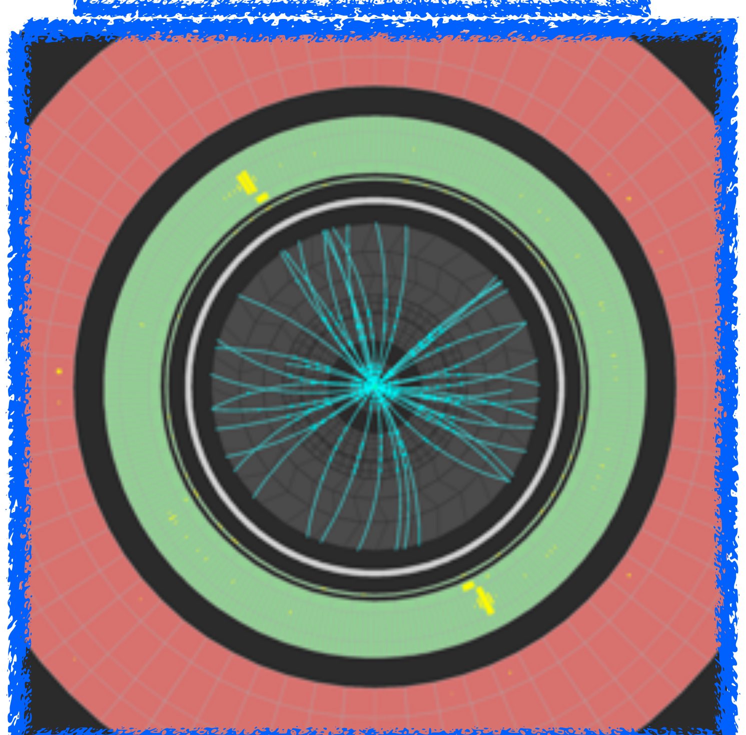
ATLAS detector performance for electrons and photons

Quentin Buat
on behalf of the ATLAS Collaboration
LPSC Grenoble
CHEF 2013

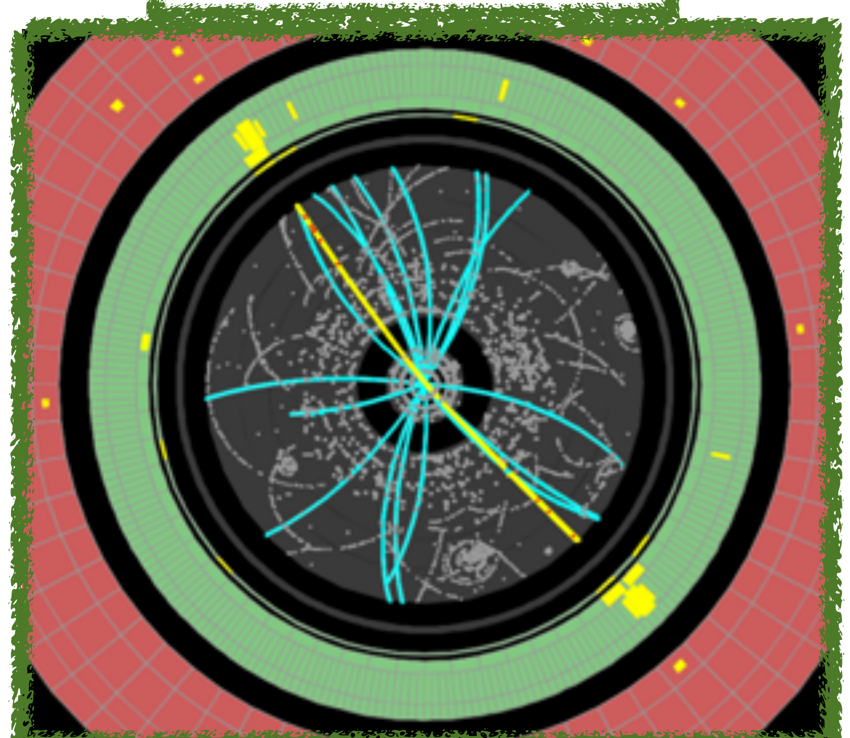
Outline

- Motivation
- Detectors for electrons and photons
- Electron and photon reconstruction
- Electromagnetic energy calibration
- Electron and photon identification
- Photon identification efficiency
- Electron efficiencies
- Isolation

