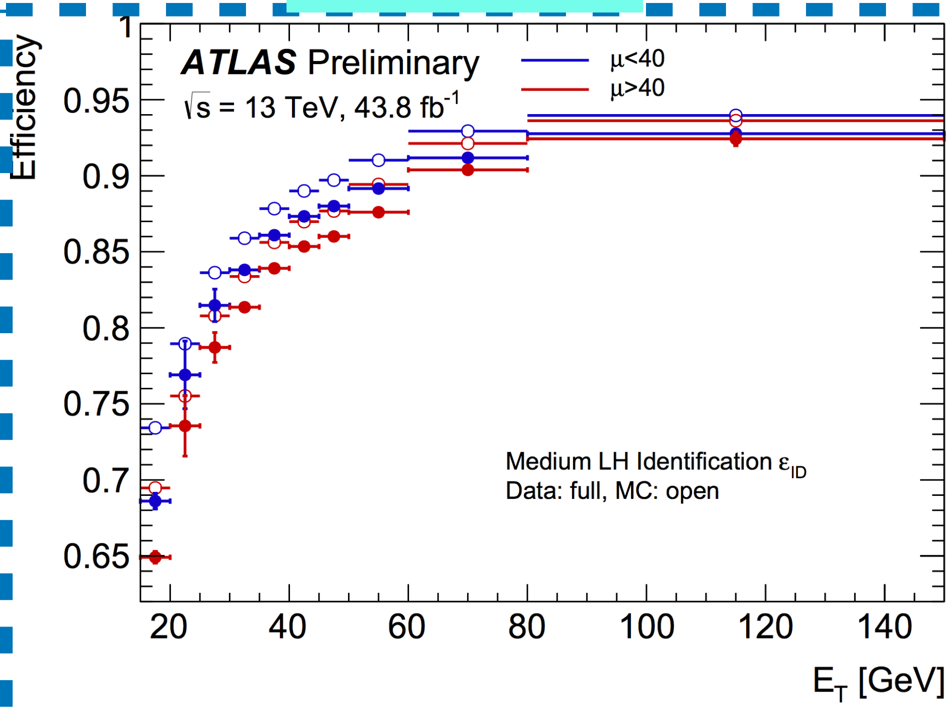
Combination





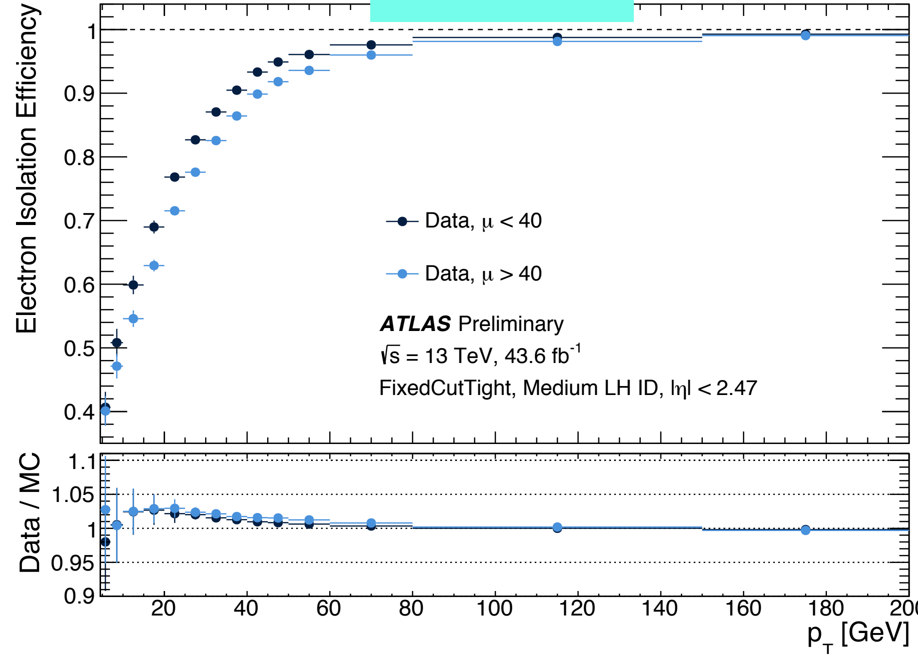
Electrons and high pile-up

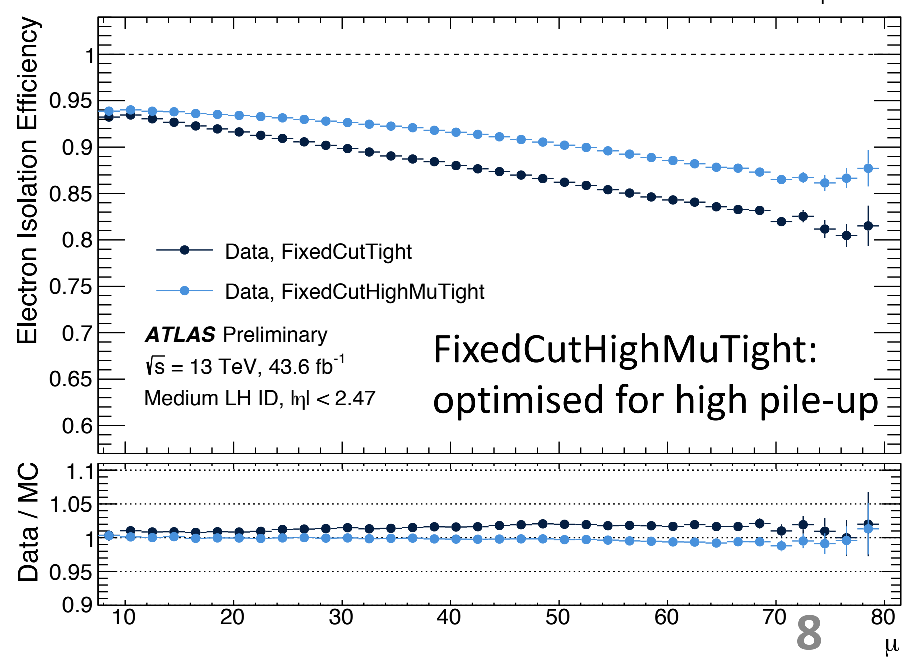
Identification



Efficiency drops in both data and MC by ~5%

Isolation





Isolation is defined as:

$\Sigma E_T < 0.2\ E_T$, the sum is over all calo clusters in a cone $\Delta R = 0.2$ &

$\Sigma p_T < 0.15\ E_T$, the sum is over all tracks (with $p_T > 1$ GeV) in a cone $\Delta R = 0.2$

Photons

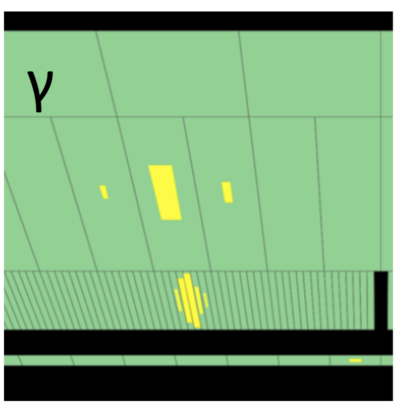
Photon reconstruction and identification

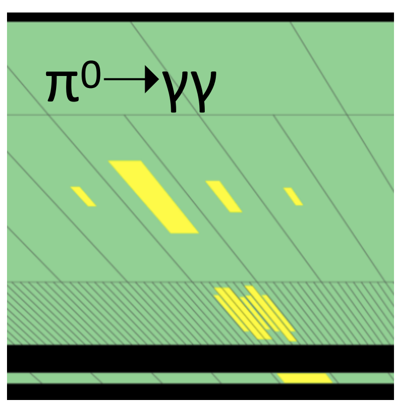
Prompt photons:

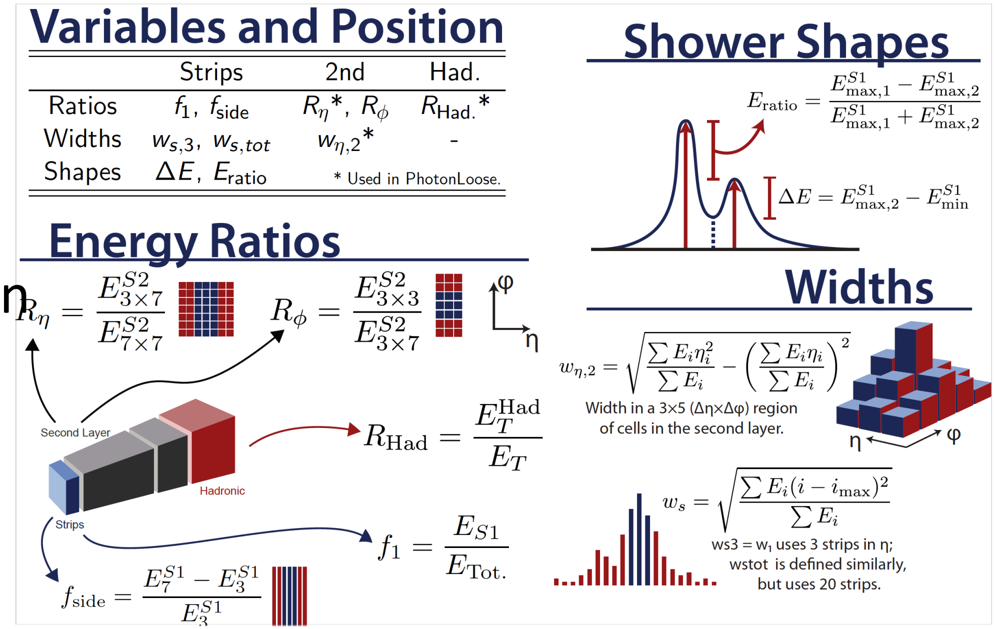
- Direct photon from the hard scattering process
- Fragmentation photon from a parton (less isolated)

Background:

- jets with large EM fraction (e.g. π0, η) that can fake photons
- Electron with similar interaction in calorimeter







ID: 9 discriminating variables (DVs) based on energy in cells of ECAL and leakage in hadronic calorimeter HCAL

loose ID

- exploits the DVs in the HCAL and in the ECAL middle layer
- used by triggers or as background control region

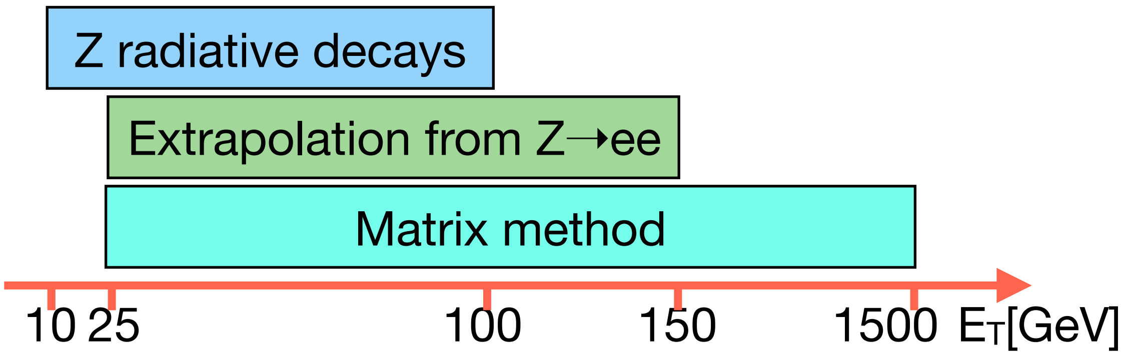
tight ID

- tighter cuts on DVs used by loose ID, use also ECAL strip layer
- used for offline analysis

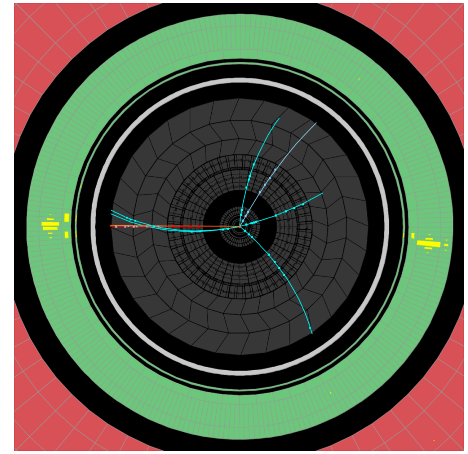
Photon reconstruction and identification

