Electron and Photon Performance Measurements with the ATLAS Detector

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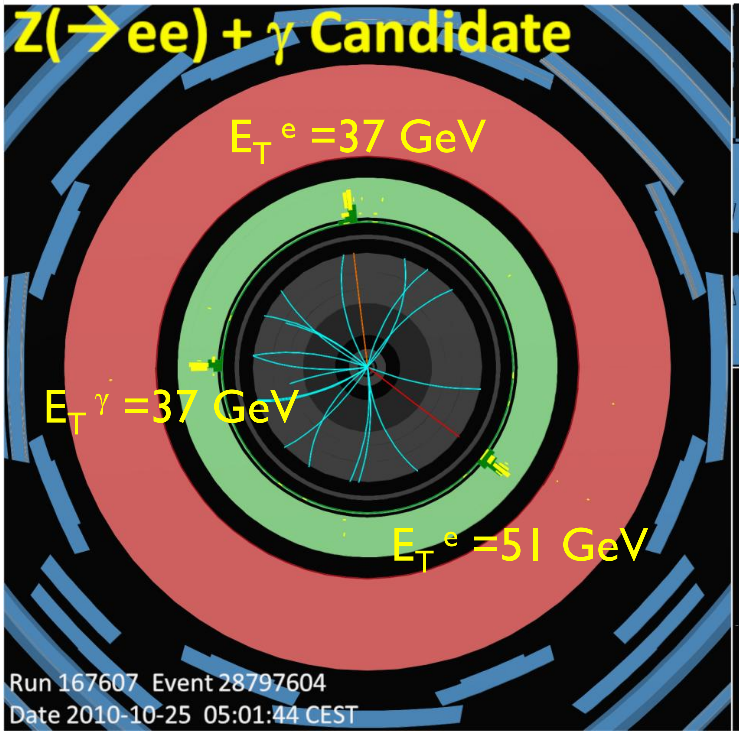
On behalf of the ATLAS collaboration

PLHC 2012, Vancouver

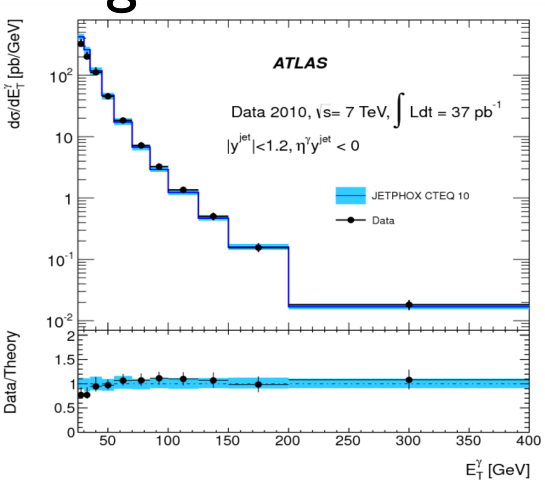
Overview

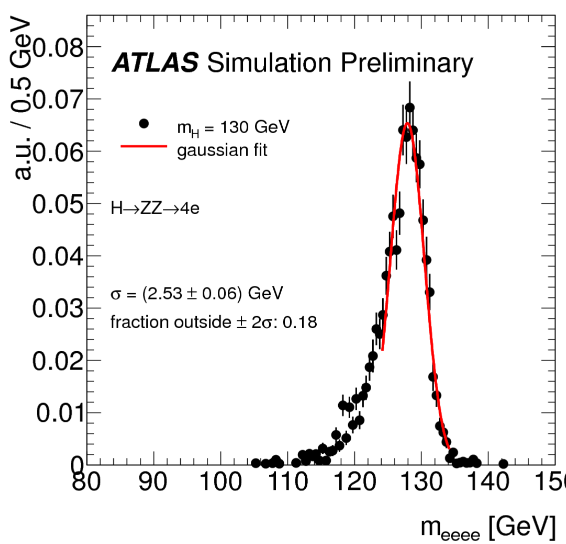
- Motivation
- ATLAS Detector
- Electron and photon reconstruction
- Reconstruction with GSF algorithm
- Electromagnetic calibration
- Electron and photon identification
- Electron and photon isolation

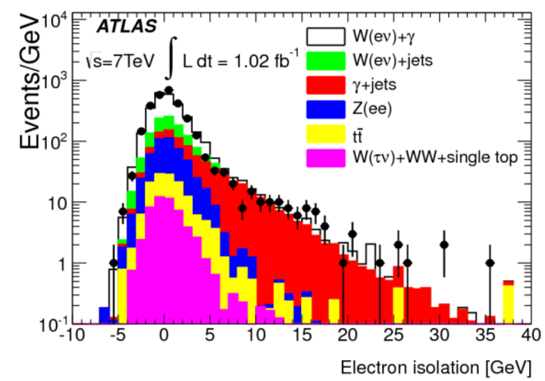


Electrons and Photons at LHC

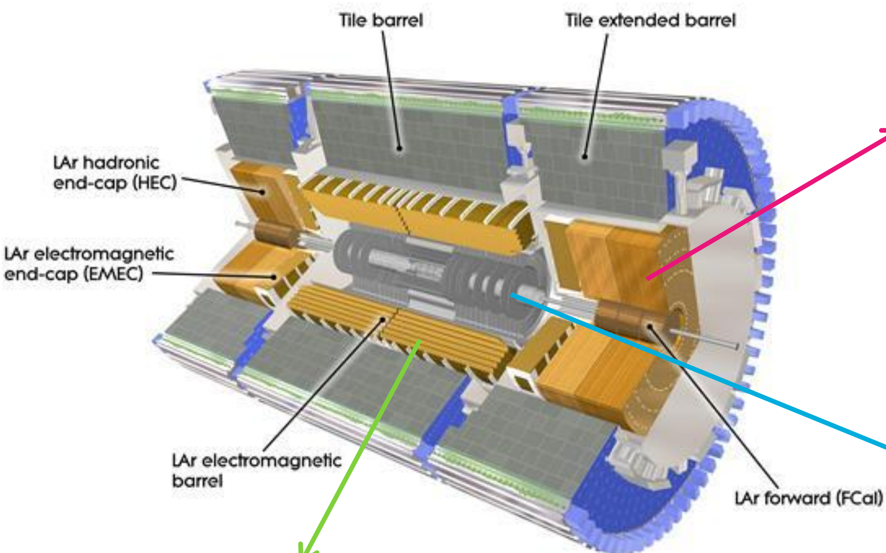
- Excellent particle reconstruction and identification is required at LHC
  - Ratio of isolated electrons over QCD jets is 10^{-5} (two orders of magnitude smaller than at TeVatron)
- Main background sources: QCD hadron jets, heavy flavours, pions, bremsstrahlung photons, electrons from photon conversions
- Used for SM, Higgs, SUSY, Exotics analyses for a wide p_T range







Inner Detector and Calorimeters

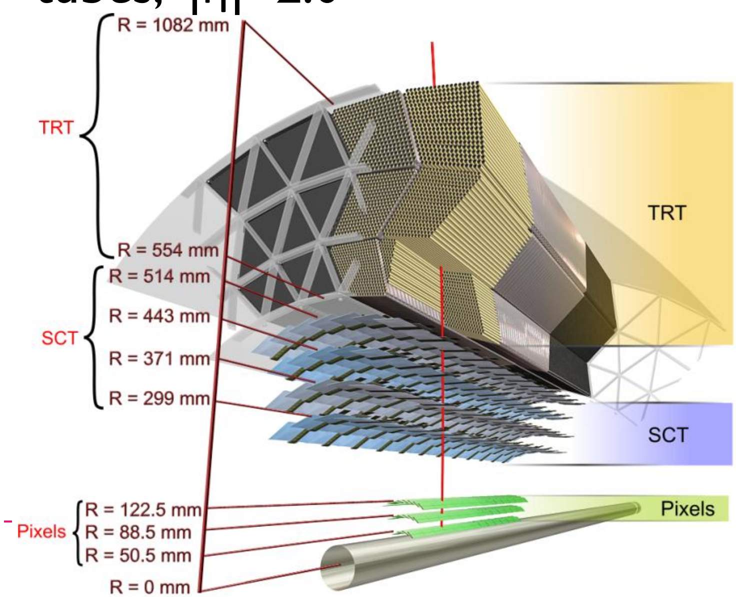


Forward calorimeter

- LAr calorimeter
- Coverage: $3.1<|\eta|<4.9$

Inner Detector: 3 sub-detectors

- Pixels: 3 layers, $|\eta|<2.5$
- SemiConductor Tracker: silicon micro-strip detector
- Transition Radiation Tracker: straw tubes, $|\eta|<2.0$