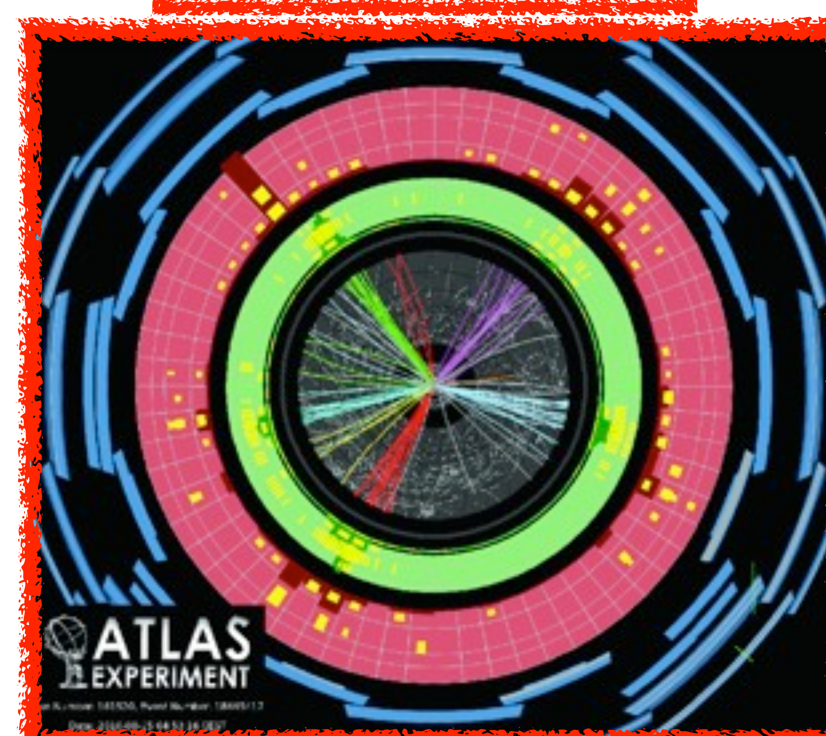
Diphoton candidate



$Z \to e^+e^-$ candidate

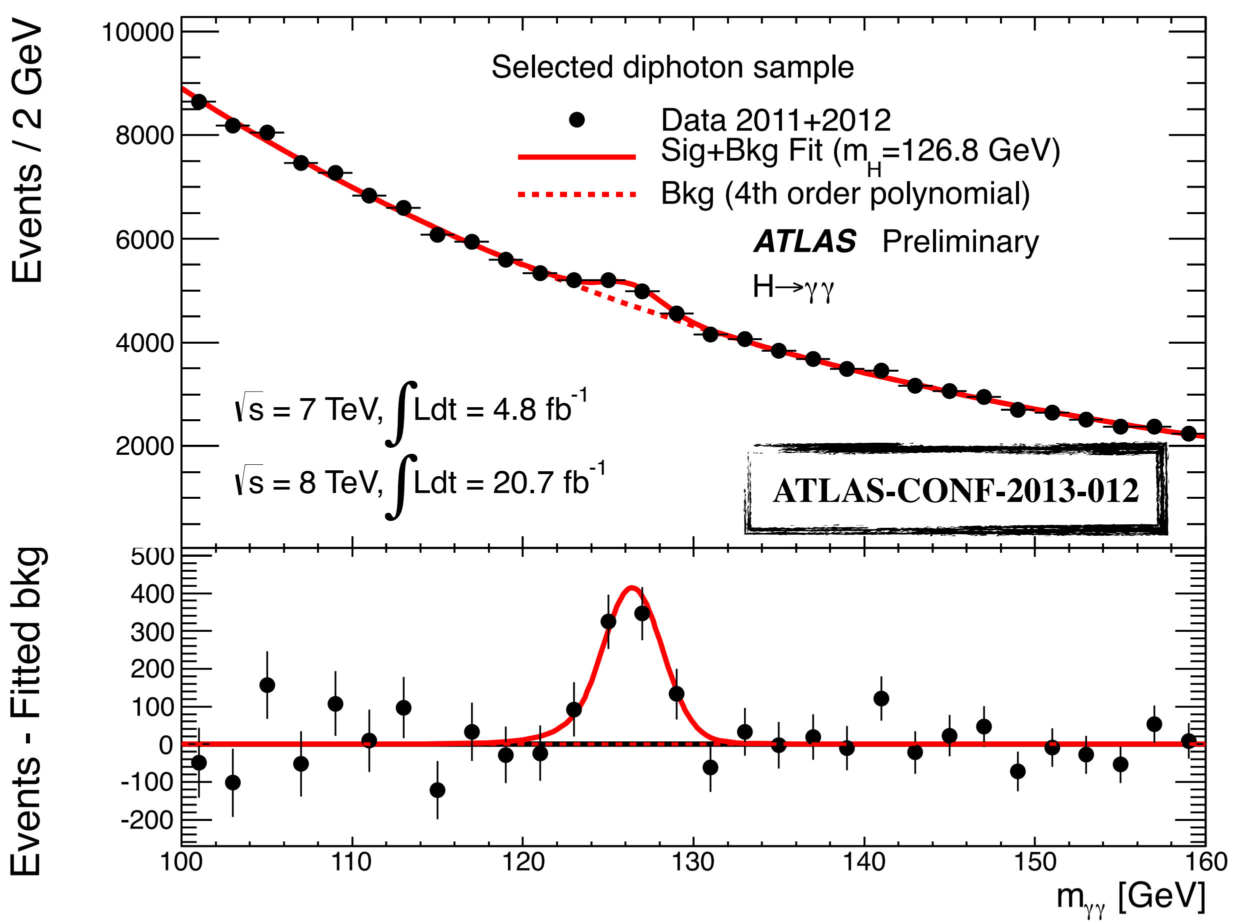


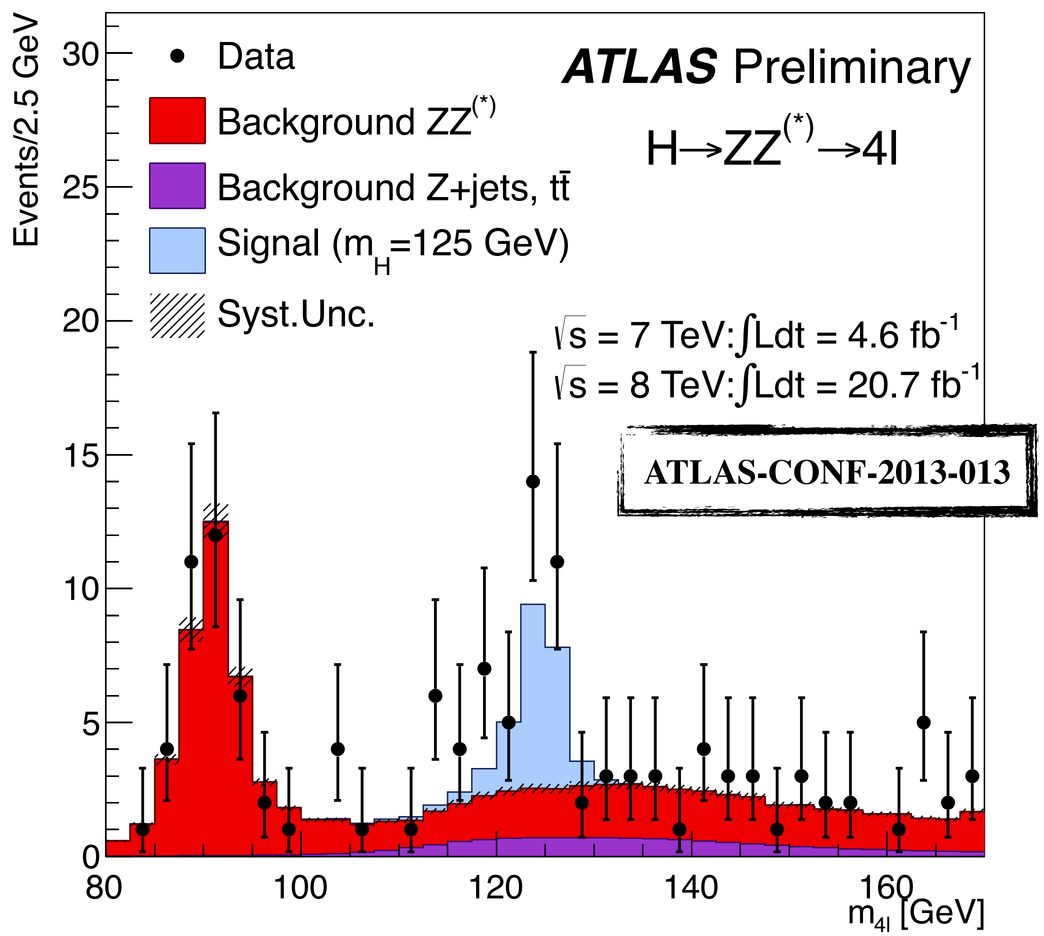
Multi-jet candidate



Motivation

- Isolated electrons and photons are the probe of many signatures:
  - Cover a large range of p_T.
  - Develop tools to reject backgrounds: $\sigma(\gamma\gamma)$= 30 pb, $\sigma(\gamma j)\sim 10^4\times\sigma(\gamma\gamma)$, $\sigma(jj)\sim 10^7\times\sigma(\gamma\gamma)$.
  - Achieve the best efficiency as possible to detect rare events (such as H→4l).
  - Excellent resolution.



