Electron and photon identification and reconstruction in ATLAS

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Contents

Electron and Photon @ LHC

- At the LHC electrons and photons are produced within a large range of energy from few GeV to several TeV
- A large variety of processes involve electrons and photons:
  - Standard Model J/Ψ, Z, W decays
  - Beyond Standard Model scenarios: Z' , W', SUSY, extra dimensions
  - Electrons and photons from Higgs decays:
    $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ \rightarrow 4e$
- Background sources: prompt electrons have to be separated from hadron jets from QCD, heavy flavor decays; prompt photons from neutral hadron decays, but very good background rejection
- The large variety of processes that can be investigated requires an excellent electron/photon reconstruction and identification
- The results from 2010 data collision at $\sqrt{s}$ = 7TeV are reported with 40 pb^{-1} of integrated luminosity

References:

- Electron performance measurements with the ATLAS detector using the 2010 LHC proton-proton collision data
http://arxiv.org/abs/1110.3174 submitted to Eur. Phys. J. C (14 October 2011)

- Observation of inclusive electrons in the ATLAS experiment at $\sqrt{s}$ = 7TeV
ATLAS-CONF-2010-073

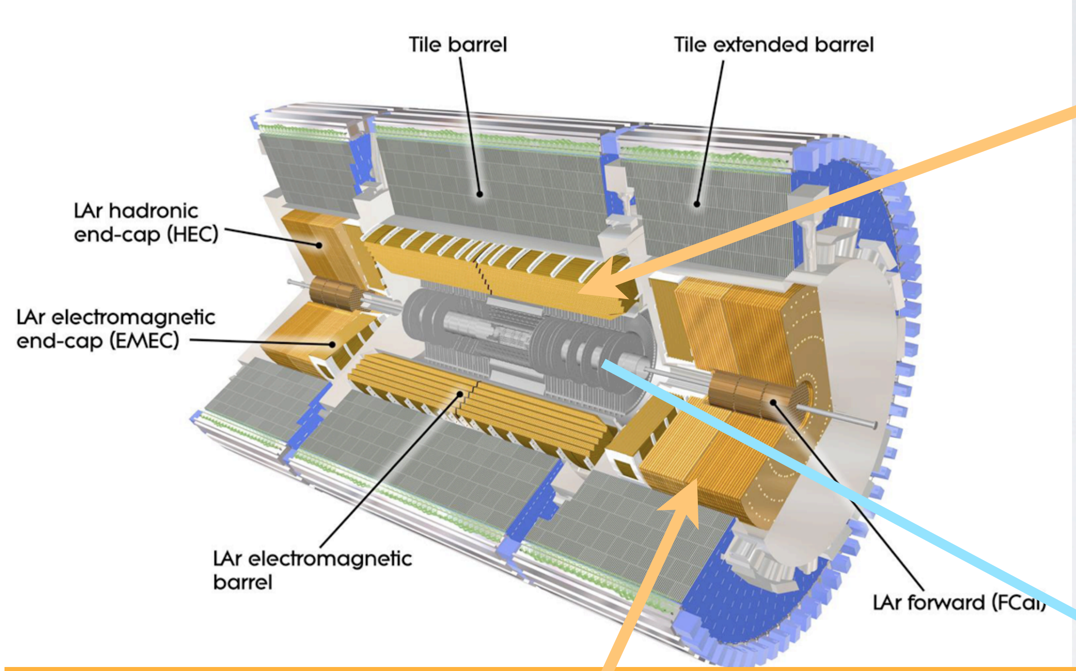
- Evidence for prompt photon production in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector ATLAS-CONF-2010-077

- Measurement of the inclusive isolated prompt photon cross section in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector
Phys.RevD 83, 052005 (2011)

- Measurement of the inclusive isolated prompt photon cross section in pp collisions at $\sqrt{s}$ = 7 TeV using 35 pb^{-1} of ATLAS data
CERN-PH-EP-2011-015

- Measurement of the isolated di-photon cross-section in pp collisions at $\sqrt{s}$ = 7 TeV with the ATLAS detector CERN-PH-EP-2011-088
submitted to Phys.Rev.D

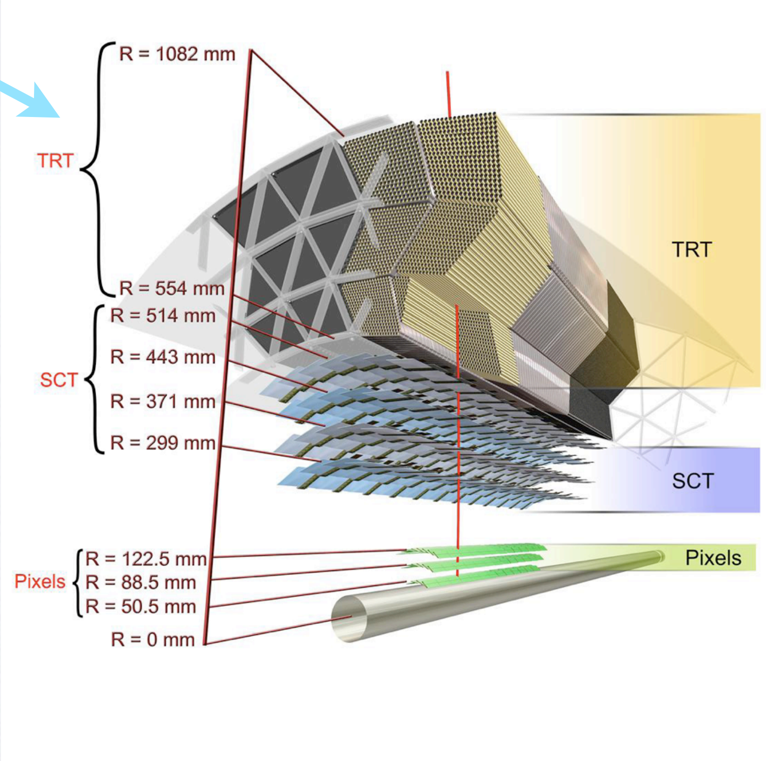
Liquid Argon and Inner Detector



Calorimeter ElectroMagnetic
- Fb-LAr(Lead-Liquid Argon) Sampling calorimeter (87K)
- Accordion geometry for full Φ coverage
- Barrel(|η|<1.45) + 2 EndCaps (1.6<|η|<3.2)
- Depth 22-30 X_0
- 3 longitudinal samplings (strip, middle, back) + PreSampler

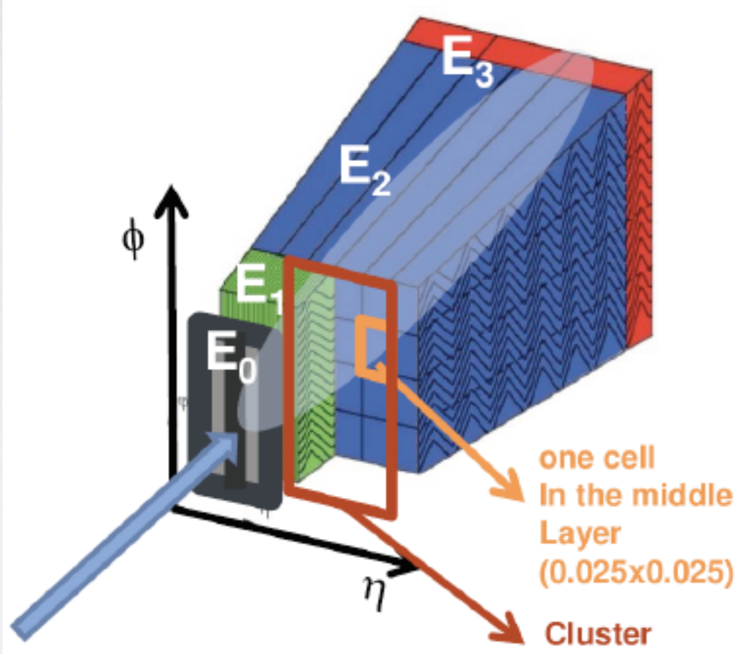
Forward Calorimeter
- 1.6<|η|<3.2
- 3 modules on each EndCap
  - first module (copper): optimize for EM showers
  - 2 module (tungsten): optimize for Hadrons

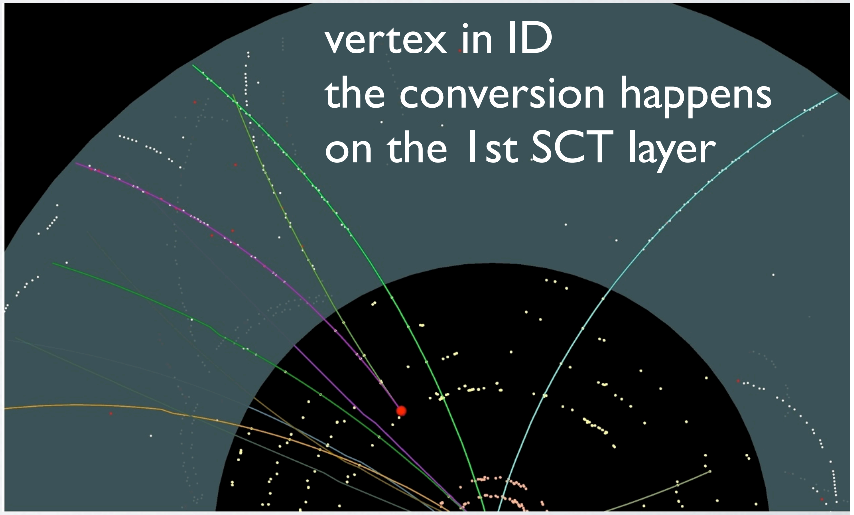
Inner Detector:
- Pixel (3 layers)
- SCT: SemiConductor Tracker (8 strips layers / 4 space point)
- TRT: Transition Radiation Tracker (straw tube, ~30 hits/ track)