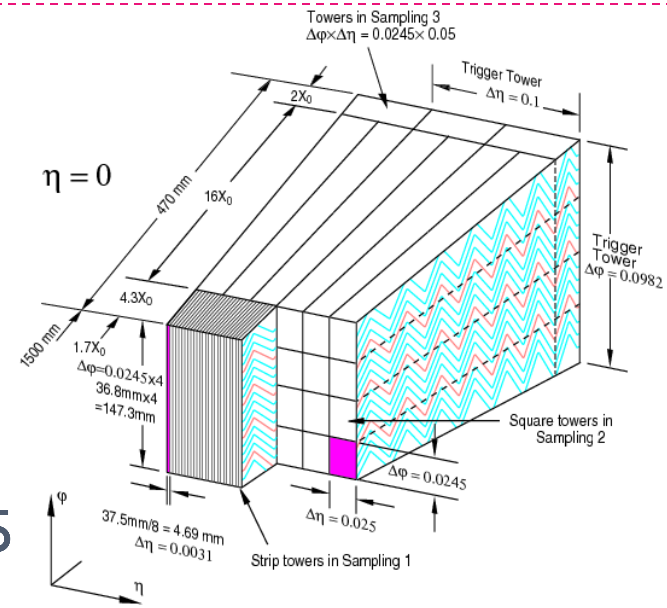


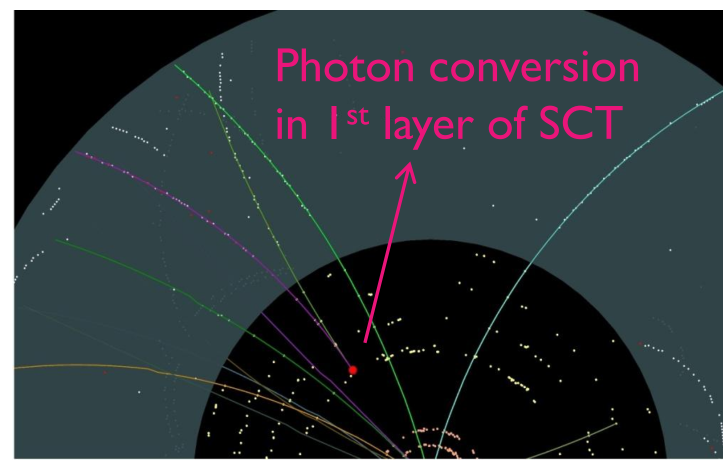
EM calorimeter

- LAr sampling calorimeter with accordion geometry
- Coverage: barrel $|\eta|<1.475$, end-cap $1.375<|\eta|<3.2$
- 3 longitudinal compartments with different granularity (strips, middle, back) + Presampler

Electron and Photon Reconstruction

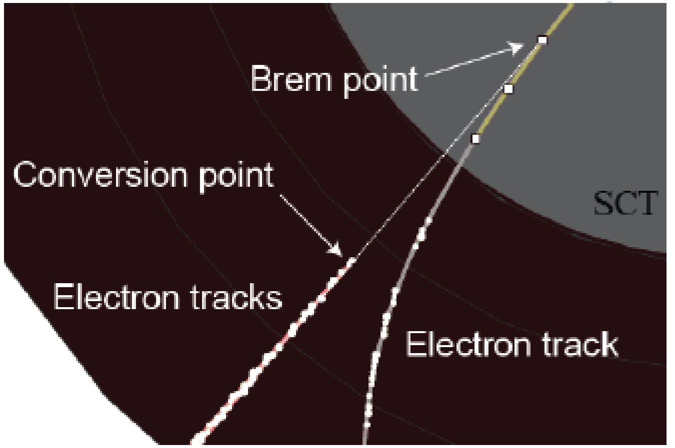
- Use sliding window algorithm
  - Find seed with energy >2.5 GeV
- Form clusters $\Delta\eta x \Delta\phi$
  - For electrons and converted photons: 0.075x0.175 in barrel and 0.125x0.125 in end-cap
  - For unconverted photons: 0.125x0.125
- Measure cluster energy → Calibrate energy
- Match cluster to an ID track
  - Electron – photon separation
- Match track to a secondary vertex
  - Converted – unconverted photons



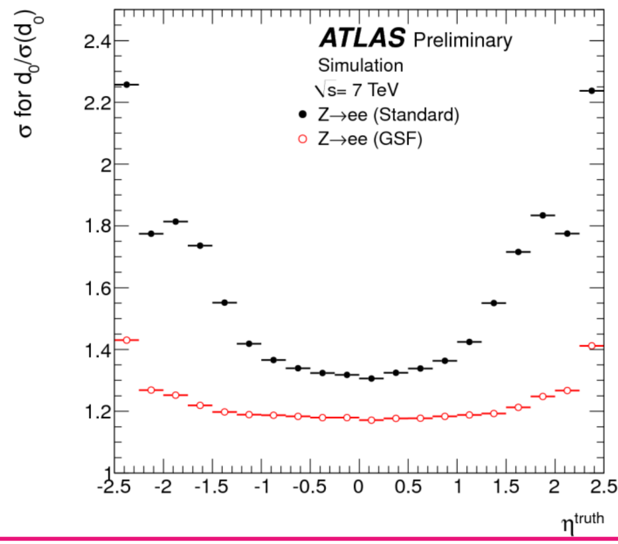


Electron reconstruction using GSF

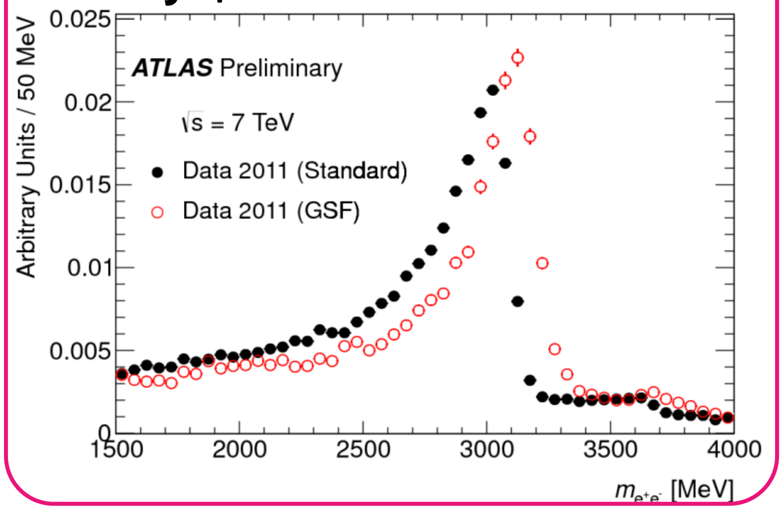
- Electron reconstruction takes into account bremsstrahlung losses at pattern recognition level
  - Gaussian Sum Filter method for improved electron track parameters and cluster-track matching



Improvement on the track transverse parameter significance

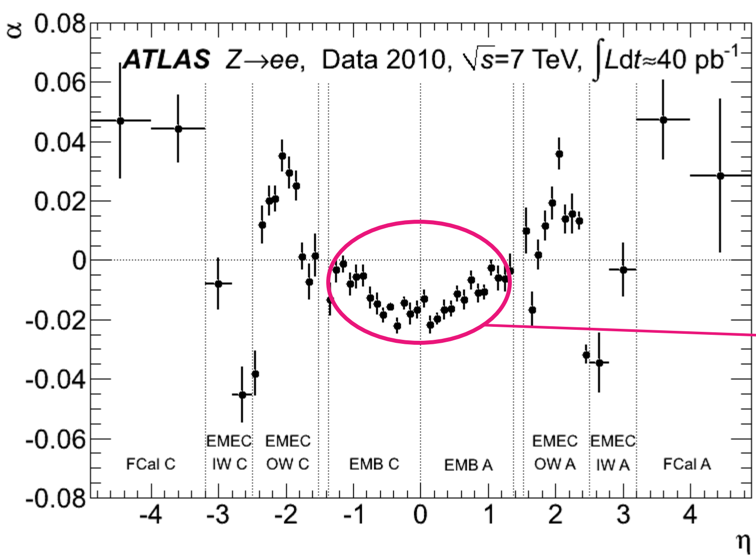


Impact on low-p_T electrons and J/ψ mass distribution

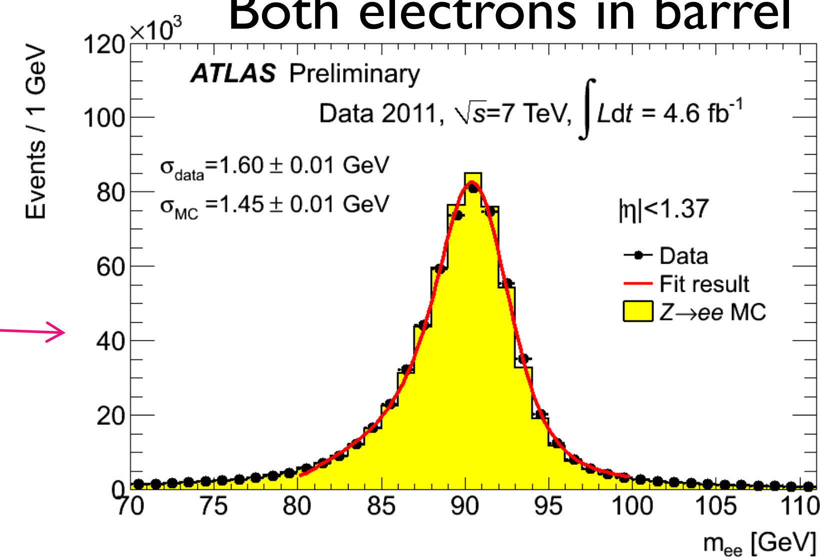


Electromagnetic calibration

- The energy measured in the cluster cells is calibrated using simulation based methods and tuned with test beam results
- Z→ee in-situ calibration is used to correct the EM scale on data
  - Used for the full pseudorapidity region |η|<4.9
  - Cross-checked for linearity, uniformity and stability with J/ψ and W events
  - Derive constant term to apply to MC resolution
    - Barrel: 1.2% ±0.1%(stat) ±0.5%(syst), End-cap: 1.8% ±0.4%(stat) ±0.4%(syst)