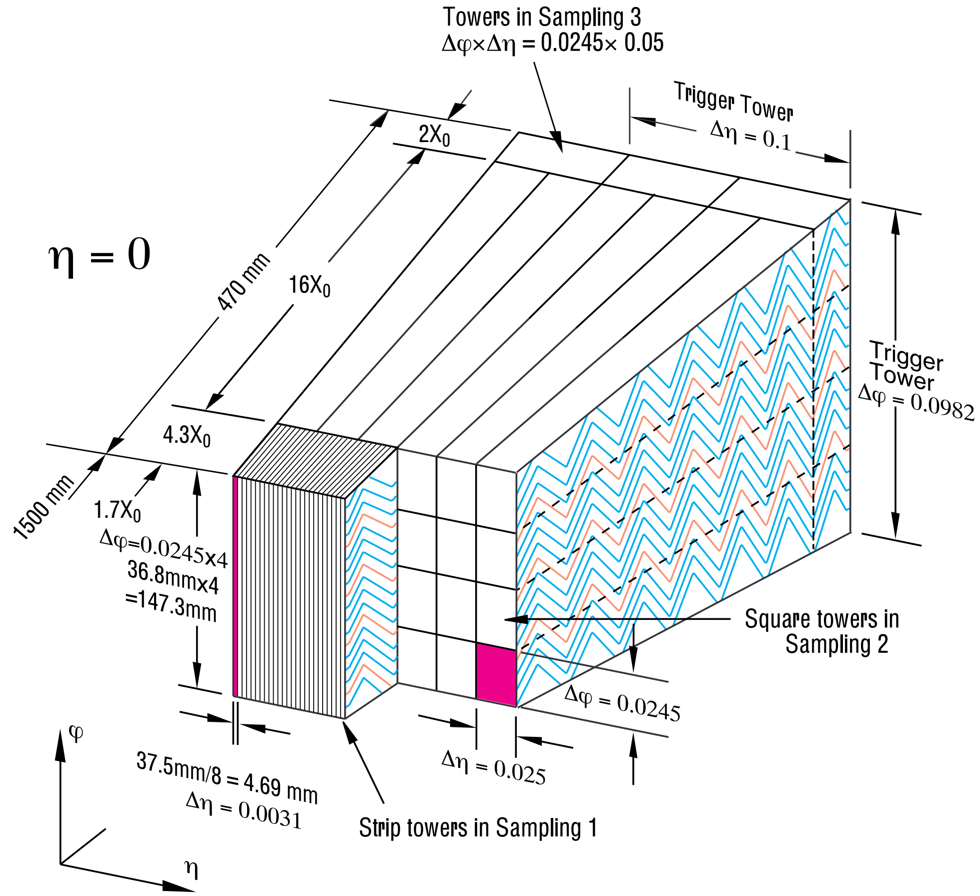


- Measuring the electron and photon properties is crucial:
  - For example: efficiencies values (and uncertainties) directly impact the Higgs signal strength measurements.

Detectors for electrons and photons

Calorimetry