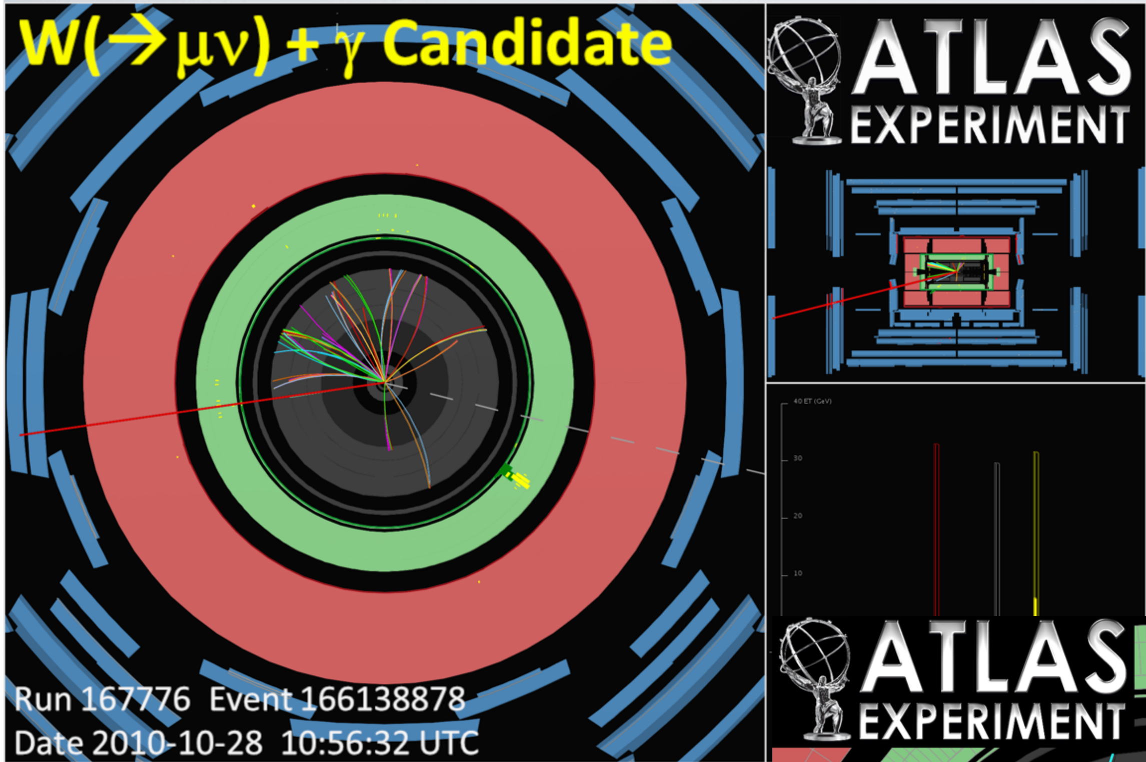
Electron/Photon Reconstruction

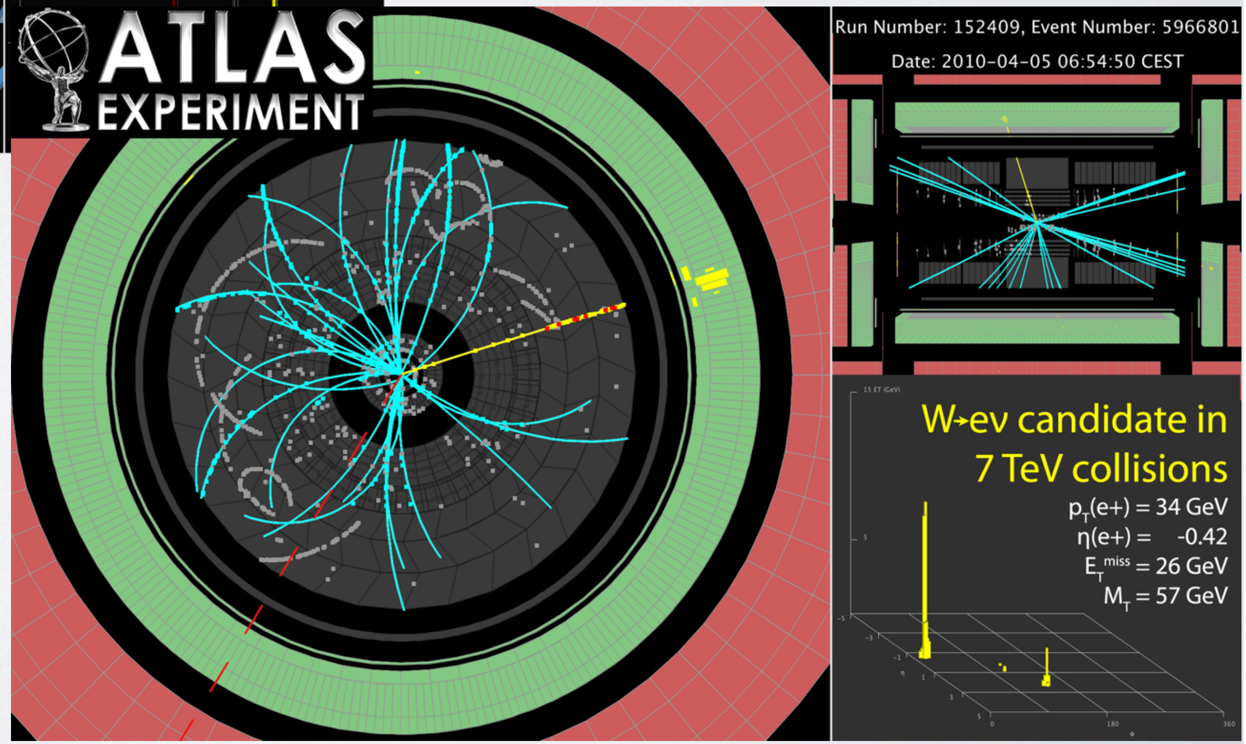
1. Find cluster seed with energy > 2.5 GeV through a sliding window algorithm.
   - the seed cluster size 3x5 η/Φ middle layer unit (0.025x0.025)
2. Match cluster to a track (ID)
   - to distinguish e from unconverted γ
3. Match track to a secondary vertex
   - to distinguish e from converted γ
4. Rebuild clusters in optimized cluster sizes
   - Δη x ΔΦ = 3x7 (5x5) barrel (endcap)
5. Compute energy measurement, summing all the cells in the cluster
6. Apply cluster position and energy calibration (next slides)





Electron/Photon Reconstruction





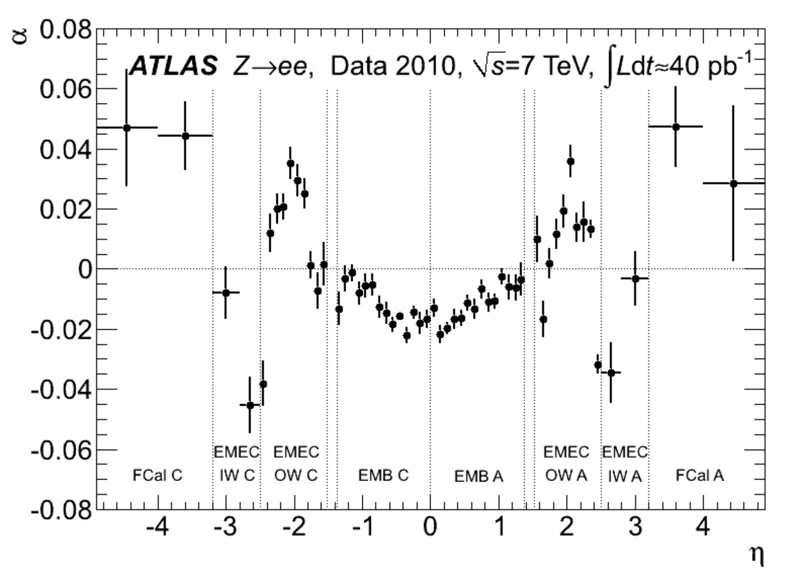
Electromagnetic In-situ inter-calibration

- The energy resolution is parameterized as:

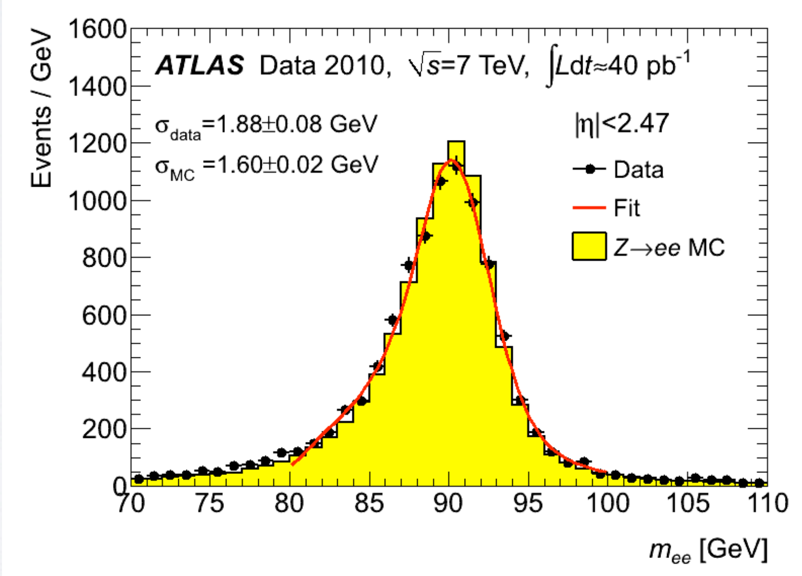
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c \quad \text{where} \quad c = c_L \oplus c_{LR}$$

  - from the test beam local constant term c_L ~ 0.5% the goal is c_{LR} ~ 0.5%

- **Absolute Electromagnetic scale has to be establish using Z →ee**
  - parameterize the electron energy in zone 'i' as: $E^{\text{meas}} = E^{\text{true}}(1+\alpha_i)$ where the E^{true} is from MC
  - method obtains the scale factors (α_i) from i likelihood fit by constrain the dilepton mass to the Z boson line shape