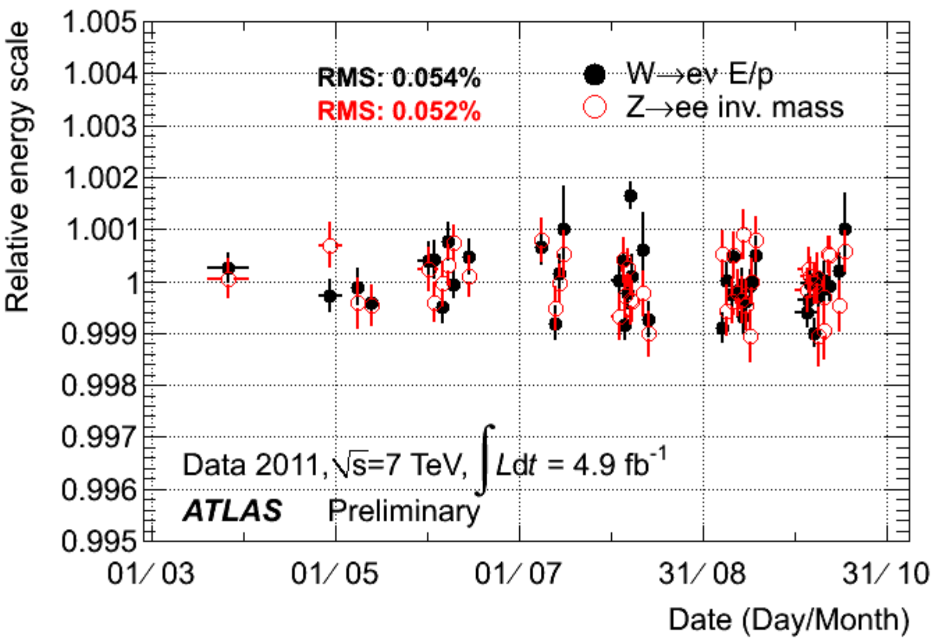


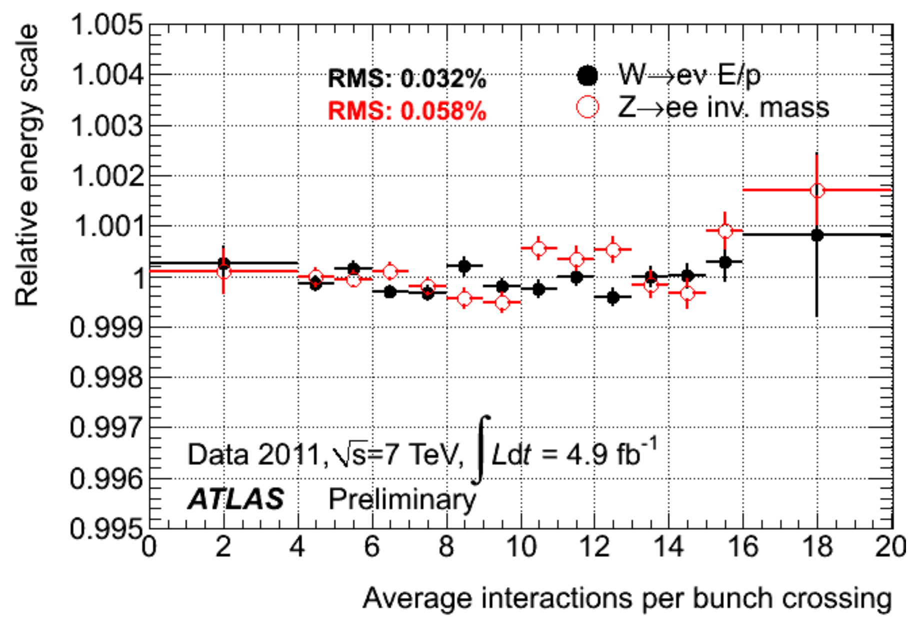
Both electrons in barrel



Stability with time and pile-up

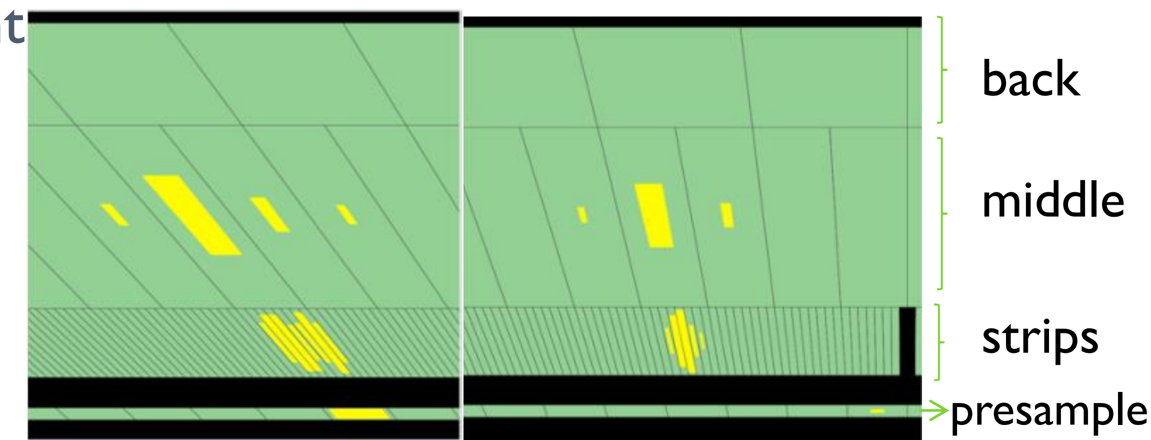
- The in-situ energy calibration is static with time
  - No energy scale dependence on time
  - No energy scale dependence on pile-up





Electron and Photon Identification

- Identification criteria include calorimetric cuts using the information from the different layers of the EM calorimeter, leakage in the hadronic calorimeter, track quality variables and cluster-track matching
- 3 (2) different sets of cuts with increasing background rejection
  - e: loose, medium, tight
  - γ: loose, tight



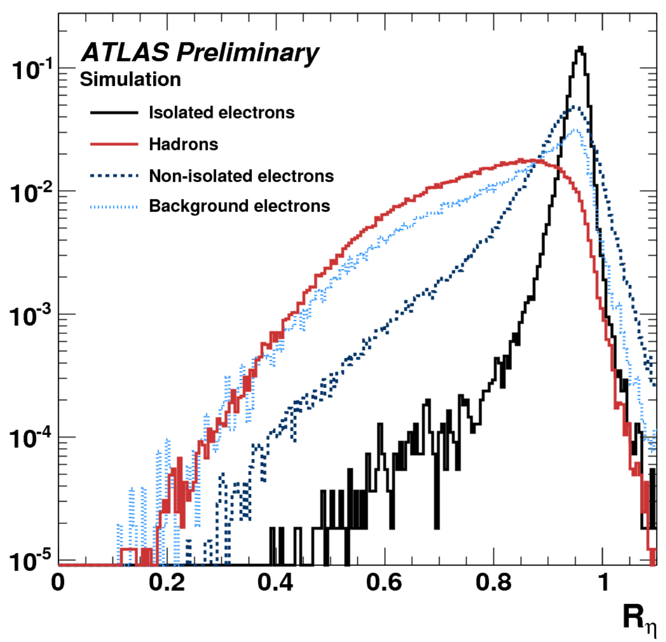
Example: Due to the fine granularity of the strips (EM), it is possible to distinguish between γ and π using strip variables.

Strip granularity in η:0.003 (barrel)

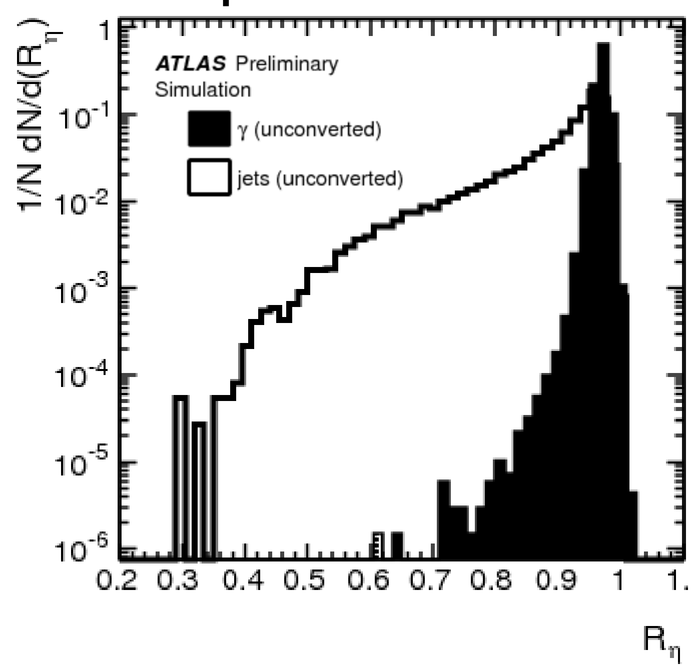
Identification – Discriminating variables