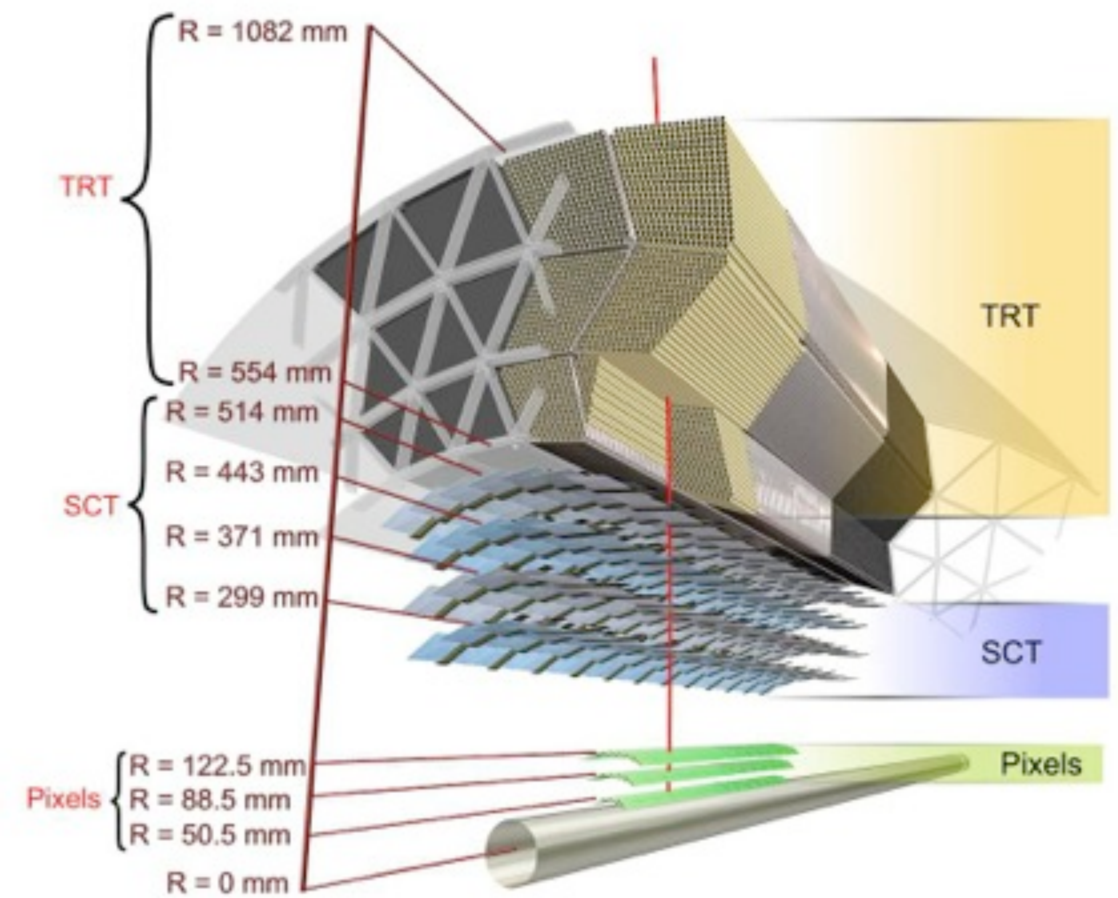
- LAr sampling calorimeter with accordion geometry:
- Coverage: $|\eta|<3.2$
- 3 layers with different granularity + presampler ($|\eta|<1.8$)
- First layer fine granularity is crucial for γ/π^0 separation
- $\sigma_E/E = 10\%/\sqrt{E} \oplus 0.7\%$