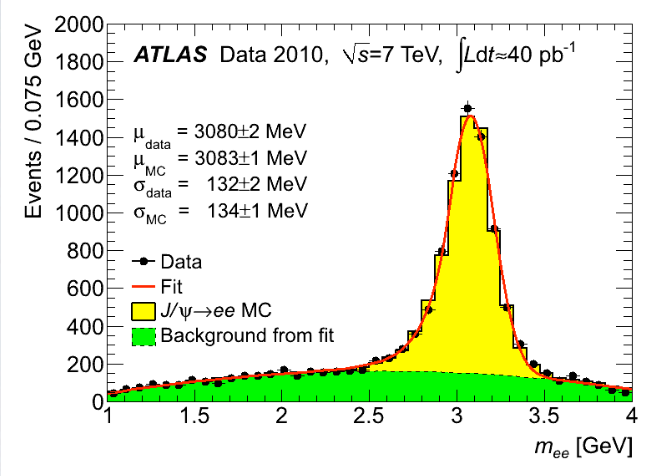
The energy scale have been determined:
0.3-1.6% in |η| < 2.47
2 - 3% in the forward region 2.5<|η|<4.9
The scale factors have been applied directly to cells for 2011 data taking

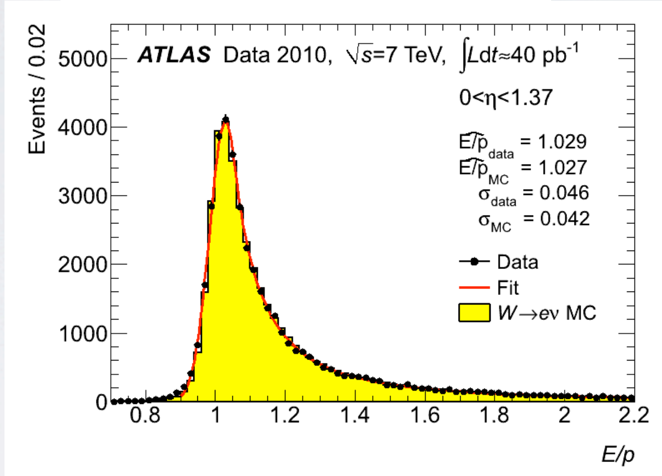


After the correction the resolution:
1.2 ± 0.1(stat)±0.3(syst)% in |η| < 1.37
increase to 1.8% in 1.54< |η| < 2.47
up to 3% in the forward

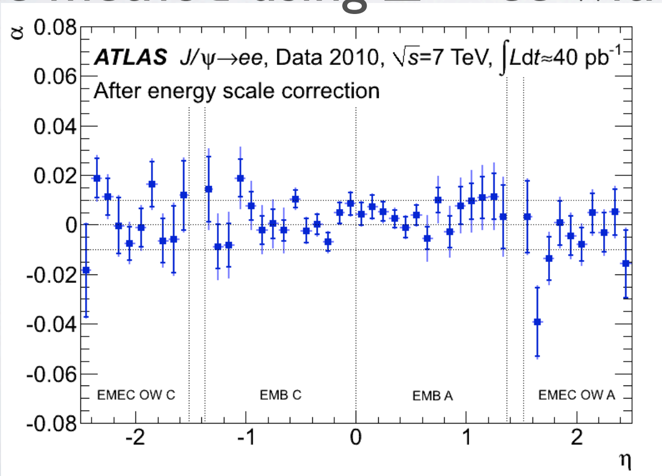
Electromagnetic In-situ inter-calibration

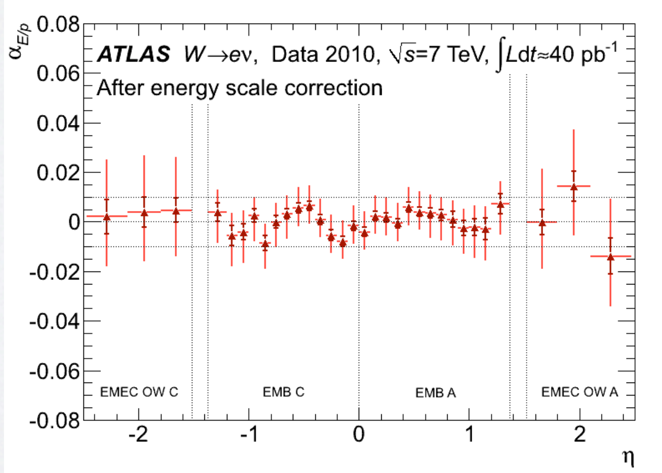
- Electromagnetic energy scale linearity has been verified after energy correction:
  - at lower energy using J/Ψ→ee : $E^{\text{meas}} = E^{\text{true}}(1+\alpha_i)$
  - with different technique using E/p from W →eν: $\widehat{E/p}_{\text{data}} = \widehat{E/p}_{\text{MC}}(1+\alpha_{E/p})$





- The determination of the electromagnetic energy scales agree with the baseline method using Z →ee with ~1%

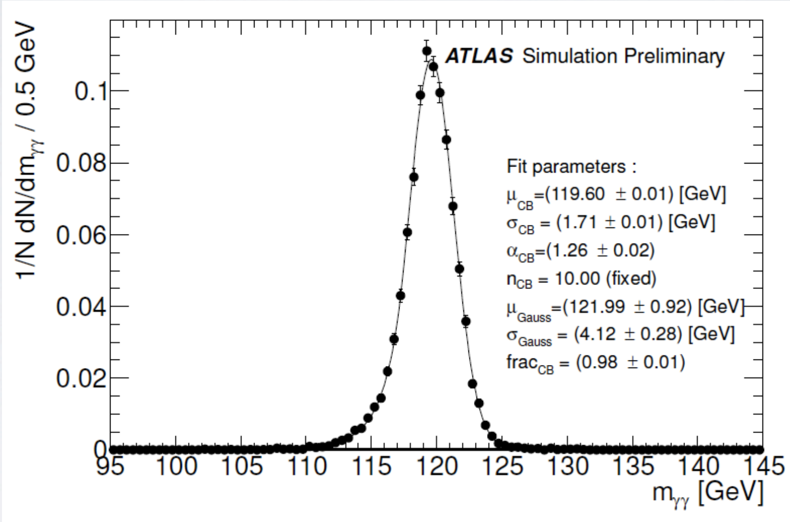


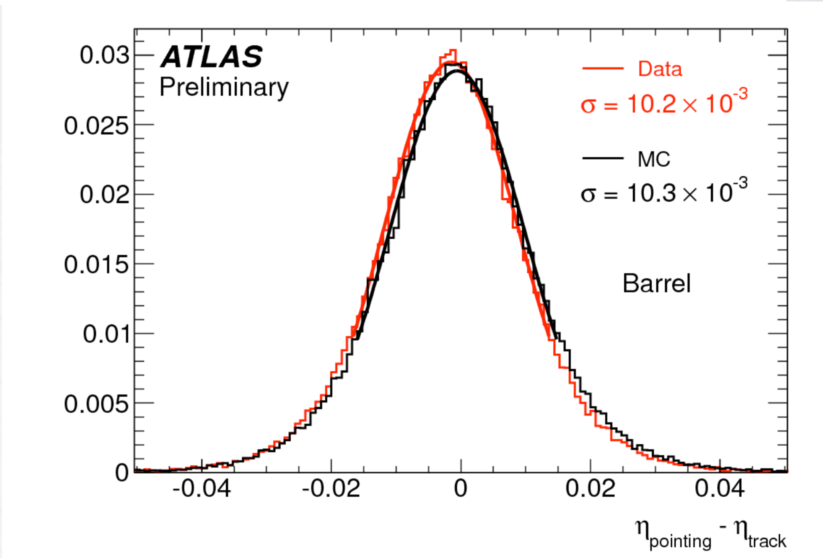


Pointing resolution

In process as H $\rightarrow\gamma\gamma$ is important to identify the correct vertex with high pile-up condition
➡ the η direction is improved using the pointing of the clusters in the calorimeter and the conversion vertex position for converted photons

The pointing resolution has been compared for data and MC for the control sample Z $\rightarrow$ ee



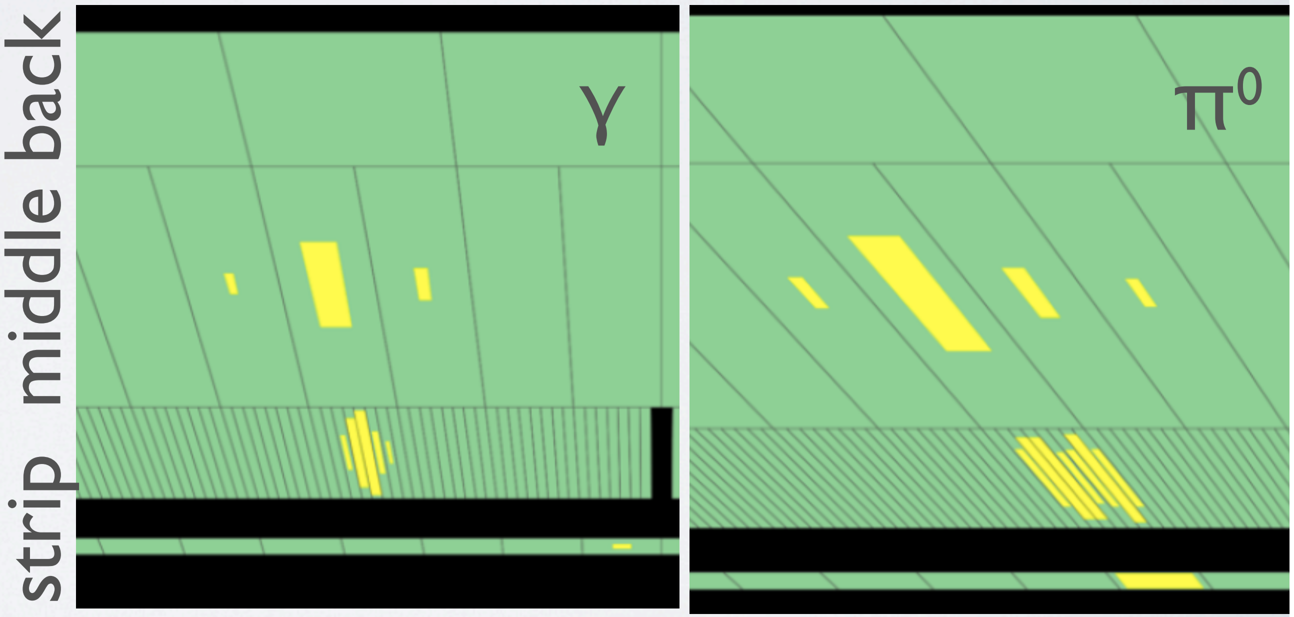


Search for the Standard Model Higgs boson in the two photon decay channel with the ATLAS detector at LHC: http://arxiv.org/abs/1108.5895