- R_η variable: ratio of energies of middle cells in $\Delta\eta \times \Delta\phi$=3x7 over 7x7. For electrons and photons it peaks close to 1

electrons

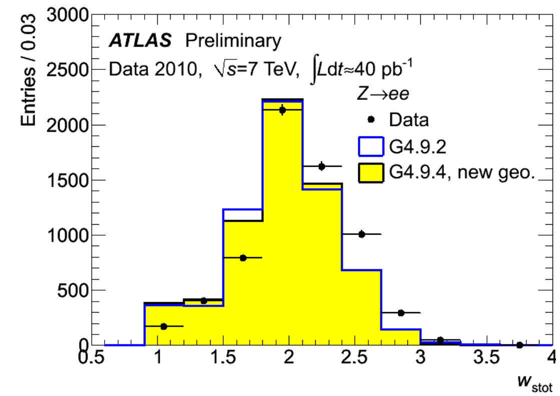


photons

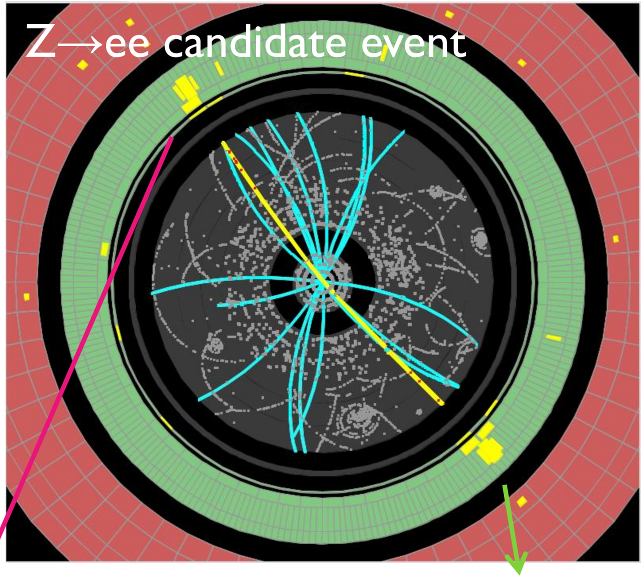


Data-driven measurements – Tag & Probe Method

- Need for data-driven performance measurements
  - Differences between data-MC shower shapes



- Tag&Probe: data-driven technique for performance analysis
- Derive efficiencies using well-known decay modes
- The method is based on the definition of a probe-like object, used to make the performance measurement, within a properly "tagged" sample of events



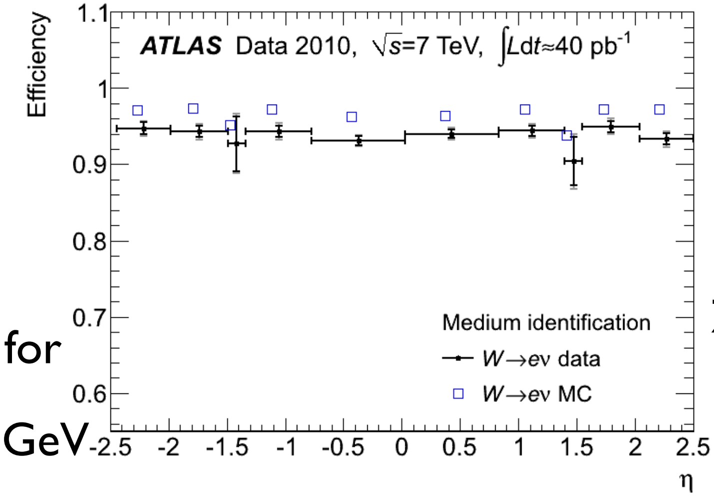
tag electron

Search for a second electron with desired properties (probe)

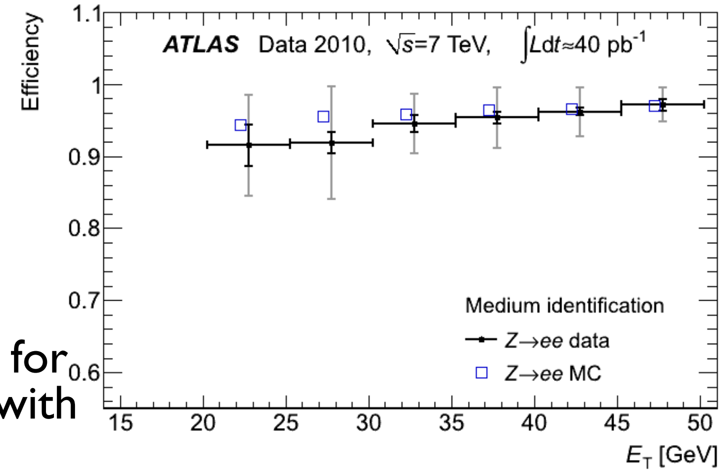
Electron Identification Efficiencies

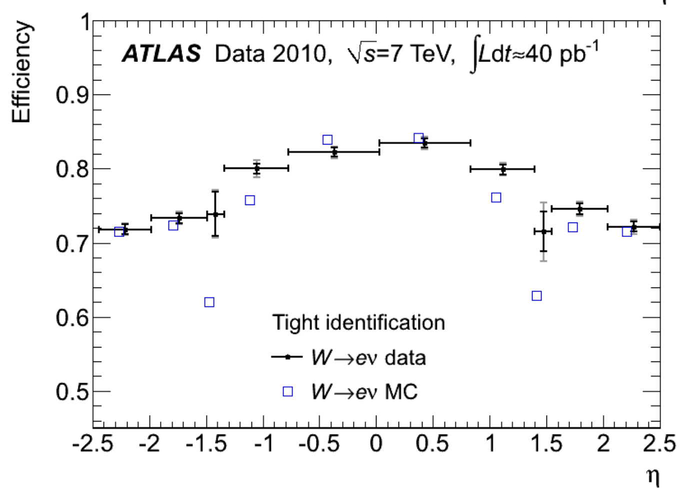
- Identification efficiencies measured using Tag&Probe method on $Z\to ee$, $W\to e\nu$, $J/\psi\to ee$
- Measured in bins of η and E_T

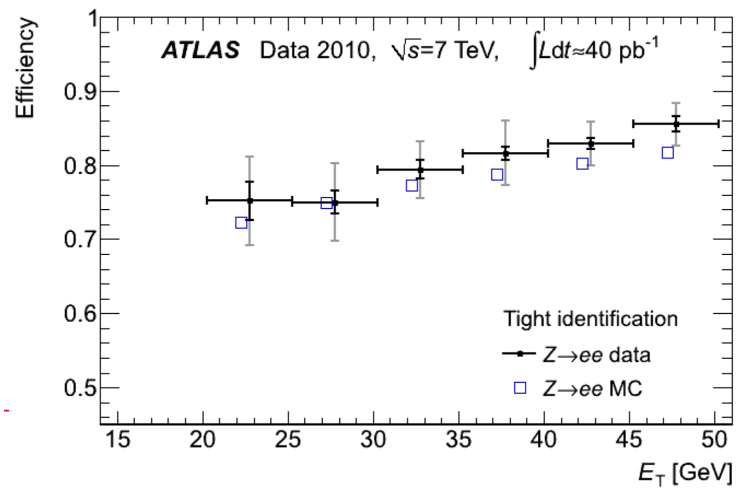
$W\to e\nu$: Integrated for electrons $20<E_T<50$ GeV



$Z\to ee$: Integrated for electrons with $|\eta|<2.47$



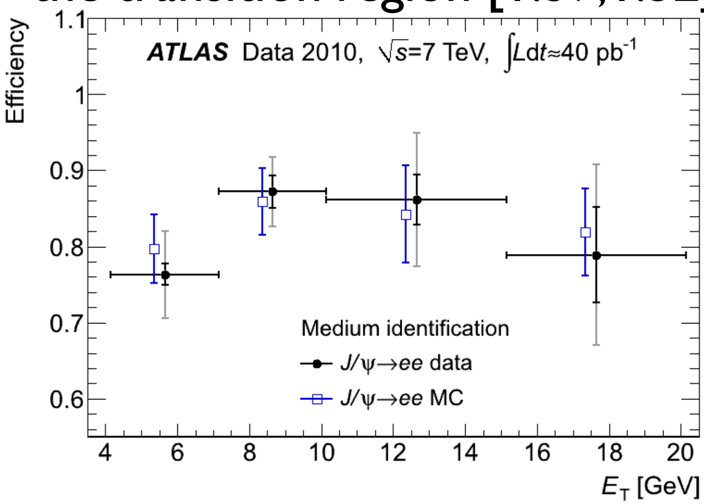




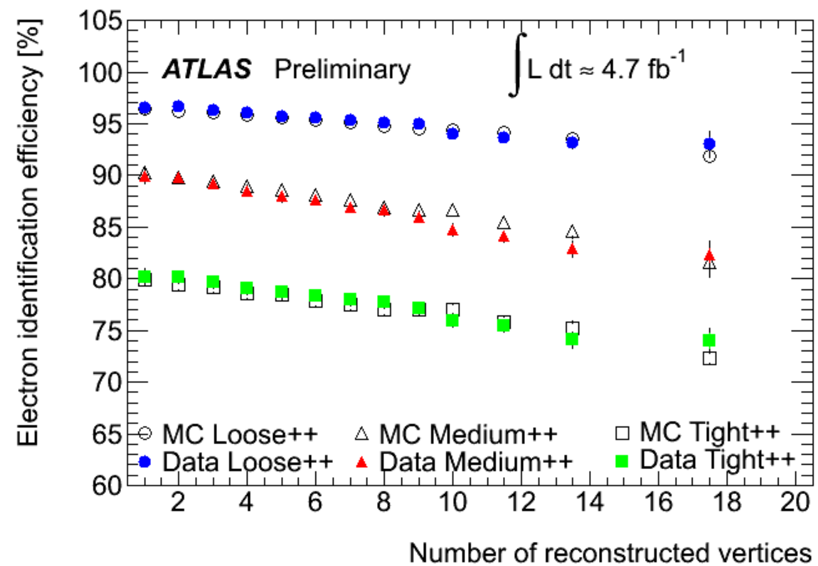
Electron Identification Efficiencies (2)

- Low ET electron efficiencies (4-20 GeV) are measured on J/ψ events.