Tight ID: cut-based menu, with dependence on conversion status and η

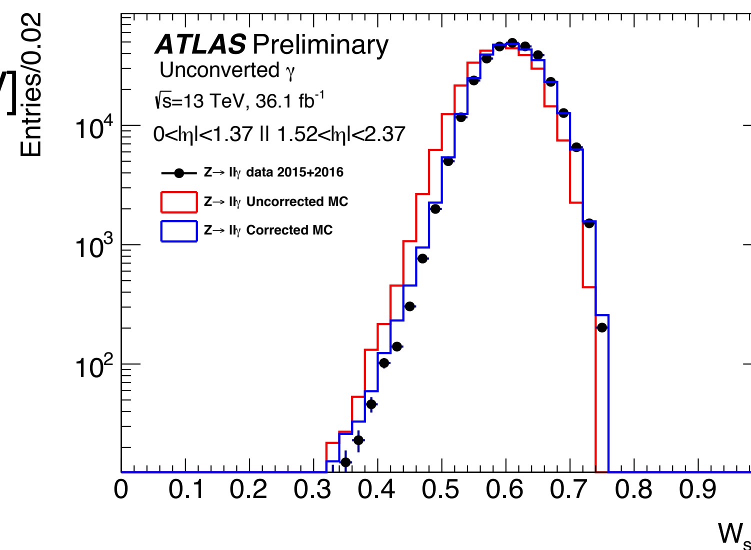
- Measured with **isolated photons**
- **3 methods** with different ET ranges



- measurements are done in **data** :
    1) MC shower shapes are shifted to data so that their means match the data means
    2) residual differences in MC corrected later to data



left photon: converted (two tracks)
right photon: unconverted

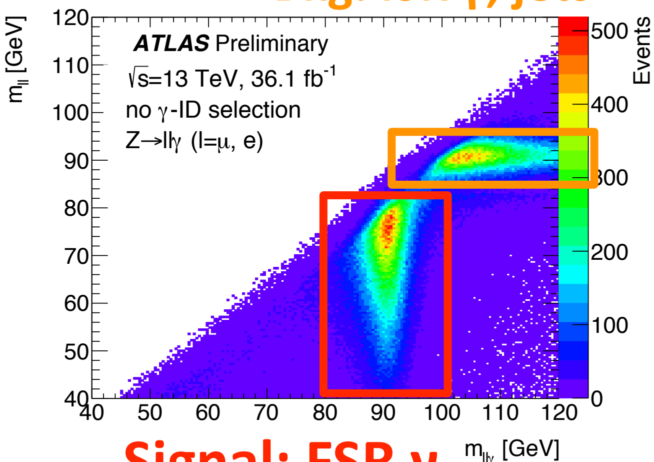


Shower shapes in MC are different than in data → MC is shifted to reproduce the data

Tight photon identification

Z radiative decays

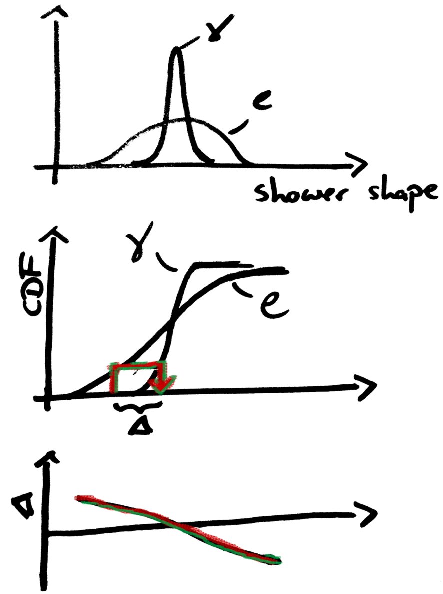
Bkg: ISR γ, jets



Signal: FSR γ

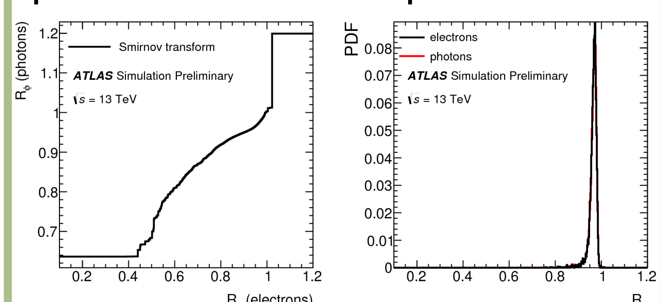
- low ET range, but pure photon sample (P=95-99%)
- For FSR selection cuts used on Mll and Mllγ
- Background contamination (Z+jets) is estimated from mllγ template fit and subtracted from data