Electron/Photon Identification

- Different sets of cuts are used to deliver a very good separation between e/γ and fake signature of QCD
- 3 (2) main operating point with increasing background rejection power have been defined for electrons (photons)
  - e: loose, medium, tight
  - γ: loose, tight

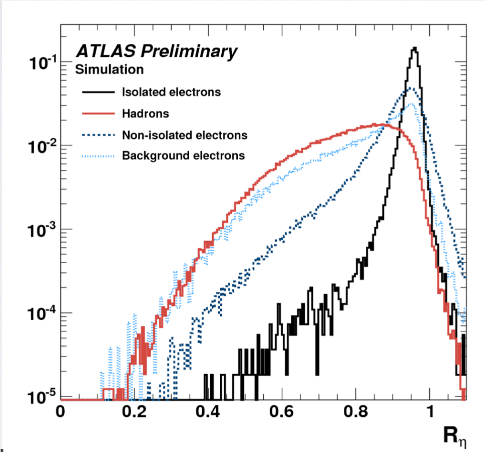
An example of γ/π^0: cut on strip variable reject the π^0

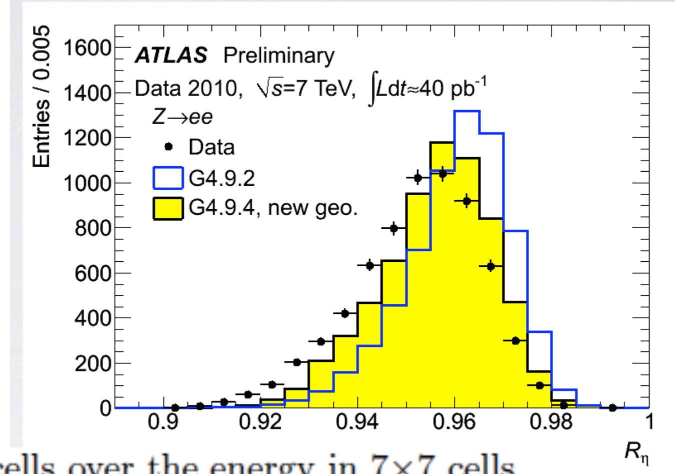


Discriminating variables

- loose (e/γ) → use variables as shower shape based on middle layer calorimeter informations, hadronic leakage (deposit in the hadronic calorimeter)

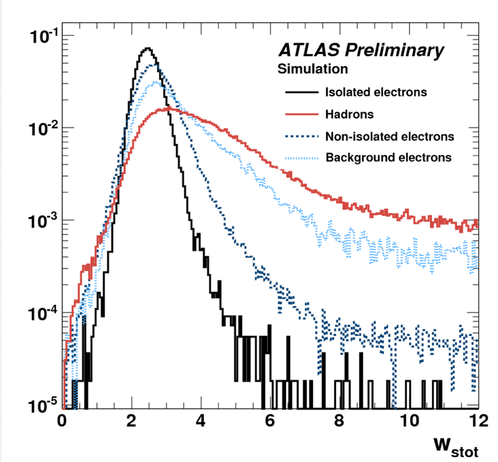
prompt electrons for R_η close to 1

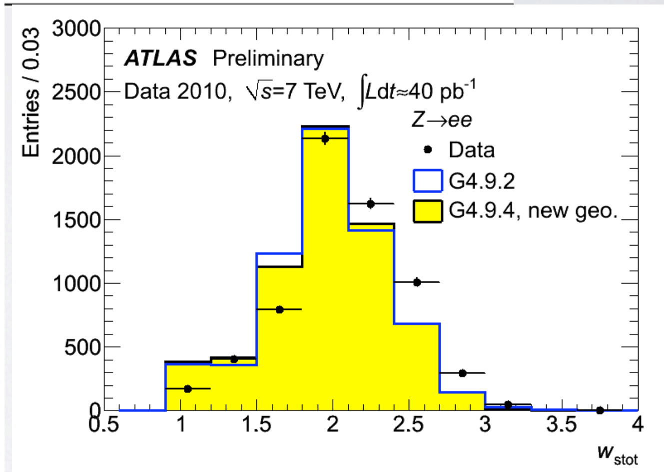




Ratio of the energy in 3×7 cells over the energy in 7×7 cells centred at the electron cluster position

medium (e) → first layer cut, track quality and track/cluster match prompt electrons within 1 mm



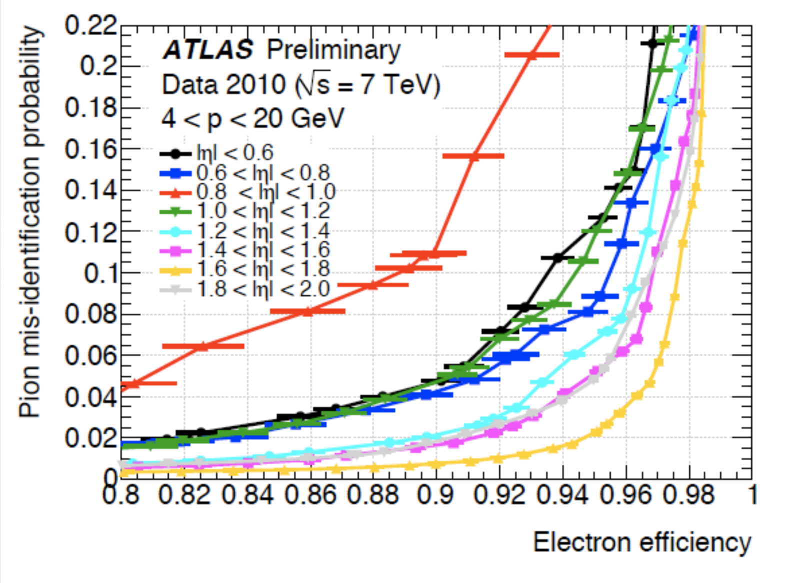


Total shower width

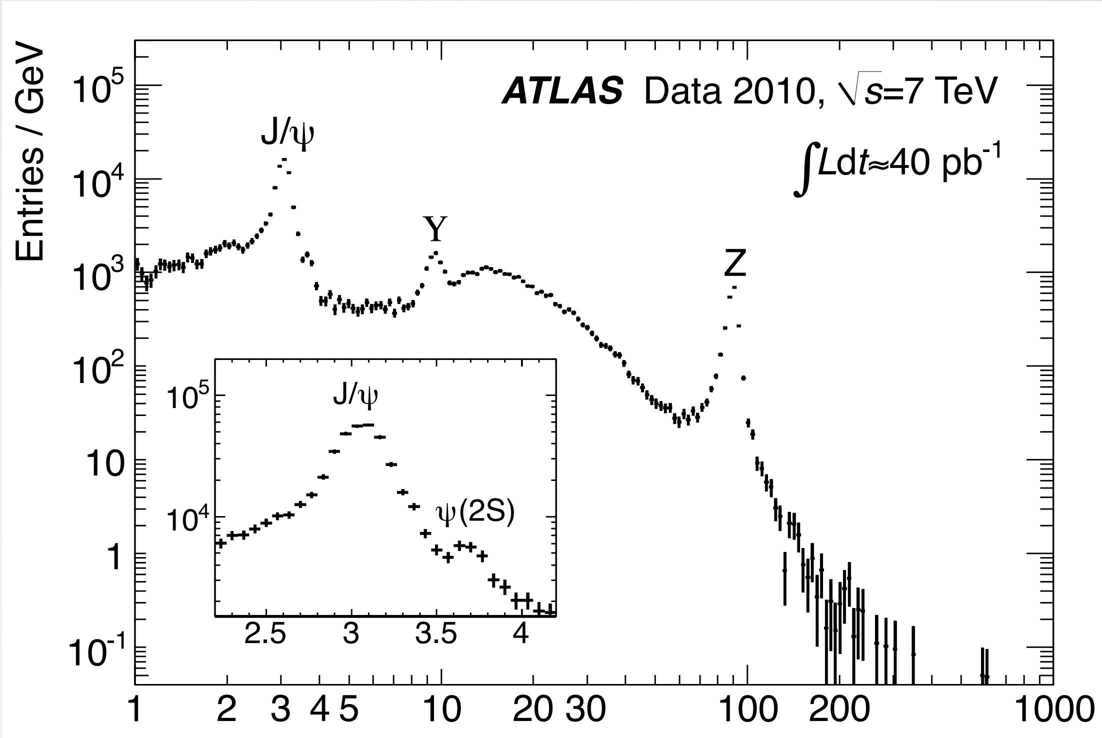
a complete list of the variables is in the back-up

Discriminating variables

- tight (e/γ) -> e: E/p, b layer hits, high-threshold hits in the TRT...
  γ: additional cuts on middle layer and first layer