  Integrated for |η|<2.47 excluding the transition region [1.37,1.52]



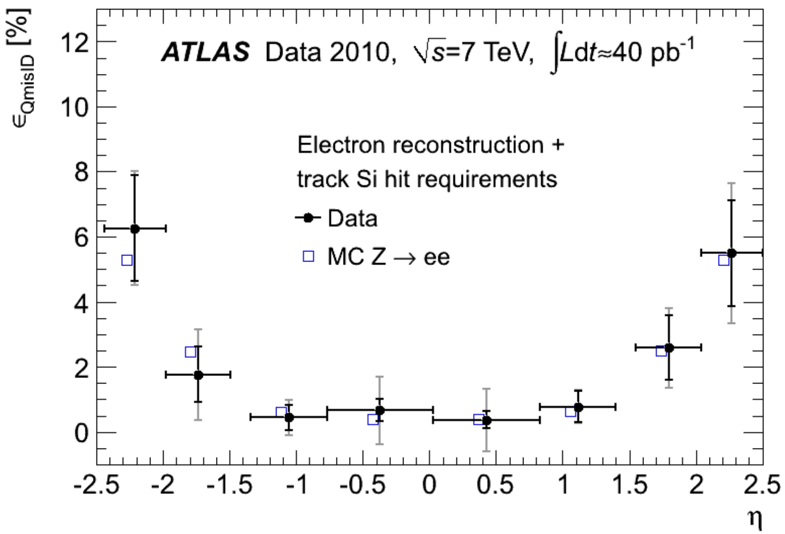
- Dependence of the identification efficiencies on pile-up. Improved for 2012 data taking

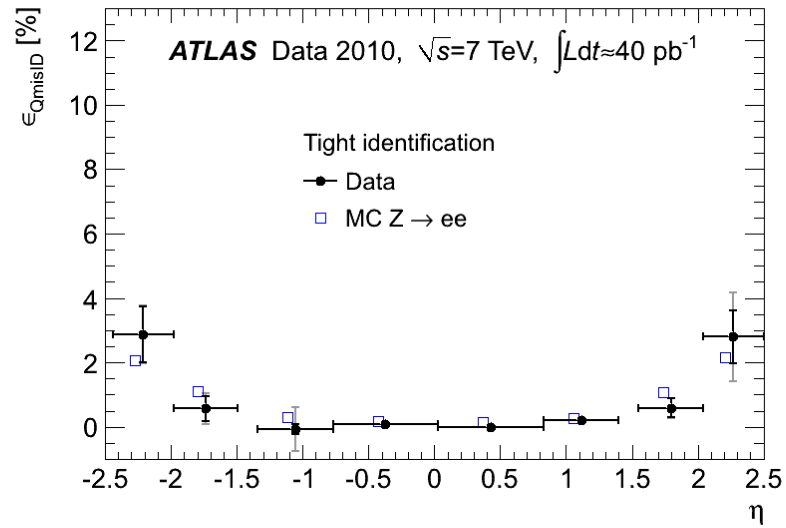


- For W and Z measurements the systematic uncertainty is dominant. More precise measurements on 2011 data being finalised

Charge Misidentification

- For electrons/positrons it is possible due to wrong track-matching to assign the wrong charge. The charge misidentification rate depends on the identification level of the candidate object

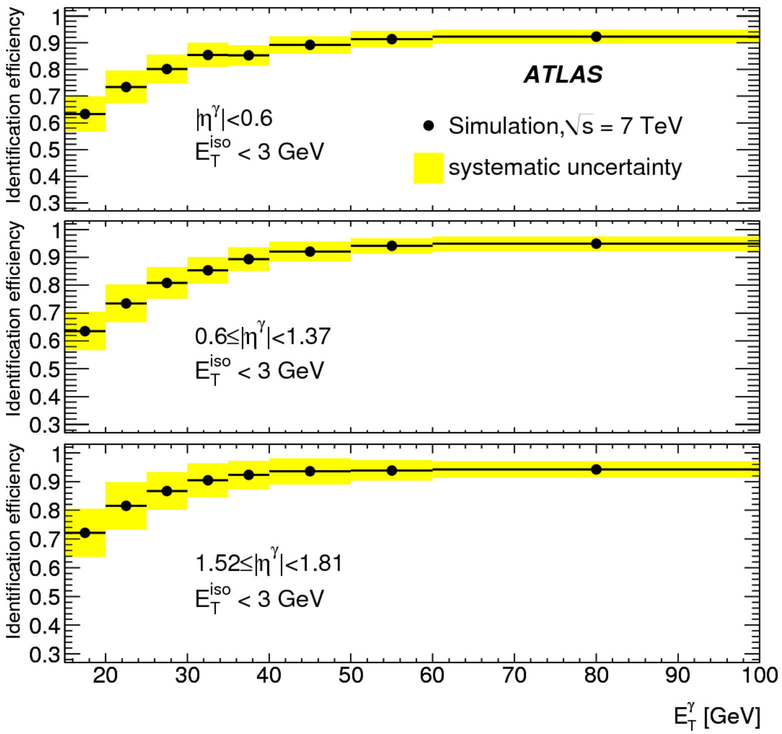


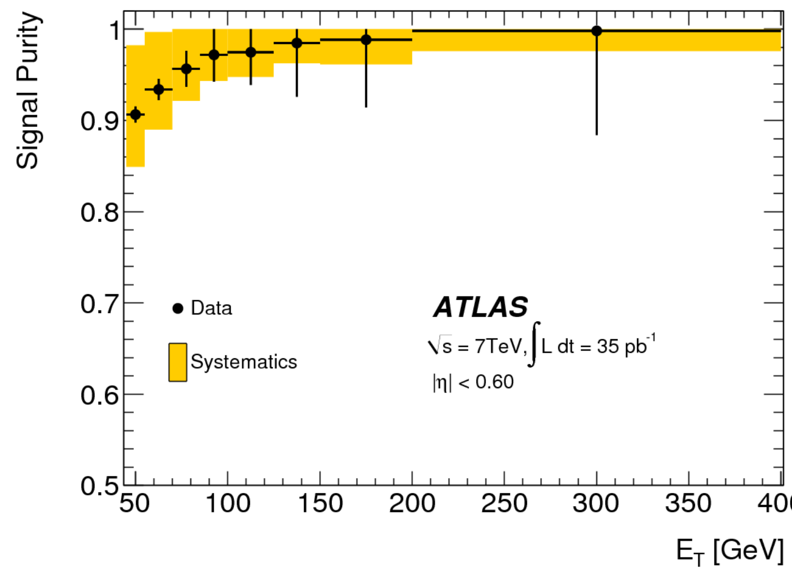


Selection	Data [%]	MC [%]
Electron reconstruction	$2.17 \pm 0.25 \pm 0.28$	2.73
Track silicon hit requirements	$1.13 \pm 0.21 \pm 0.16$	1.28
Medium identification	$1.04 \pm 0.11 \pm 0.14$	1.20
Tight identification	$0.37 \pm 0.07 \pm 0.11$	0.50

Photon Identification Measurements

- Photon identification efficiency measured on MC events corrected for data-MC differences

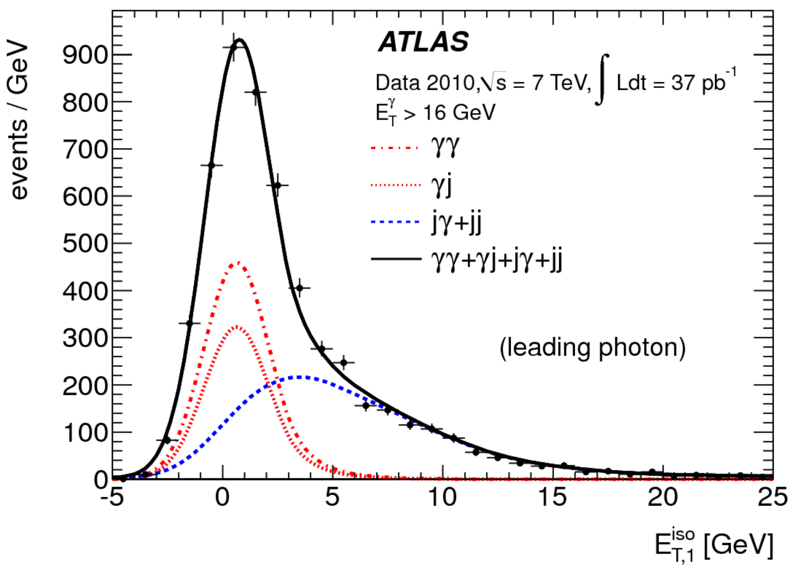




- Photon purity estimated on data using a 2D side-band method (tight identification and isolation)