Tracking

- 3 sub-detectors:
- Pixels: 1744 modules, 3 layers, $|\eta|<2.5$
- SemiConductor Tracker: 6.10^6 silicon micro-strips, $|\eta|<2.0$
- Transition Radiation Tracker: straw tubes, $|\eta|<2.0$

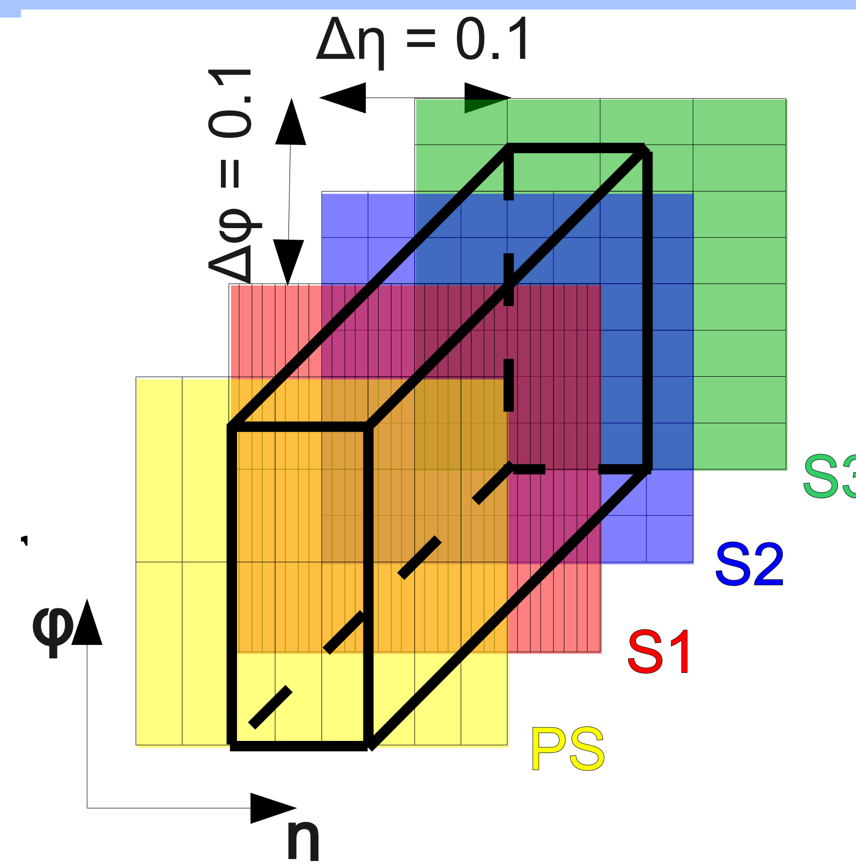
  - Electron track reconstruction
  - Conversion reconstruction
  - Electron/Photon separation
  - Electron/Charged pion separation