rejection power to pions of the TRT vs the electron efficiency

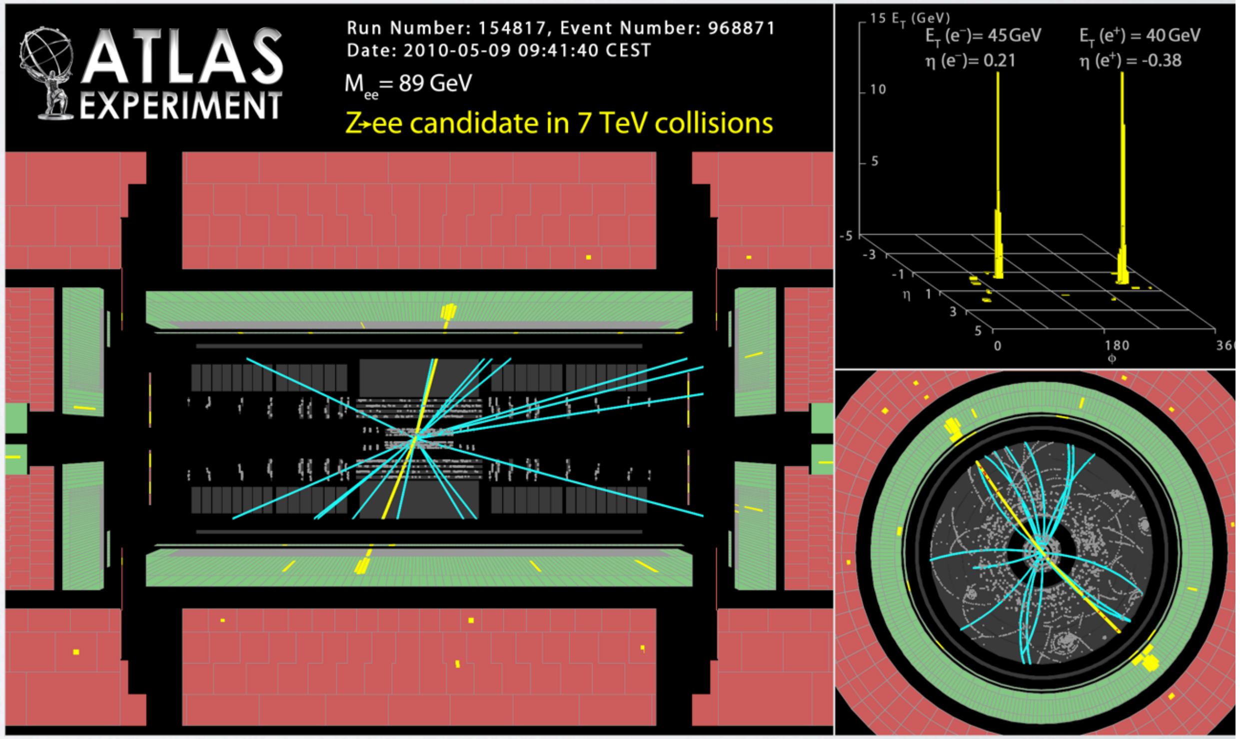


Efficiency Measurement for Electrons

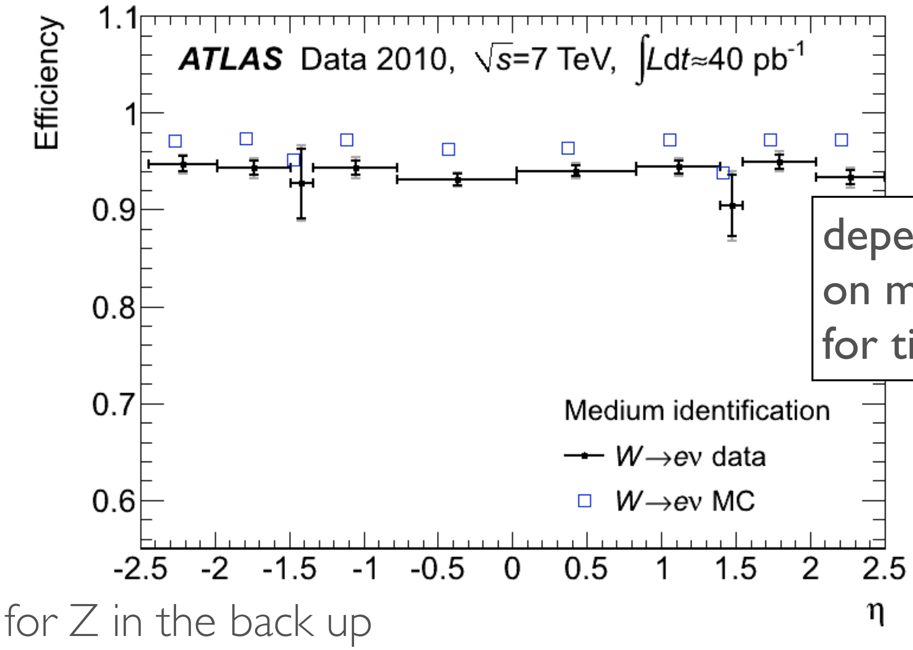
- **Efficiency Measurement performed purely with data**
  - Tag & Probe method involving: $Z \rightarrow ee$, $J/\psi \rightarrow ee$, $W \rightarrow e\nu$
  - Efficiency (defined as #probe$^{\text{passing the cut}}$/ #probe) estimation in E_T = 4 - 50 GeV and in the whole pseudorapidity range
  - Method applied to both data and MC separately
- **Identification Efficiency**
- **Reconstruction Efficiency**
- **Charge misidentification**

Example of T&P for Z

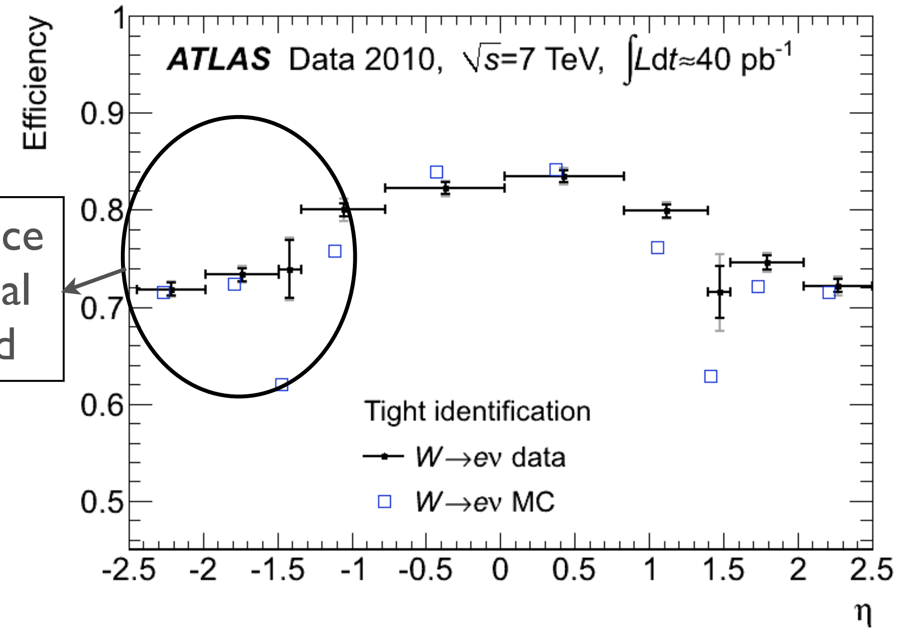
- Tag
  - E_T > 20 GeV
  - tight id
- Probe
  - opposite charge
  - medium or tight



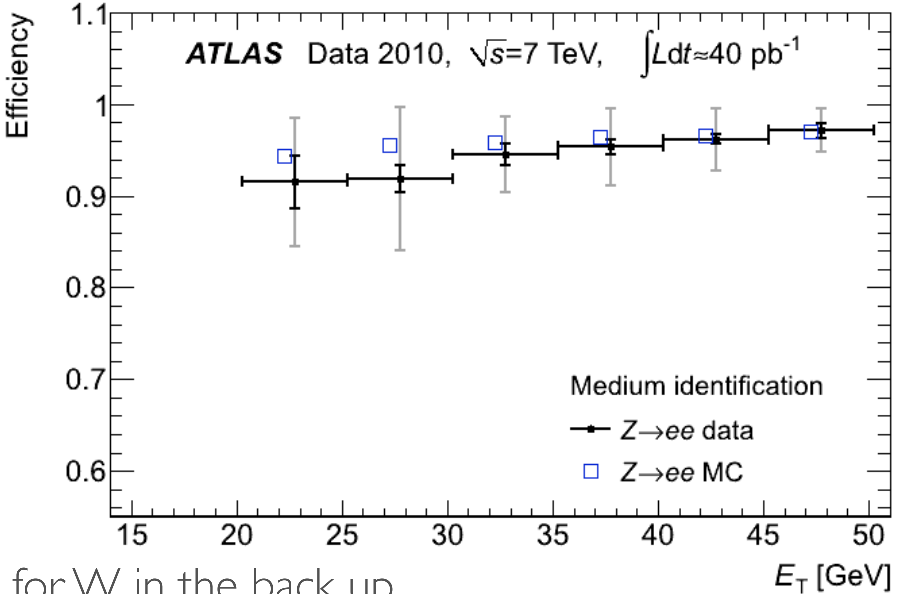
Electron Identification Efficiency (1/2)