Electron and Photon Isolation

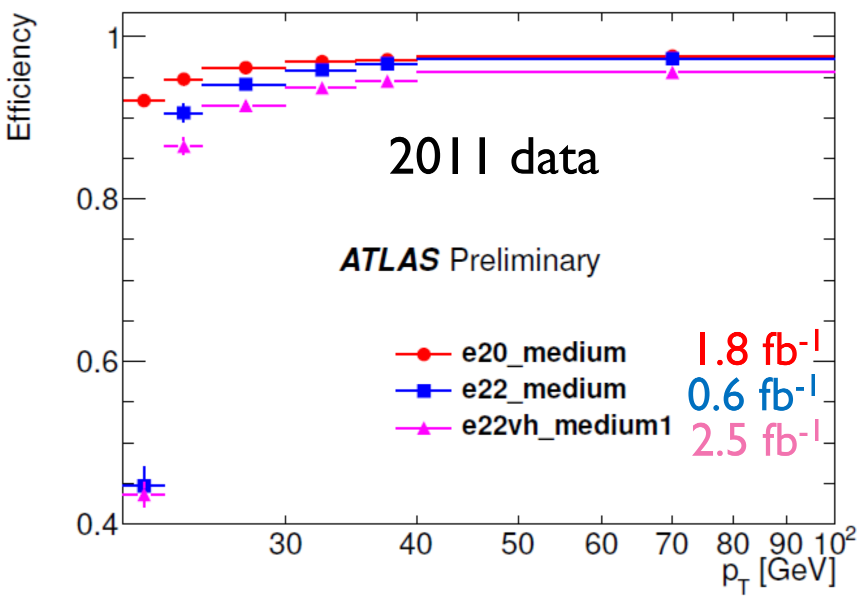
- More than 1 methods used: topocluster based, cell based (calorimetric), track based
  - Measure p_T of tracks around the electron track
  - Measure energy in a cone ΔR around the electron/photon cluster (typically $\Delta R = 0.2, 0.3, 0.4$)
  - Corrections for the underlying event and pile-up are derived by using low E_T jets to correct for the ambient energy

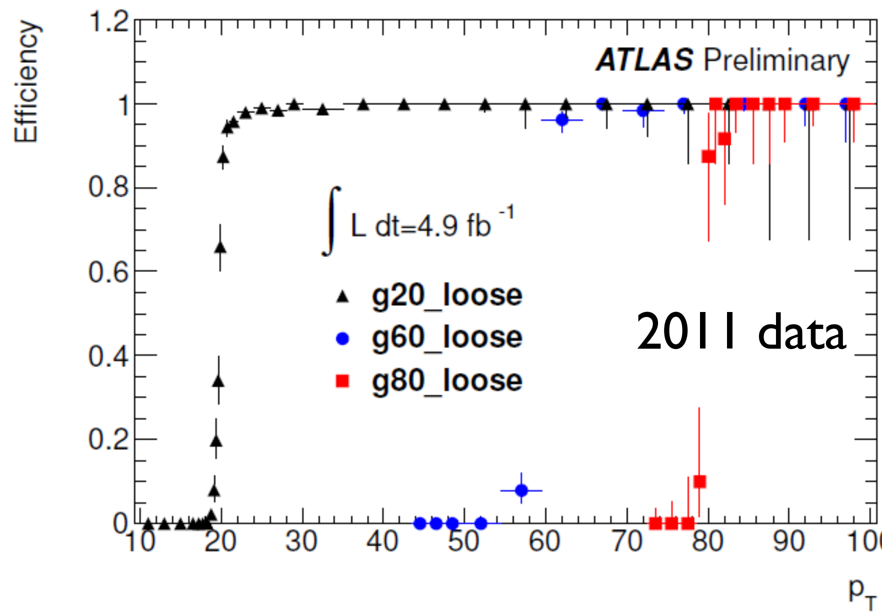


Photon isolation obtained by extrapolating the electron isolation and correcting for differences using MC

Electron and Photon Trigger

- 3 levels of trigger
- High Level Trigger includes identification cuts for signal electron and photon triggers

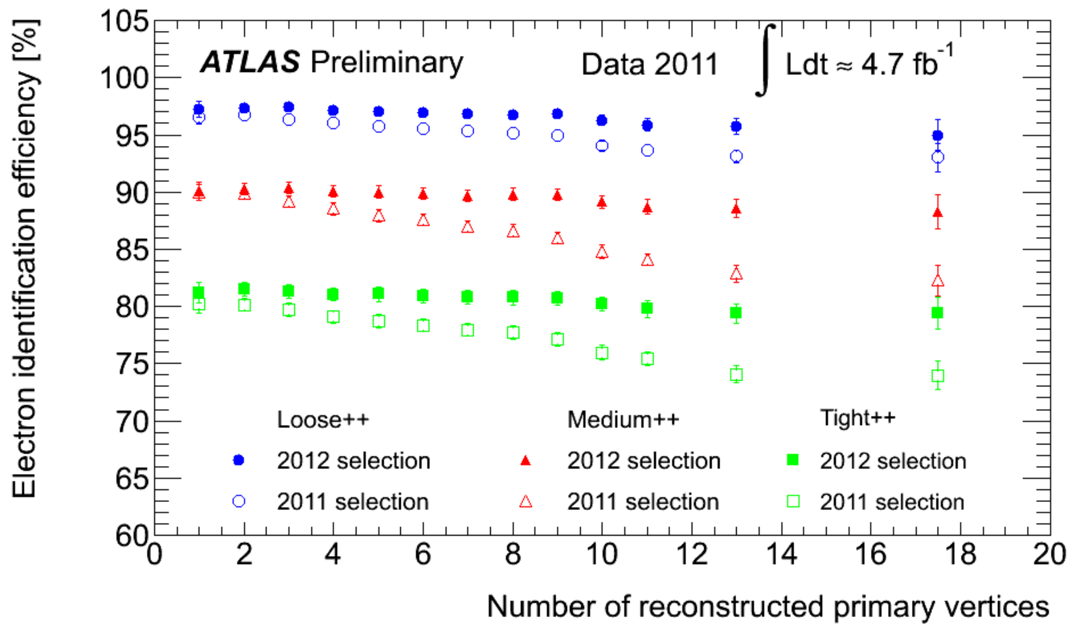




- Trigger fully efficient within ~3 GeV from the applied p_T cut

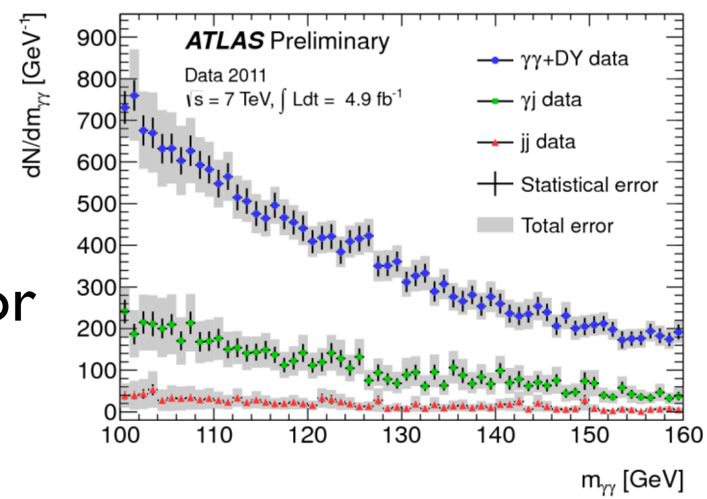
Prospects for 2012 data-taking

- Well prepared for 2012 conditions!
- Electron and photon identification criteria re-optimised for high pile-up conditions
- Isolated single electron unprescaled trigger with E_T threshold at 24 GeV (~108 Hz at $7 \cdot 10^{-33}$) → Dominated by real W events



Conclusions

- Very good electron and photon reconstruction and identification
  - Electron measurements performed on $Z\rightarrow ee$, $W\rightarrow e\nu$ and $J/\psi\rightarrow ee$
- Measurements performed in η and E_T
- In situ calibration of the EM calorimeter for the full pseudorapidity region
- Improvement of the electron reconstruction and track quality using the Gaussian Sum Fitter method
- Electrons and photons are the tools for many interesting results!



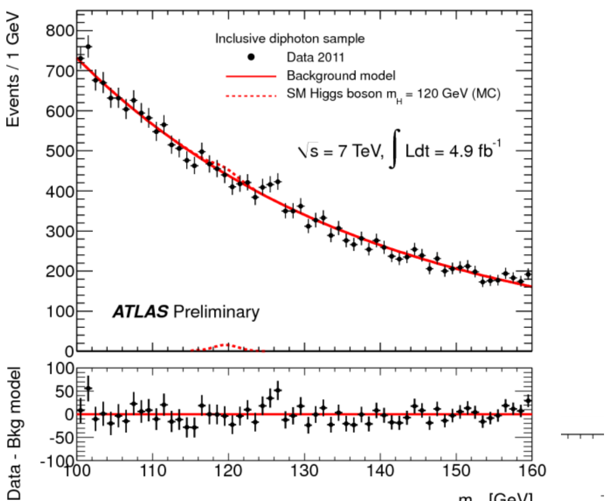
References

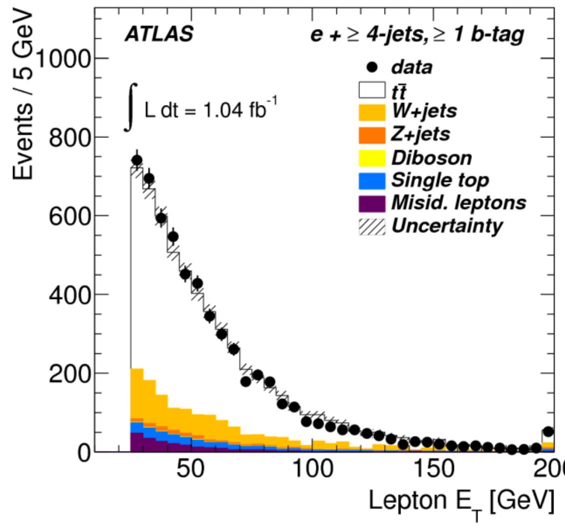
- Electron performance measurements with the ATLAS detector using the 2010 LHC proton-proton collision data, Eur. Phys. J. C72 (2012) 1909
- Measurement of the inclusive isolated prompt photon cross-section in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector using 35 pb-1, Phys.Lett. B706 (2011) 150-167
- Improved electron reconstruction in ATLAS using the Gaussian Sum Filter-based model for bremsstrahlung, ATLAS-CONF-2012-047
- Expected electron performance in the ATLAS experiment, ATL-PHYS-PUB-2011-006
- Measurement of isolated di-photon cross-section in pp collisions at sqrt(s) = 7 TeV with the ATLAS detector, Phys.Rev. D85 (2012) 012003
- Expected photon performance in the ATLAS experiment, ATL-PHYS-PUB-2011-00
- ATLAS EGamma twiki page: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ElectronGammaPublicCollisionResults