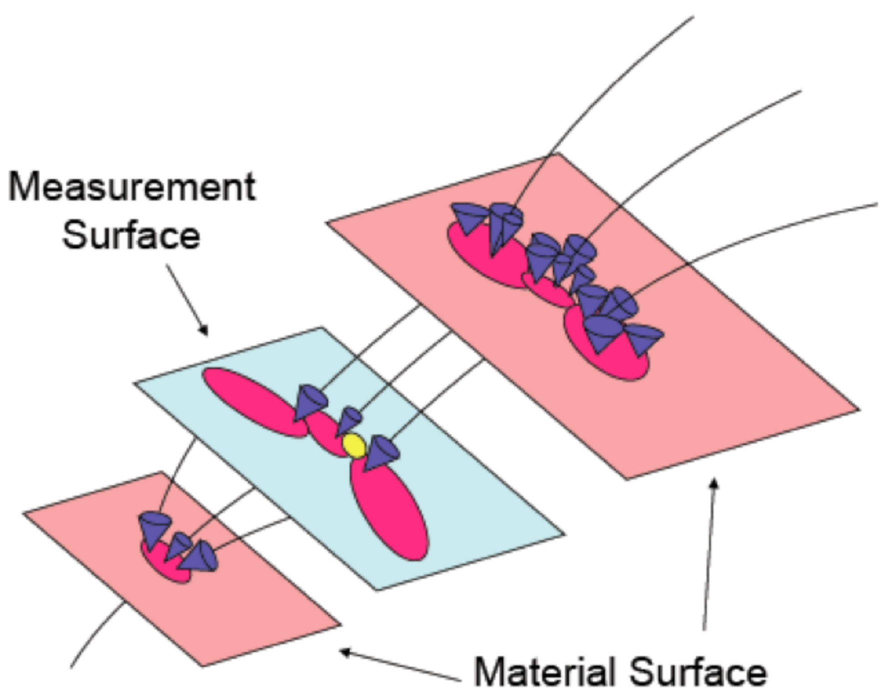


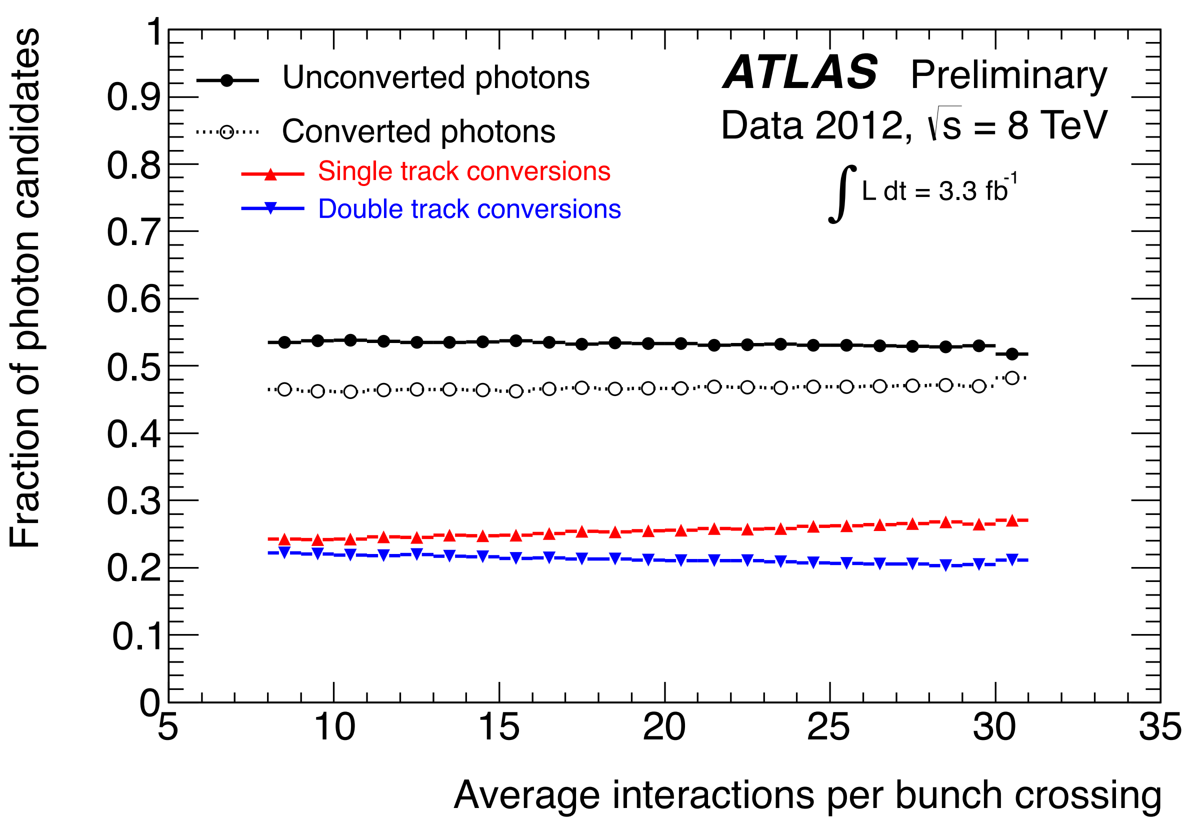
Electron and photon reconstruction

Photons / Electrons

- Cluster formation (sliding-window algorithm):
  - Find seed with E_T>2.5 GeV.
  - Final cluster built with dedicated window size.
    - Electrons and converted photons: $\Delta\eta \times \Delta\varphi$ = 0.075X0.175 (barrel).
    - Unconverted photons: $\Delta\eta \times \Delta\varphi$ = 0.075X0.125 (barrel).