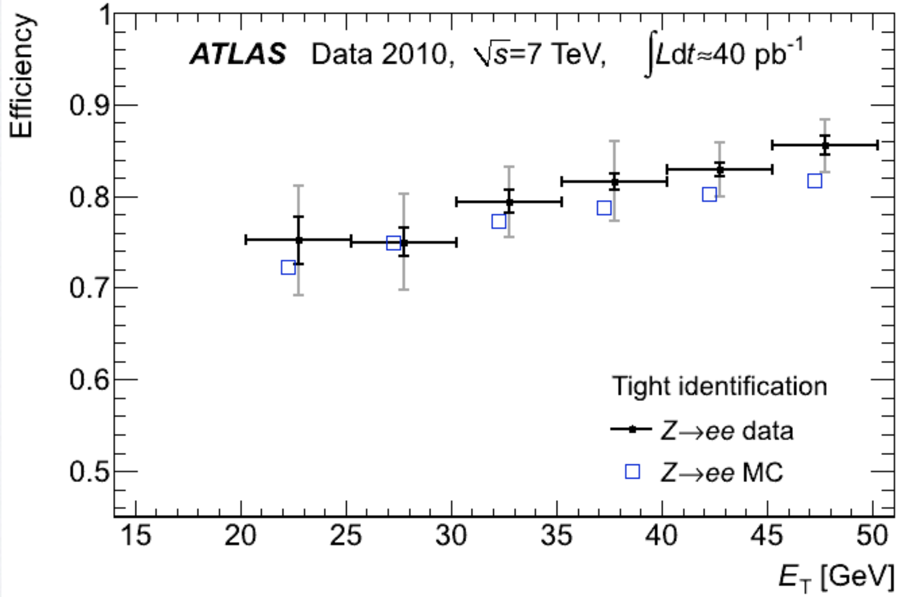
for Z in the back up



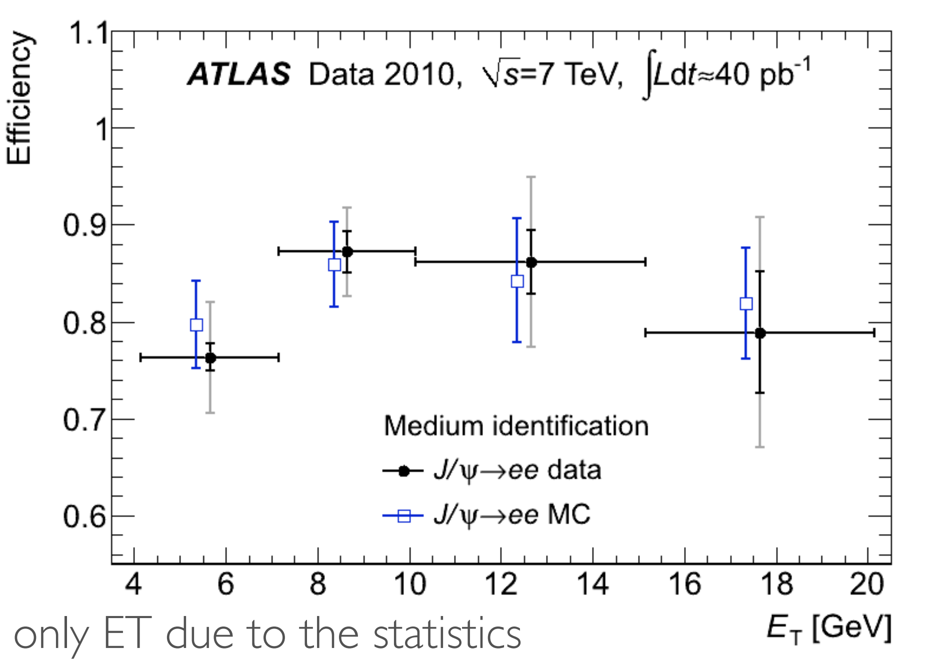
dependence on material for tight id

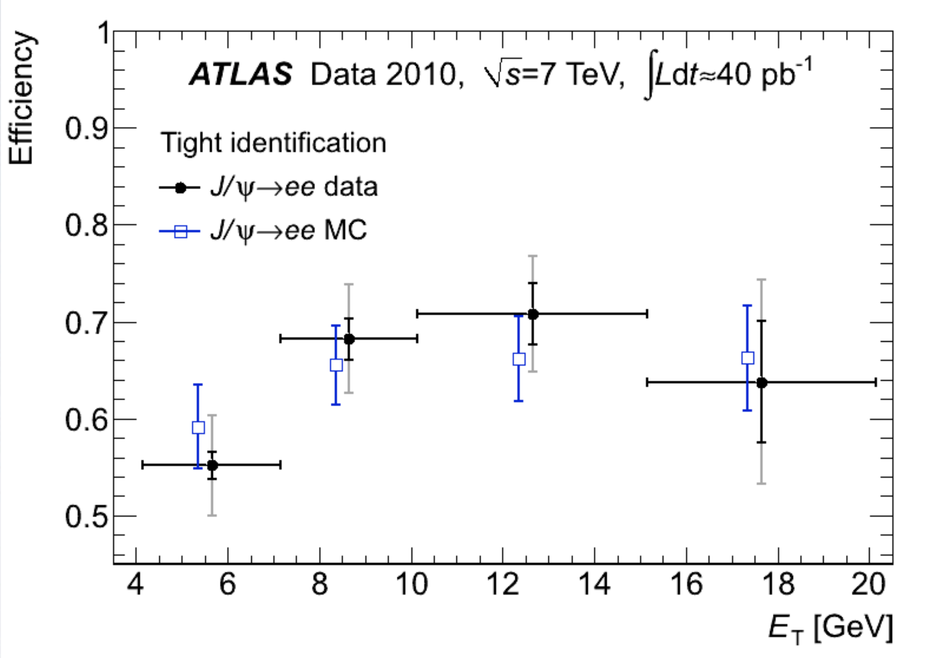


for W in the back up



Electron Identification Efficiency (2/2)





only ET due to the statistics

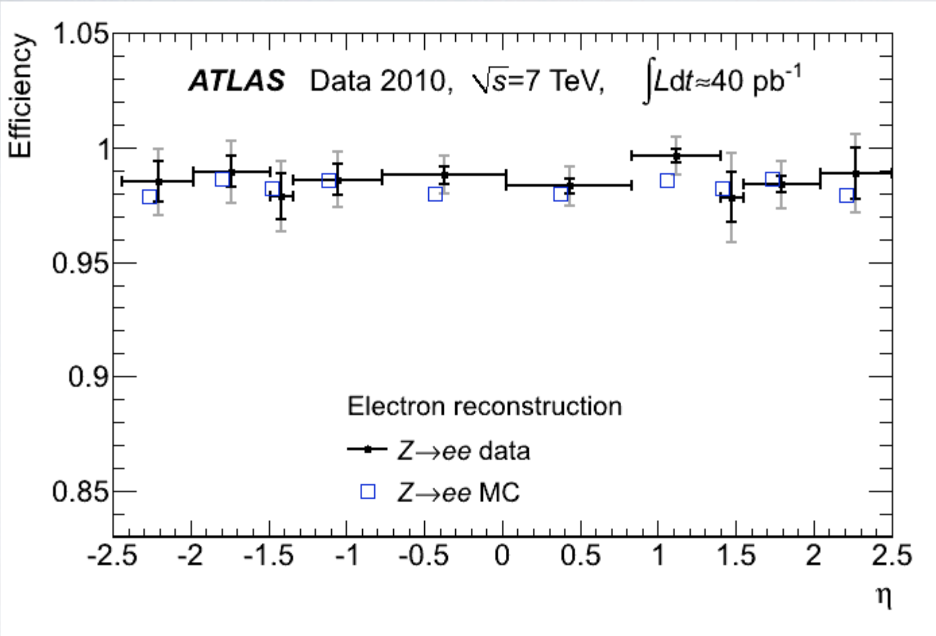
Selection	Channel	Data [%]	MC [%]	Ratio
Medium	$W \to e\nu$	$94.1 \pm 0.2 \pm 0.6$	96.9	$0.971 \pm 0.002 \pm 0.007$
	$Z \to ee$	$94.7 \pm 0.4 \pm 1.5$	96.3	$0.984 \pm 0.004 \pm 0.015$
Tight	$W \to e\nu$	$78.1 \pm 0.2 \pm 0.6$	77.5	$1.009 \pm 0.003 \pm 0.007$
	$Z \to ee$	$80.7 \pm 0.5 \pm 1.5$	78.5	$1.028 \pm 0.006 \pm 0.016$

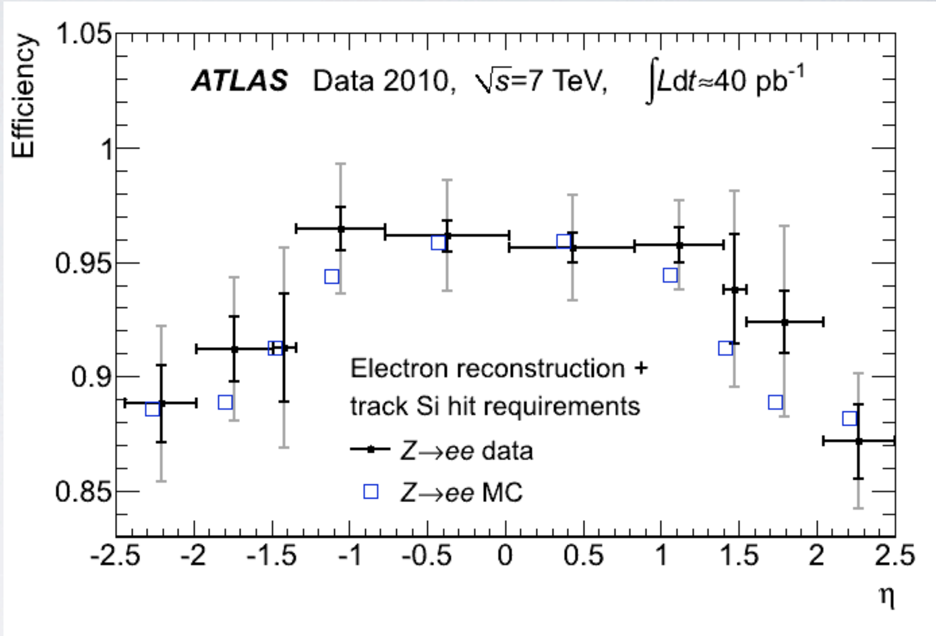
Identification efficiency integrated in $20<E_T<50$GeV and $|\eta|< 2.47$

Selection	Channel	Data [%]	MC [%]	Ratio	MC [%] prompt J/ψ
Medium	$W \to e\nu$	$75.8 \pm 8.8 \pm 8.1$	94.9	$0.80 \pm 0.09 \pm 0.07$	
	$J/\psi \to ee$	$80.0 \pm 7.3 \pm 10.2$	81.9	$0.98 \pm 0.09 \pm 0.14$	92.9
Tight	$W \to e\nu$	$61.9 \pm 6.0 \pm 7.0$	78.3	$0.79 \pm 0.08 \pm 0.09$	
	$J/\psi \to ee$	$68.1 \pm 7.3 \pm 9.0$	69.1	$0.99 \pm 0.11 \pm 0.15$	78.3