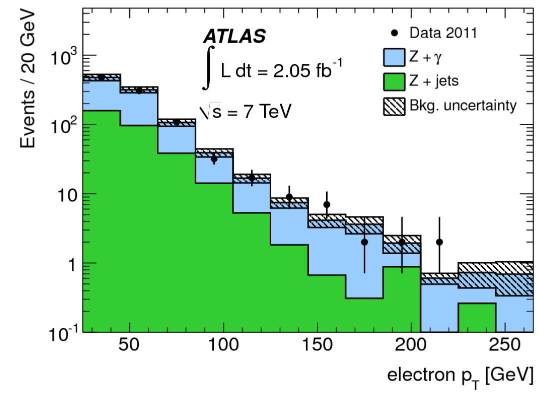
Back-Up

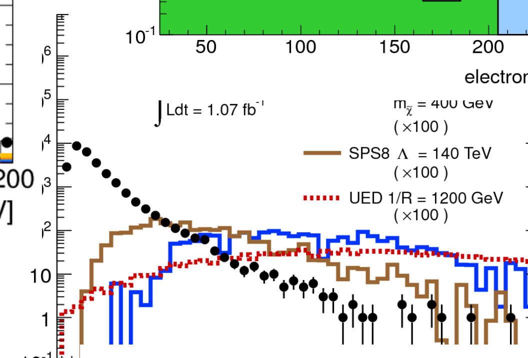
Electron and Photon Physics Measurements

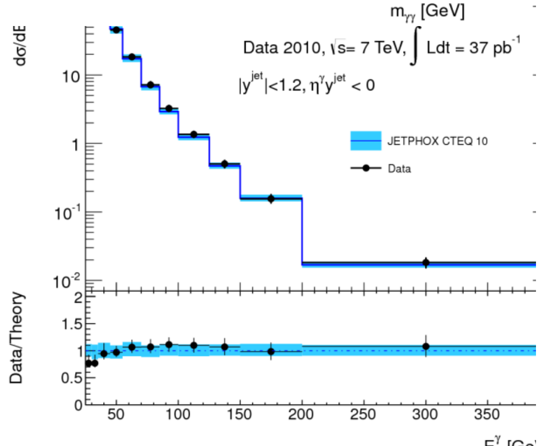
- Used for SM, Higgs, SYSU, Exotics analyses for a wide p_T range

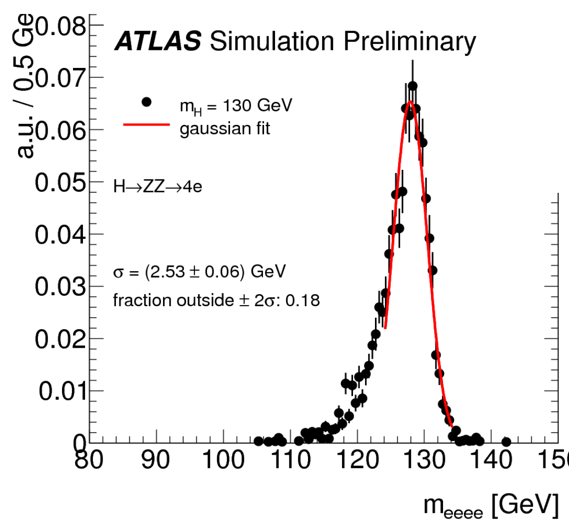


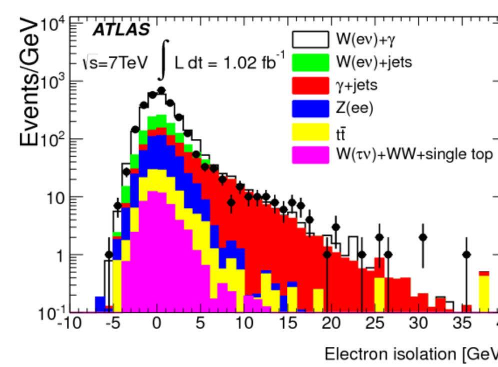












Electron Identification Cuts

Table 1 Definition of variables used for *loose*, *medium* and *tight* electron identification cuts for the central region of the detector with $|\eta| < 2.47$

Type	Description	Name
Loose selection		
Acceptance	$\|\eta\| < 2.47$	
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 $\|\eta\| < 0.8$ 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 EM calorimeter	Ratio of the energy in 3×7 cells over the energy in 7×7 cells centred at the electron cluster position	R_η
	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	$w_{\eta 2}$
Medium selection (includes loose)		
Strip layer of EM calorimeter	Shower width, $\sqrt{(\Sigma E_i (i - i_{max})^2)(\Sigma E_i)}$, 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}
Track quality	Number of hits in the pixel detector (≥ 1)	n_{pixel}
	Number of total hits in the pixel and SCT detectors (≥ 7)	n_{Si}
	Transverse impact parameter ($\|d_0\| < 5$ mm)	d_0
Track–cluster matching	$\Delta\eta$ between the cluster position in the strip layer and the extrapolated track ($\|\Delta\eta\| < 0.01$)	$\Delta\eta$
Tight selection (includes medium)		
Track–cluster matching	$\Delta\phi$ between the cluster position in the middle layer and the extrapolated track ($\|\Delta\phi\| < 0.02$)	$\Delta\phi$
	Ratio of the cluster energy to the track momentum	E/p
	Tighter $\Delta\eta$ requirement ($\|\Delta\eta\| < 0.005$)	$\Delta\eta$
Track quality	Tighter transverse impact parameter requirement ($\|d_0\| < 1$ mm)	d_0
TRT	Total number of hits in the TRT	n_{TRT}
	Ratio of the number of high-threshold hits to the total number of hits in the TRT	f_{HT}
Conversions	Number of hits in the b-layer (≥ 1)	n_{BL}
	Veto electron candidates matched to reconstructed photon conversions	

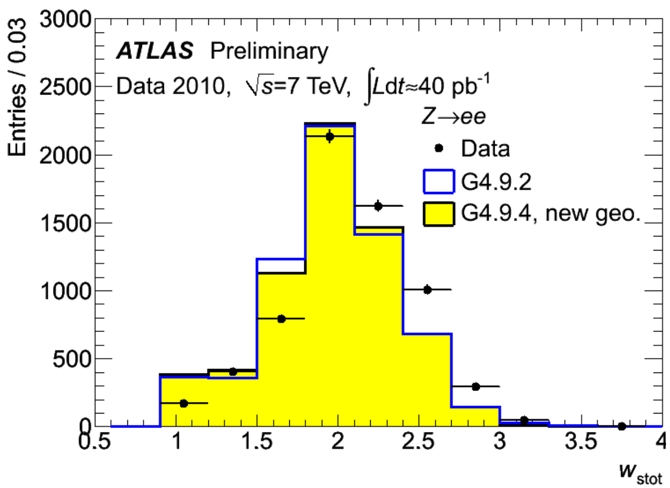
Photon Identification Cuts

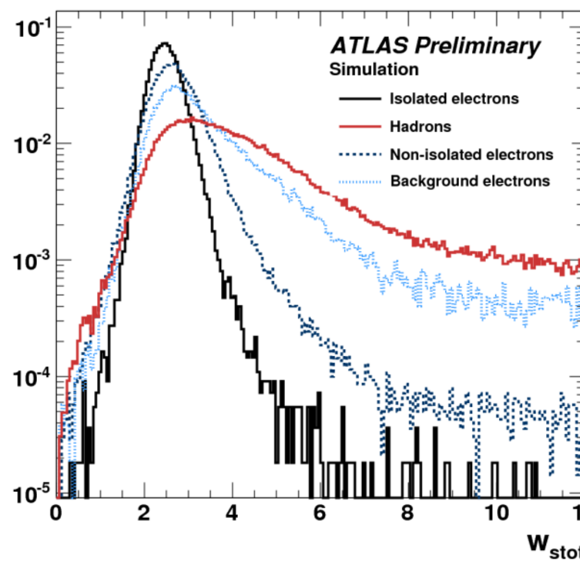
Category	Description	Name	Loose	Tight
Acceptance	$\|\eta\| < 2.37$, $1.37 < \|\eta\| < 1.52$ excluded	–		✓
Hadronic leakage	Ratio of E_T in the first sampling of the hadronic calorimeter to E_T of the EM cluster (used over the range $\|\eta\| < 0.8$ and $\|\eta\| > 1.37$)	R_{had_1}	✓	✓
	Ratio of E_T in all 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 in η of cell energies in 3×7 versus 7×7 cells	R_η	✓	✓
	Lateral width of the shower	w_2	✓	✓
	Ratio in ϕ of cell energies in 3×3 and 3×7 cells	R_ϕ		✓
EM Strip layer	Shower width for three strips around maximum strip	$w_{s\,3}$		✓
	Total lateral shower width	$w_{s\,\mathrm{tot}}$		✓
	Fraction of energy outside core of three central strips but within seven 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 minimal value found between the first and second maxima	ΔE		✓
	Ratio of the energy difference associated with the largest and second largest energy deposits over the sum of these energies	E_{ratio}		✓

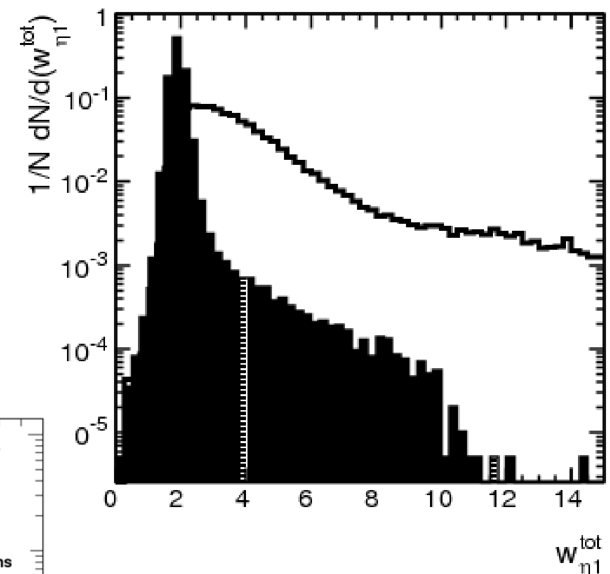
Table 5: Variables used for loose and tight photon identification cuts.