Extrapolation from Z->ee

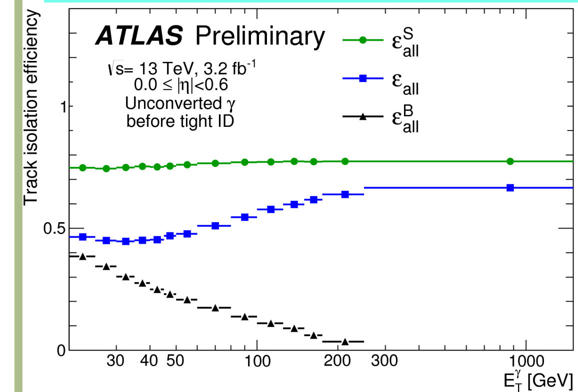


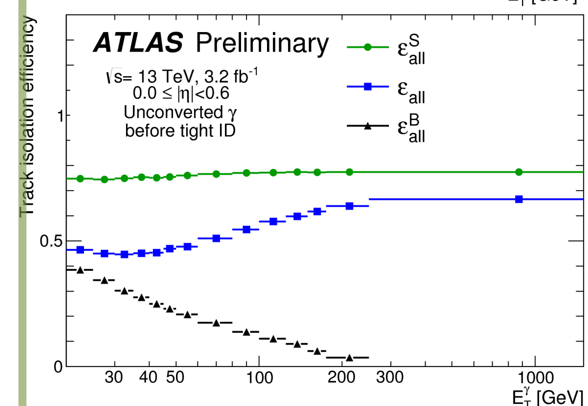
Use of Smirnov Transformation

(based on CDFs) to transform electron shower shapes to photon shower shapes



Matrix method

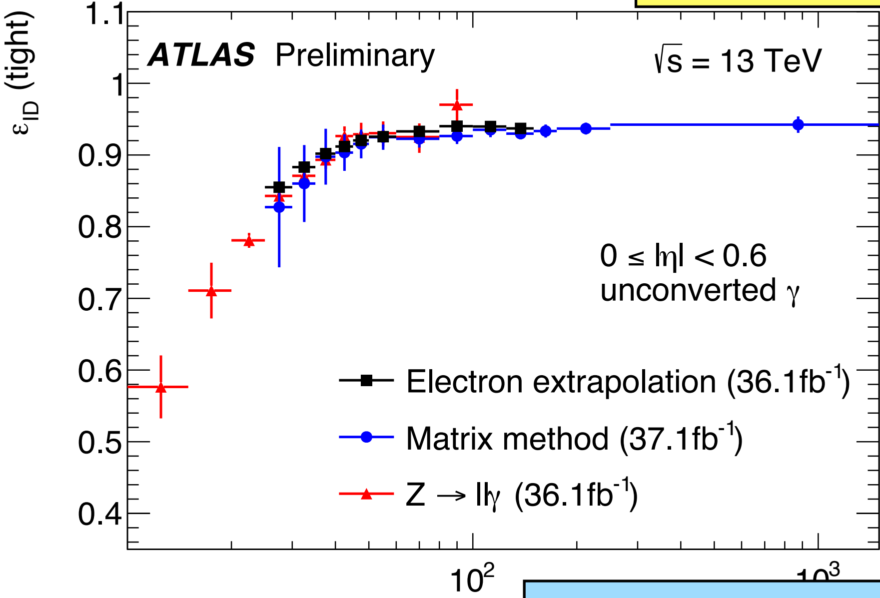


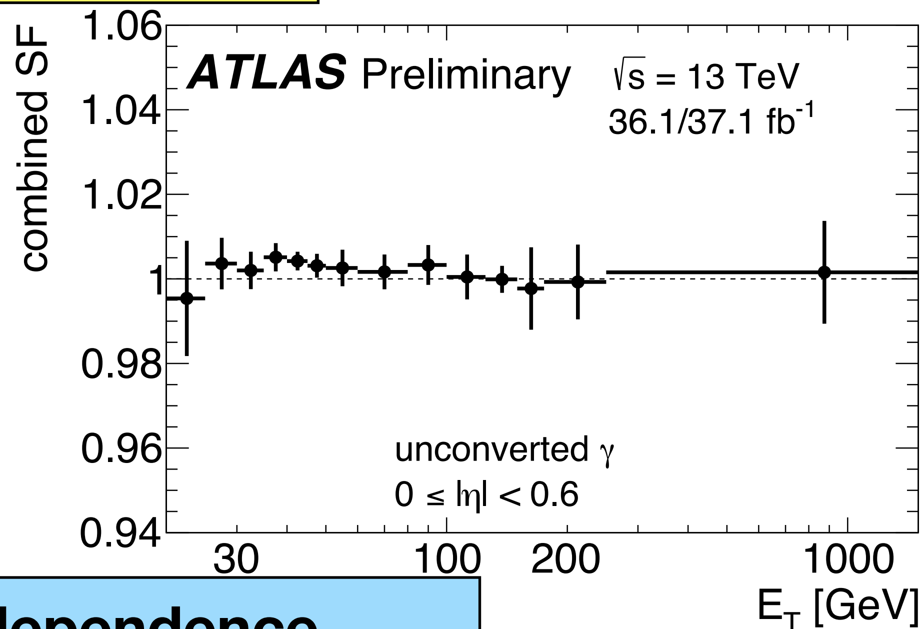


- Select photon sample using loose photon triggers, extracting signal purities before and after tight ID
- Purities computed by the use of track isolation efficiencies