Identification efficiency integrated in $15<E_T<20$GeV and $|\eta|<0.8$

Electron Reconstruction Efficiency

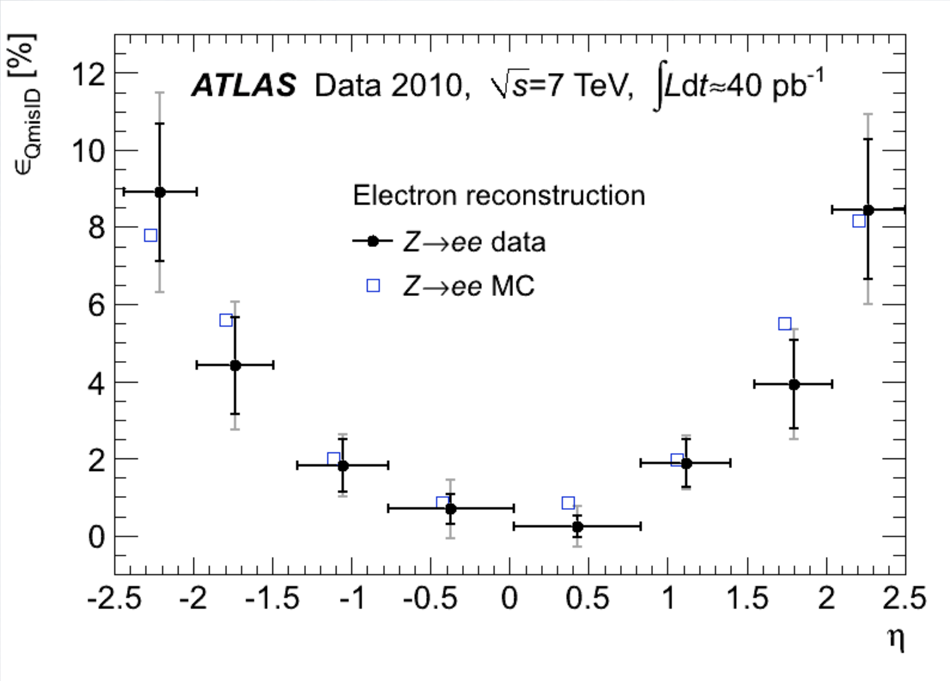


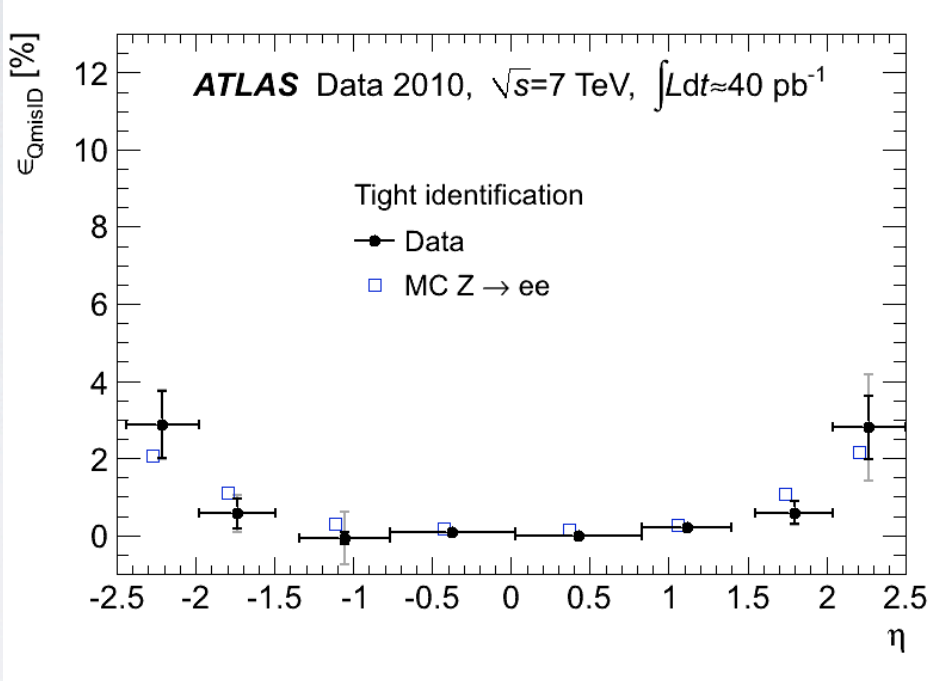


Selection	Data [%]	MC [%]	Ratio
Electron reconstruction	$98.7 \pm 0.1 \pm 0.2$	98.3	$1.005 \pm 0.001 \pm 0.002$
Track silicon hit requirements	$94.3 \pm 0.2 \pm 0.8$	93.1	$1.013 \pm 0.002 \pm 0.008$

- Electron reconstruction efficiency $20 < E_T < 50$ GeV from $Z \rightarrow ee$
- Small decrease due to the material at higher η with the Si hits requirements

Charge Misidentification





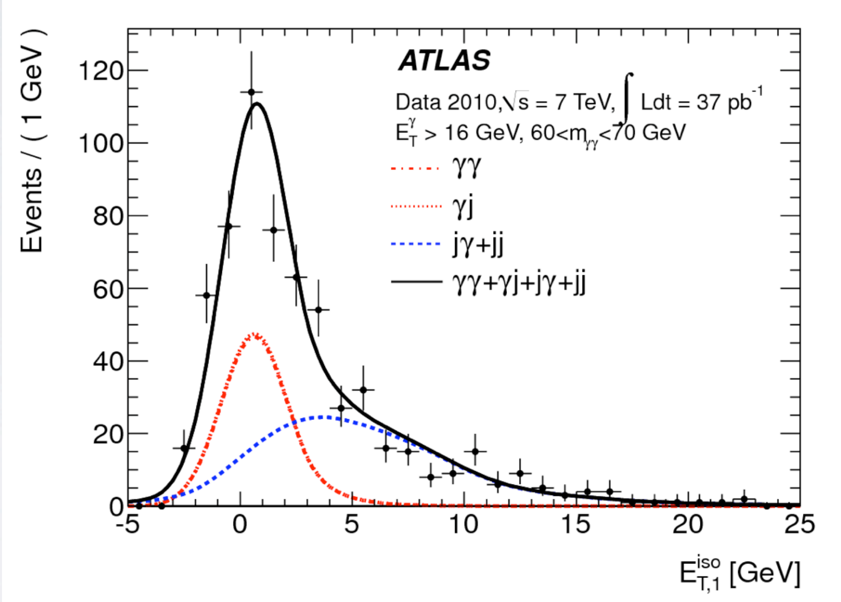
ε_{QmisID} is the fraction of electrons with incorrectly measured charge

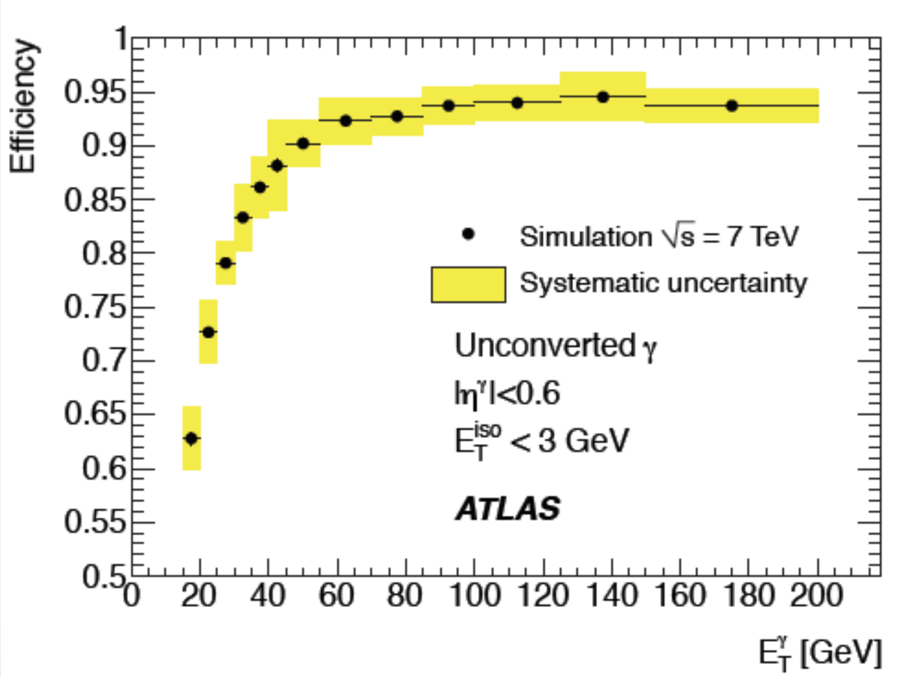
- good agreement data/MC and low misidentification percentage

Selection	Data [%]	MC [%]
Electron reconstruction	$2.17 \pm 0.25 \pm 0.28$	2.73
Track silicon hit requirements	$1.13 \pm 0.21 \pm 0.16$	1.28
Medium identification	$1.04 \pm 0.11 \pm 0.14$	1.20
Tight identification	$0.37 \pm 0.07 \pm 0.11$	0.50

Photon identification efficiency

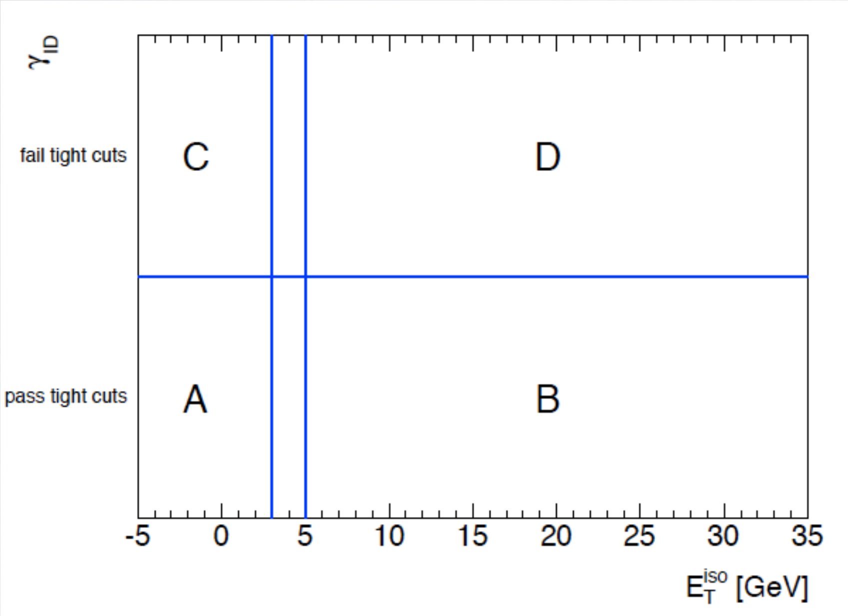
-Isolation defined as the sum calorimeter energy within a cone of ΔR < 0.4
-The measurement of the inclusive isolated prompt photon production cross section is a test of perturbative QCD (more details in the references)