Discriminating Variables for Identification

- W_{tot} variable: width of the shower in the strips







Electron Identification Efficiencies

- Identification efficiency comparison

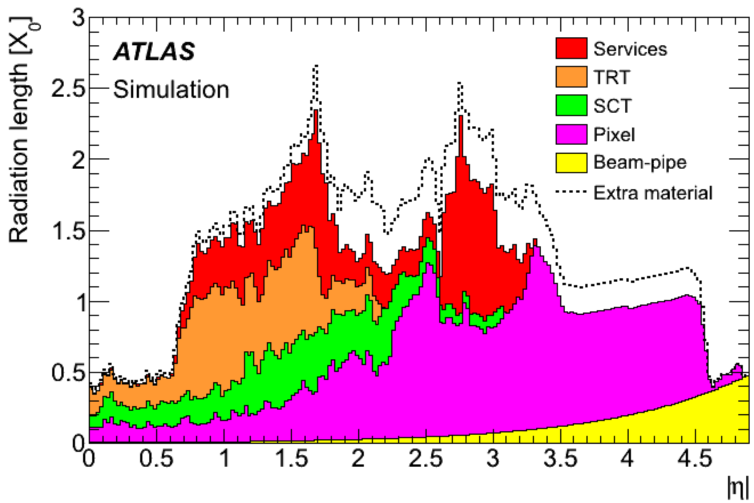
Selection	Channel	Data [%]	MC [%]	Ratio
Medium	$W \to e\nu$	$94.1 \pm 0.2 \pm 0.6$	96.9	$0.971 \pm 0.002 \pm 0.007$
	$Z \to ee$	$94.7 \pm 0.4 \pm 1.5$	96.3	$0.984 \pm 0.004 \pm 0.015$
Tight	$W \to e\nu$	$78.1 \pm 0.2 \pm 0.6$	77.5	$1.009 \pm 0.003 \pm 0.007$
	$Z \to ee$	$80.7 \pm 0.5 \pm 1.5$	78.5	$1.028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

Integrated in $20<E_T<50$ GeV and $|\eta|<2.47$

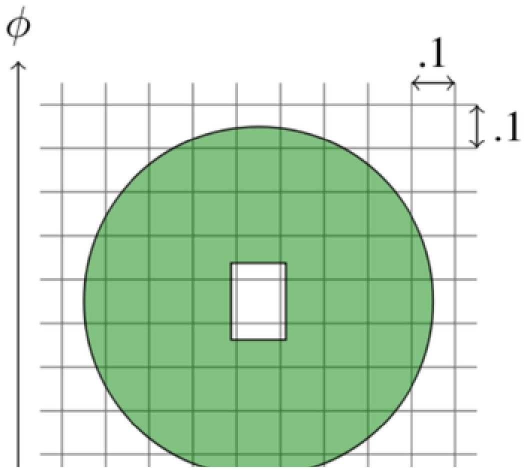
Selection	Channel	Data [%]	MC [%]	Ratio	MC [%] prompt J/ψ
Medium	$W \to e\nu$	$75.8 \pm 8.8 \pm 8.1$	94.9	$0.80 \pm 0.09 \pm 0.07$	
	$J/\psi \to ee$	$80.0 \pm 7.3 \pm 10.2$	81.9	$0.98 \pm 0.09 \pm 0.14$	92.9
Tight	$W \to e\nu$	$61.9 \pm 6.0 \pm 7.0$	78.3	$0.79 \pm 0.08 \pm 0.09$	
	$J/\psi \to ee$	$68.1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

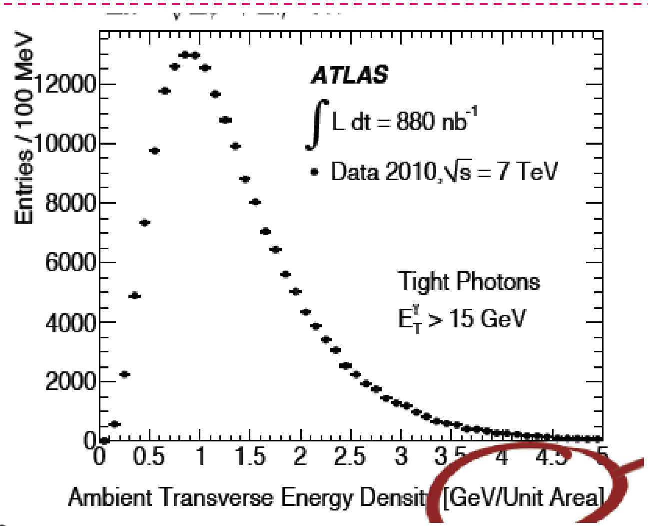
Integrated in $15<E_T<20$ GeV and $|\eta|<0.8$

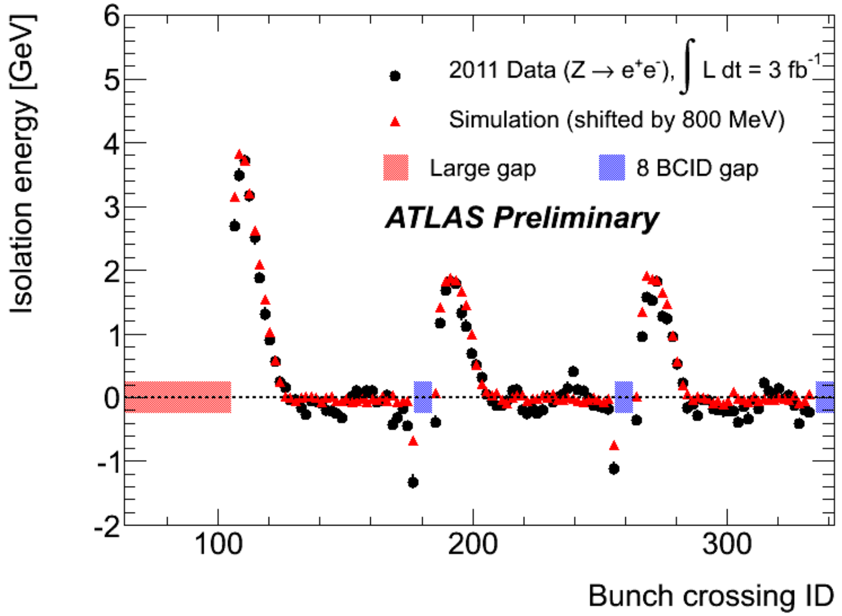
- Material plot

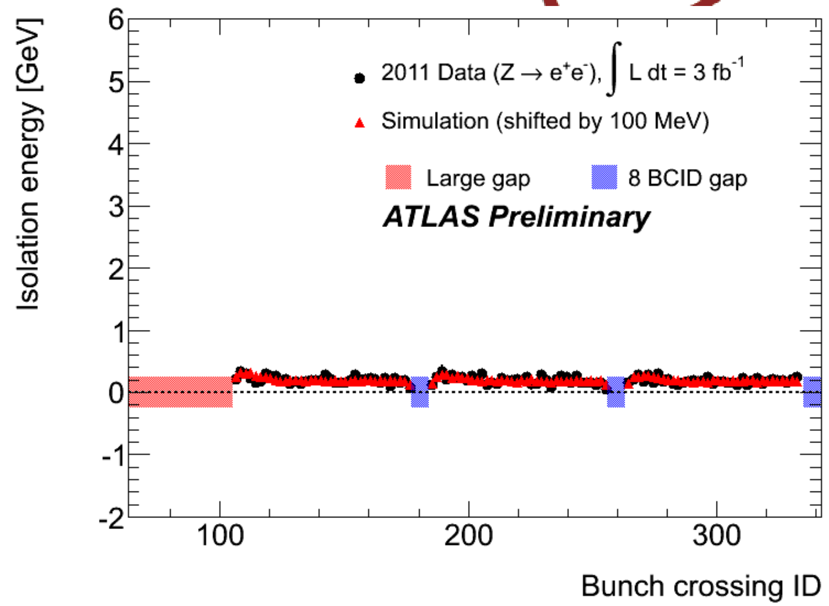


Isolation corrections









Pointing Resolution

- Estimate z vertex position from unconverted photons
- η direction improved using the pointing of the calorimeter clusters
- Use tracks for unconverted photons