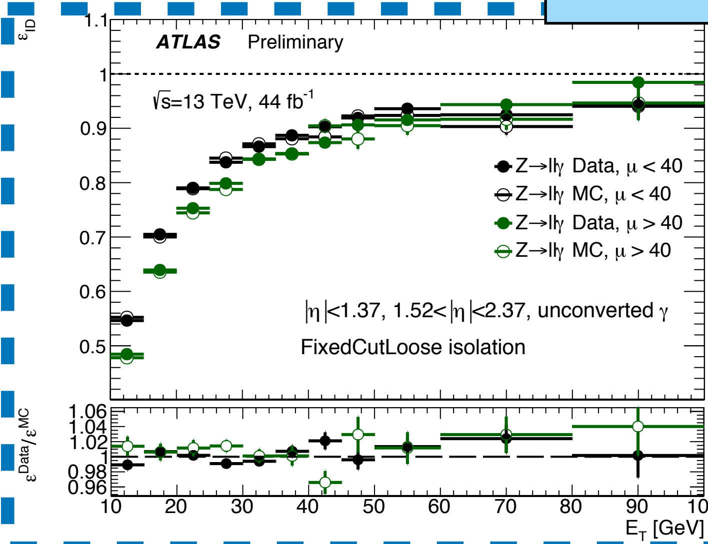
Tight photon identification

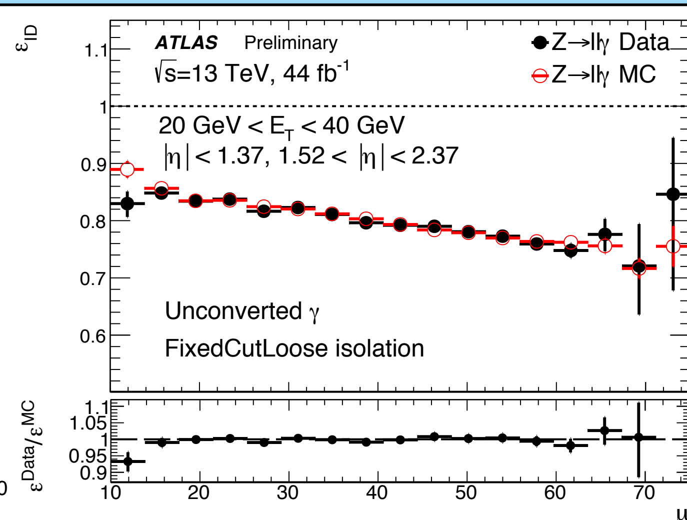
Combination





Pile-up dependence





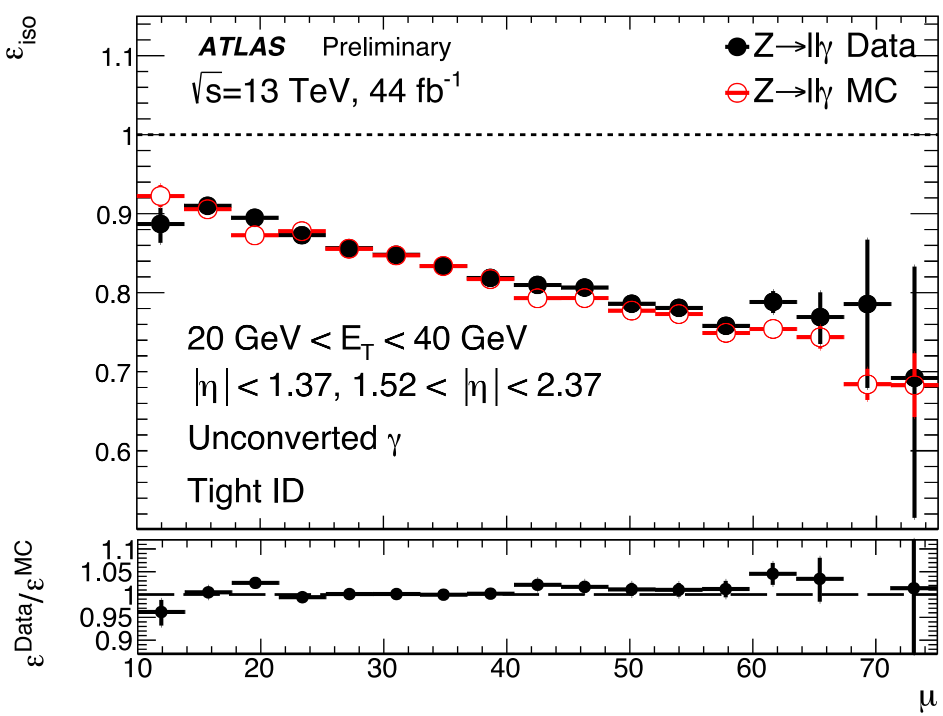
Efficiency is dropping in both data and MC by ~10% when going from μ~10 to μ~75

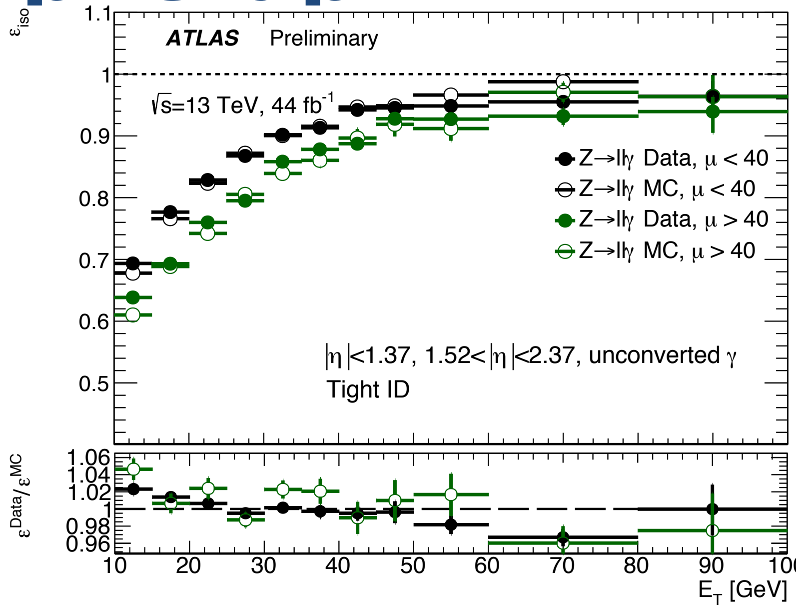
Photon isolation and pile-up

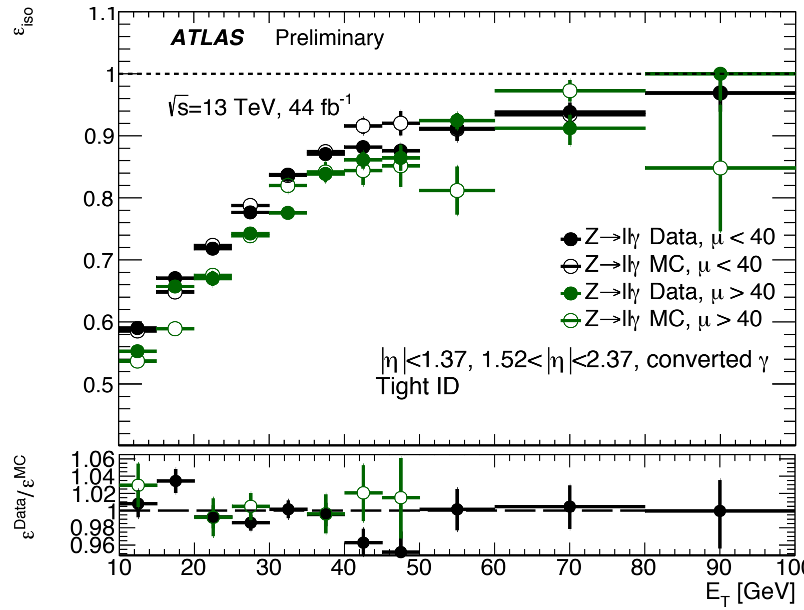
Isolation is defined as:

$\Sigma E_T/E_T < 0.065$, the sum is over all calo clusters in a cone $\Delta R < 0.2$ &

$\Sigma p_T/E_T < 0.05$, the sum is over all tracks (with $p_T > 1$ GeV) in a cone $\Delta R = 0.2$