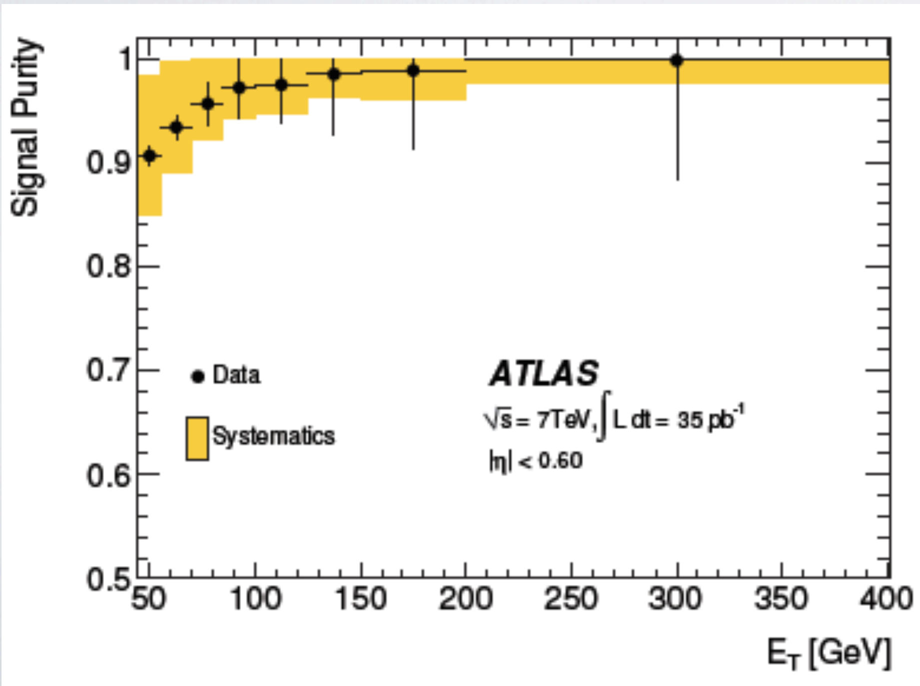
- Estimation from the MC corrected for Data/MC discrepancies for ε_{ID}
- ε_{ID} ~ 95% for E_T > 100 GeV

Photon Purity



The photon purity has been measured using data with a side band method:
- Signal Region: A
- Control Regions: B, C, D
- Hypothesis: control Regions dominated by the background and isolation profile is the same in no-tight regions:

$$N_A^{\mathrm{sig}} = N_A - N_B \frac{N_C}{N_D}$$



Conclusions

Electron and photon reconstruction and identification provided very good results in 2010 collisions at $\sqrt{s}$ = 7TeV

Good selection of electron and photon candidates has allowed to investigate several physics scenarios

With more than 5 fb^{-1} an exiting period has began!

- precisely measurement of the material in front of the EM calorimeter and of the EM shower development in the calorimeter
- accuracy and efficiency measurements in two dimensions (E_T, η), finer η granularity will be obtained with accuracies better then 1% and at higher E_T (useful for exotic searches)

In situ calibration of the Electromagnetic Calorimeter has been performed with an integrated luminosity of 40 pb^{-1}in ATLAS

- the electron energy scale is 0.3-1.6% in $|\eta| < 2.47$, 2-3% in the forward region $2.5<|\eta|<4.9$
- the energy resolution is 1.2 ± 0.1(stat)±0.3(syst)% in $|\eta| < 1.37$ increase to 1.8% in $1.54< |\eta| < 2.47$ up to 3% in the forward

The electron identification efficiency has been measured with 40 pb^{-1} of data down to 7 GeV with a total accuracy at high E_T better than 1%

Other important component of the electron efficiency have been determinate as reconstruction efficiency and charge misidentification

Here just few examples of the use of photon properties have been showed

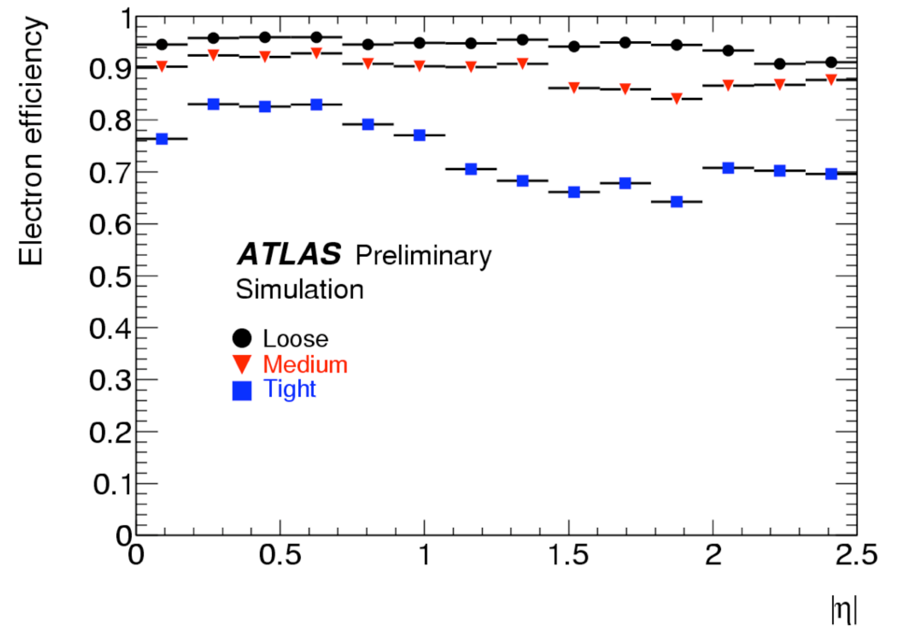
- Photons efficiency and purity have been used for measurements as the prompt photon cross section and di-photon cross section and they have been performed for 40 $pb^{-1}$of integrated luminosity
- pointing resolution has been performed in order to improve the performance in $H \rightarrow \gamma\gamma$ channel in particular in the high pileup condition

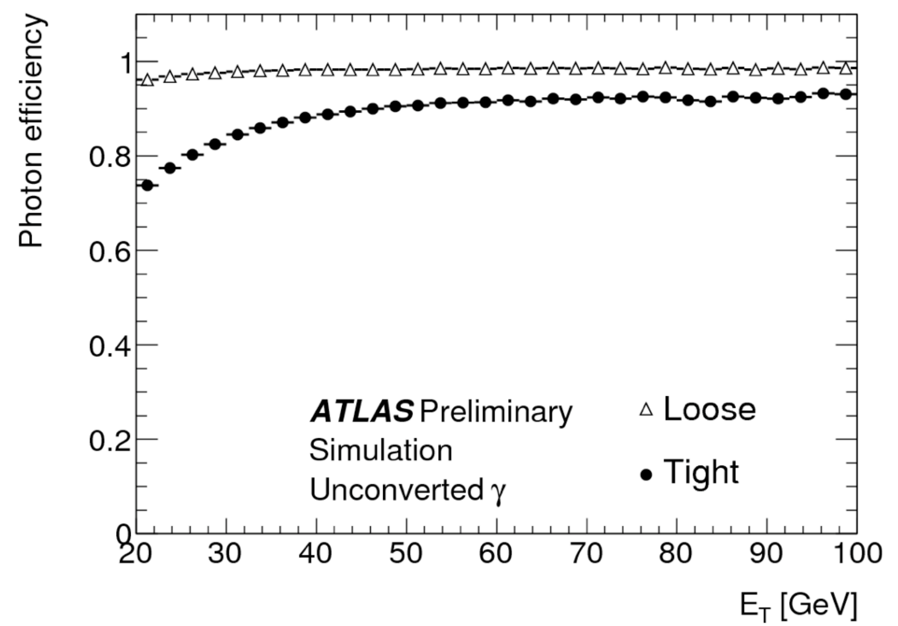
BACK-UP

Expected Electron/Photon Efficiency

- The identification relies on a cut based selection using both calorimeter and inner detector
  - separation isolated e/γ and fake from QC
  - rejection of jets faking e
- Different sets of cuts:
  - e: loose, medium, tight
  - γ: loose, tight
- The expected efficiency for reconstruction and identification

$$\varepsilon_{e,\gamma}^{truth} = \frac{N_{e,\gamma}^{reco}}{N_{e,\gamma}^{truth}}$$





List of Discriminating Variables

Type	Description	Name
Loose electron and photon cuts		
Acceptance of the detector	$\|\eta\| < 2.47$ for electrons, $\|\eta\| < 2.37$ for photons ($1.37 < \|\eta\| < 1.52$ excluded)	-
Hadronic leakage	Ratio of E_T in the 1st sampling of the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| < 0.8$ and $\|\eta\| > 1.37$)	R_{had1}
	Ratio of E_T in the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| > 0.8$ and $\|\eta\| < 1.37$)	R_{had}
Middle layer of the EM calorimeter	Ratio in η of cell energies in 3×7 versus 7×7 cells.	R_η
	Lateral width of the shower	w_2
Medium electron cuts (in addition to the loose cuts)		
Strip layer of the EM calorimeter	Total lateral shower width (20 strips)	w_{stot}
	Ratio of the energy difference between the largest and second largest energy deposits over the sum of these energies	E_{ratio}
Track quality	Number of hits in the pixel detector (at least one)	-
	Number of hits in the pixels and SCT (at least seven)	-
	Transverse impact parameter (<5 mm)	d_0
Track matching	$\Delta\eta$ between the cluster and the track in the strip layer of the EM calorimeter	$\Delta\eta_1$
Tight electron cuts (in addition to the medium electron cuts)		
B-layer	Number of hits in the B-layer (at least one)	
Track matching	$\Delta\phi$ between the cluster and the track in the middle layer of the EM calorimeter	$\Delta\phi_2$
	Ratio of the cluster energy to the track momentum	E/p
TRT	Total number of hits in the TRT (used over the acceptance of the TRT, $\|\eta\| < 2.0$)	-
	Ratio of the number of high-threshold hits to the total number of TRT hits (used over the acceptance of the TRT, $\|\eta\| < 2.0$)	-
Tight photon cuts (in addition to the loose cuts, applied with stricter thresholds)		
Middle layer of the EM calorimeter	Ratio in ϕ of cell energies in 3×3 and 3×7 cells	R_ϕ
Strip layer of the EM calorimeter	Shower width for three strips around maximum strip	w_{s3}
	Total lateral shower width	w_{stot}
	Fraction of energy outside core of three central strips but within seven strips	F_{side}
	Difference between the energy of the strip with the second largest energy deposit and the energy of the strip with the smallest energy deposit between the two leading strips	ΔE
	Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies	E_{ratio}

Electron Identification Efficiency