Efficiency drops in both data and MC by ~10%

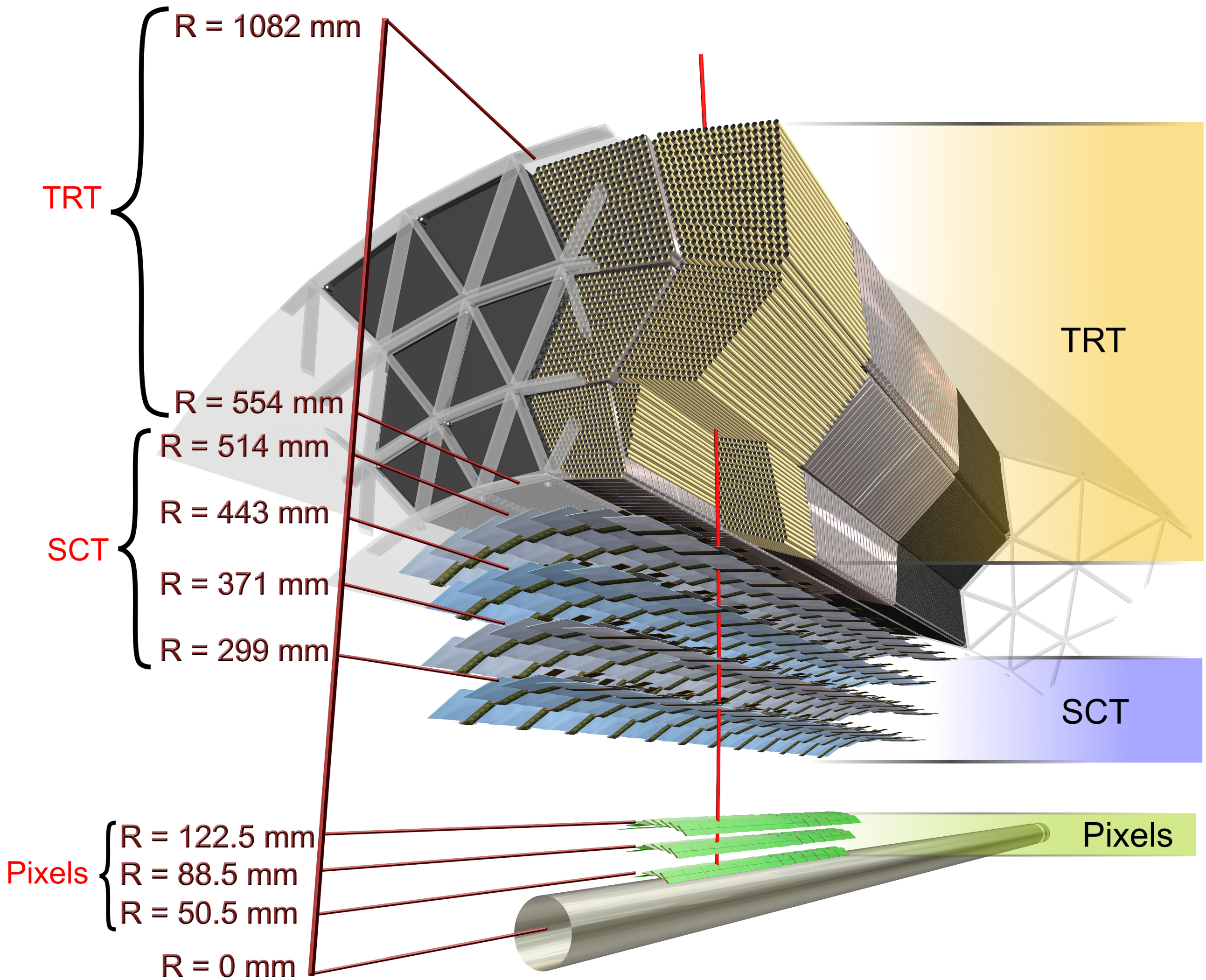
Summary

- Excellent electron and photon performance measurements during Run-II

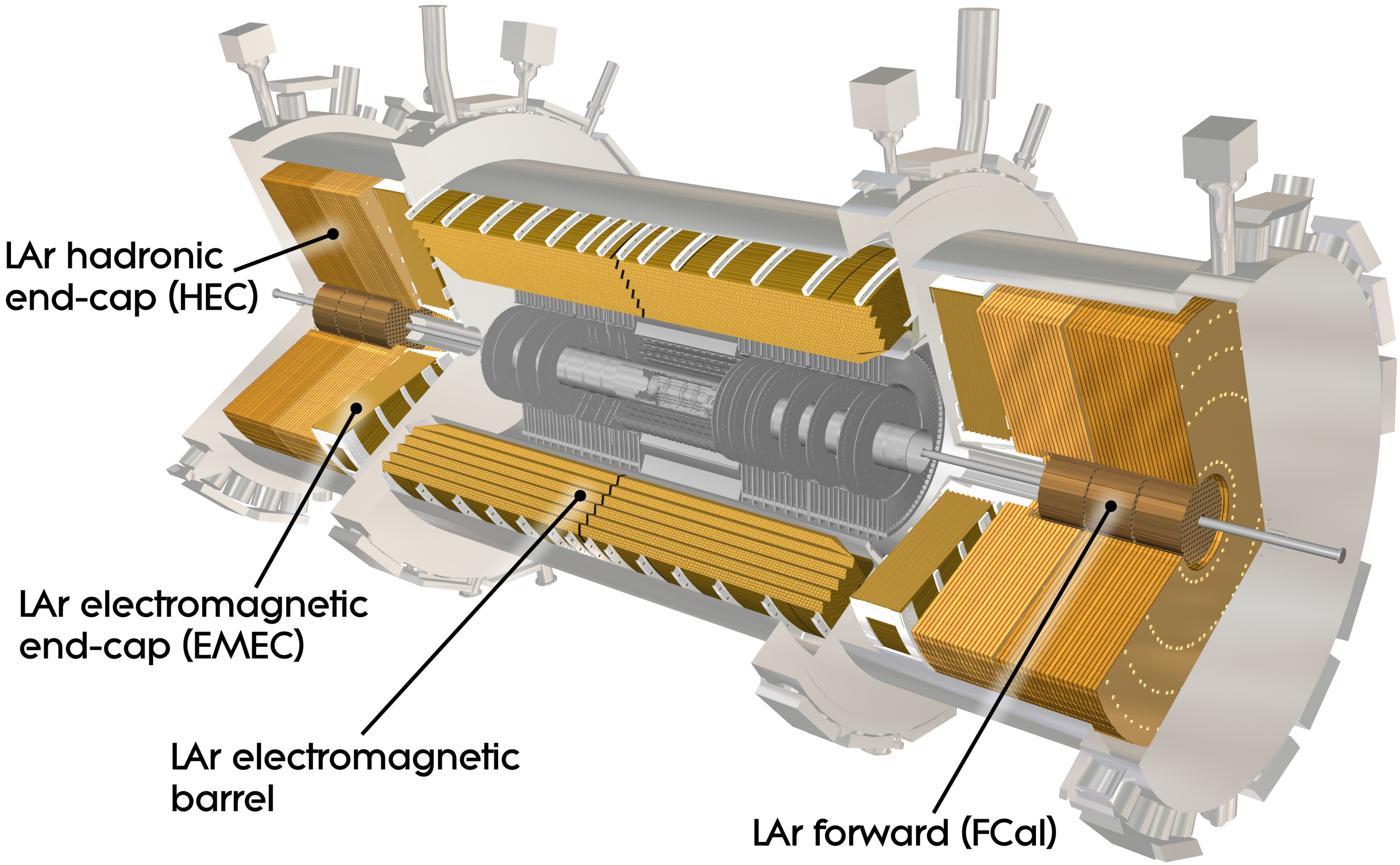
- Improved strategies for electron and photon identification are introduced to cope with the increase of instantaneous luminosity and high pile-up

Backup Slides

Inner tracker



Calorimeter



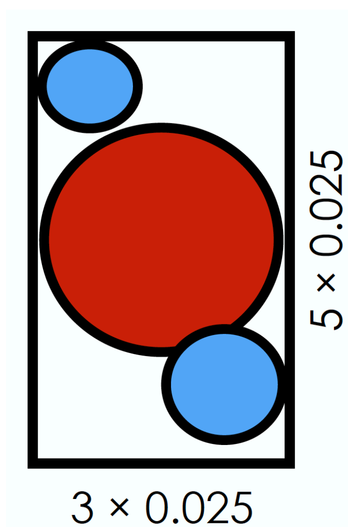
Supercluster building

The supercluster algorithm:

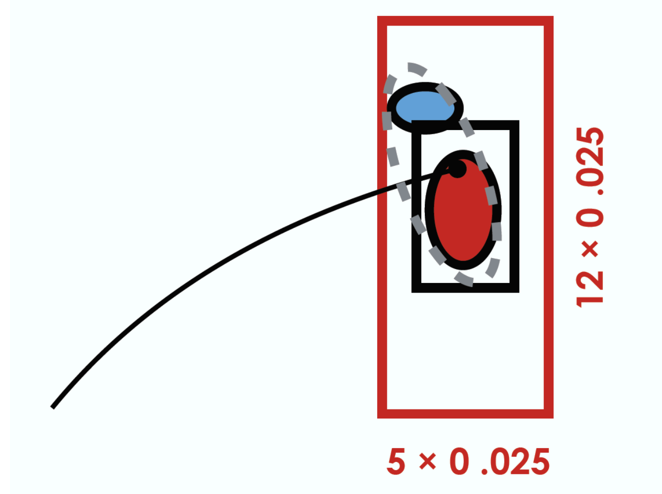
  - the seed cluster
  - the satellite cluster.
- around the extrapolated track a $\Delta\eta \times \Delta\phi = 3 \times 7$ cluster in the barrel and 5×5 in the end-caps
- 8% (5%) better resolution in $J/\Psi \rightarrow ee$ ($Z \rightarrow ee$) mass with better bkg rejection
- Electron candidates start with track-matched seed clusters ET > 1 GeV
- Photon candidates start with seed clusters with ET > 1.5 GeV
- Currently only using best track/conversion vertex for all the matching

All e±, γ:

Add all clusters within 3 × 5 window around seed cluster.



Electrons only:



Seed, secondary cluster match the same track.

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 3×7 $\eta \times \phi$ to 7×7 cell energies	R_η	✓	✓
	Lateral width of the shower	w_{η_2}	✓	✓
	Ratio of 3×3 $\eta \times \phi$ 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.

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_{had1}
	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, $\sqrt{(\Sigma E_i \eta_i^2)/(\Sigma E_i) - ((\Sigma E_i \eta_i)/(\Sigma E_i))^2}$, where E_i is the energy and η_i is the pseudorapidity of cell i and the sum is calculated within a window of 3×5 cells	$w_{\eta 2}$
	Ratio of the energy in 3×3 cells over the energy in 3×7 cells centered at the electron cluster position	R_{ϕ}
	Ratio of the energy in 3×7 cells over the energy in 7×7 cells centered at the electron cluster position	R_{η}
Strip layer of EM calorimeter	Shower width, $\sqrt{(\Sigma E_i (i - i_{\mathrm{max}})^2)/(\Sigma E_i)}$, where i runs over all strips in a window of $\Delta\eta \times \Delta\phi \approx 0.0625 \times 0.2$, corresponding typically to 20 strips in η, and i_{max} is the index of the highest-energy strip	w_{stot}
	Ratio of the energy difference between the largest and second largest energy deposits in the cluster over the sum of these energies	E_{ratio}
	Ratio of the energy in the strip layer to the total energy 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	$\Delta\phi_{\mathrm{res}}$
	Ratio of the cluster energy to the track momentum	E/p

Photon ID: Radiative Z method

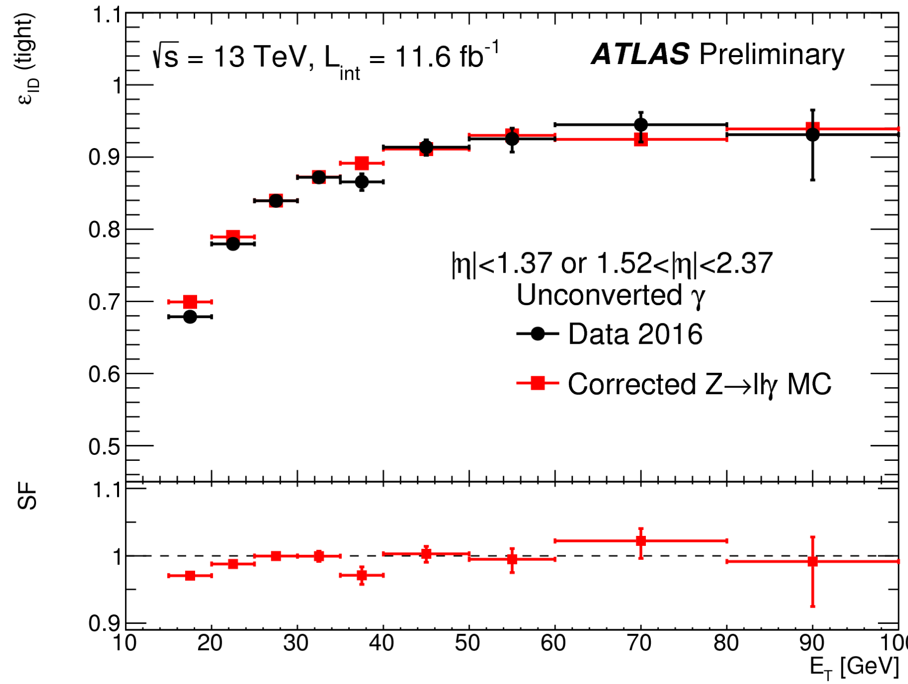
Purity estimation with a template fit

- Number of background events could be estimated in data from the template fit
Signal (Zllγ) PDF + background (Z+jets) PDF = fit to data

Purity: $$P = \frac{N_{sig}}{N_{sig} + N_{bkg}}$$

- Efficiency is corrected by doing background subtraction:

$$\varepsilon = \frac{N_{probes,pID} - N_{bkg,pID}}{N_{probes} - N_{bkg}} = \frac{N_{sig,pID}}{N_{sig}}$$



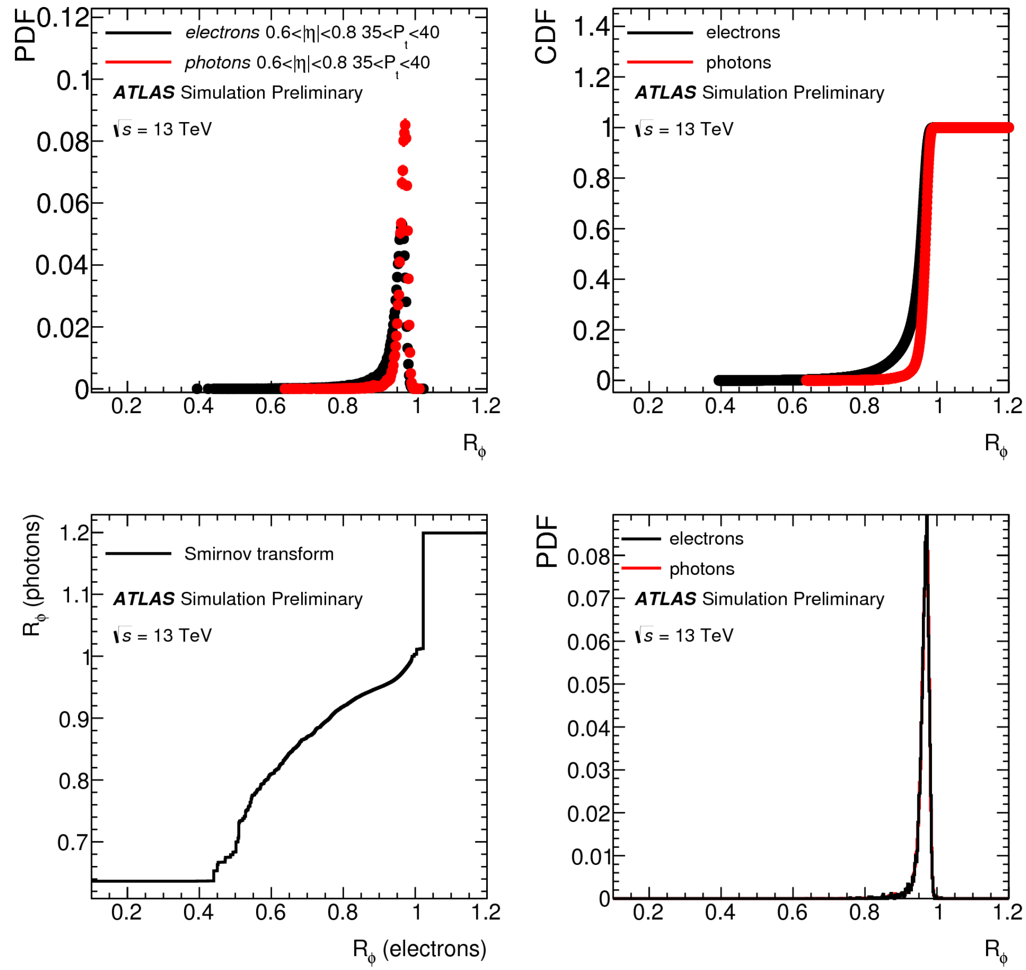
- Method allows to correct data up to ~25 GeV (P=~95-99%)
- **E_T range in [10; 100] GeV**

Photon ID: Electron extrapolation method

- Shower shape distributions of electrons and photons γ are similar due to similar interactions of photons and electrons in the detector
- Select a pure sample of electrons from Z decays using a tag-and-probe method and transform their shower shape distributions such that the resulting object has photon properties:

$$s' = \mathrm{CDF}_{\gamma}{}^{-1}(\mathrm{CDF}_{\mathrm{e}}(s))$$

- Typical E_T of electrons from Z decays of order $m_Z/2$ -> measurement in range:
  - **E_T in [25; 150] GeV**



Photon ID: Matrix method

- Sample of inclusive photons collected with a single-photon trigger
- Large kinematic range: **E_T in [25; 1500] GeV**
- ID efficiency can be computed by employing an additional discriminating variable: track isolation (assumed uncorrelated with shower shape variables) which is applied before and after ID cuts

$$\varepsilon_{\mathrm{ID}} = \frac{N^S_{\mathrm{ID}}}{N^S}$$

$$\hat{N}_{\mathrm{ID}} = \hat{\varepsilon}^S_{\mathrm{ID}} \cdot N^S_{\mathrm{ID}} + \hat{\varepsilon}^B_{\mathrm{ID}} \cdot N^B_{\mathrm{ID}}$$

$$\hat{N} = \hat{\varepsilon}^S \cdot N^S + \hat{\varepsilon}^B \cdot N^B$$

$$\boxed{\varepsilon_{\mathrm{ID}} = \frac{\frac{\hat{\varepsilon}_{\mathrm{ID}} - \hat{\varepsilon}^B_{\mathrm{ID}}}{\hat{\varepsilon}^S_{\mathrm{ID}} - \hat{\varepsilon}^B_{\mathrm{ID}}} \cdot N_{\mathrm{ID}}}{\frac{\hat{\varepsilon} - \hat{\varepsilon}^B}{\hat{\varepsilon}^S - \hat{\varepsilon}^B} \cdot N}}$$

Track-isolation efficiencies are obtained:

- from MC for signal (photons)
- from data for background, making use of low correlation between strip layer variables and track isolation