- Match cluster to a track:
  - electron-unconverted photon separation.
- Match track to a secondary vertex:
  - electron-converted photon separation.
- Electron track reconstruction takes into account bremsstrahlung losses at pattern recognition level:
  - Use a Gaussian Sum Filter algorithm





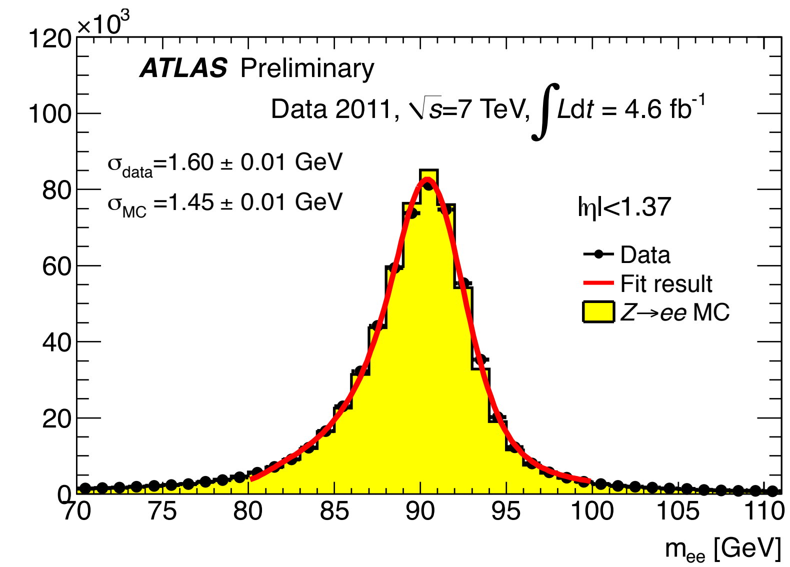


Electromagnetic energy calibration

Photons

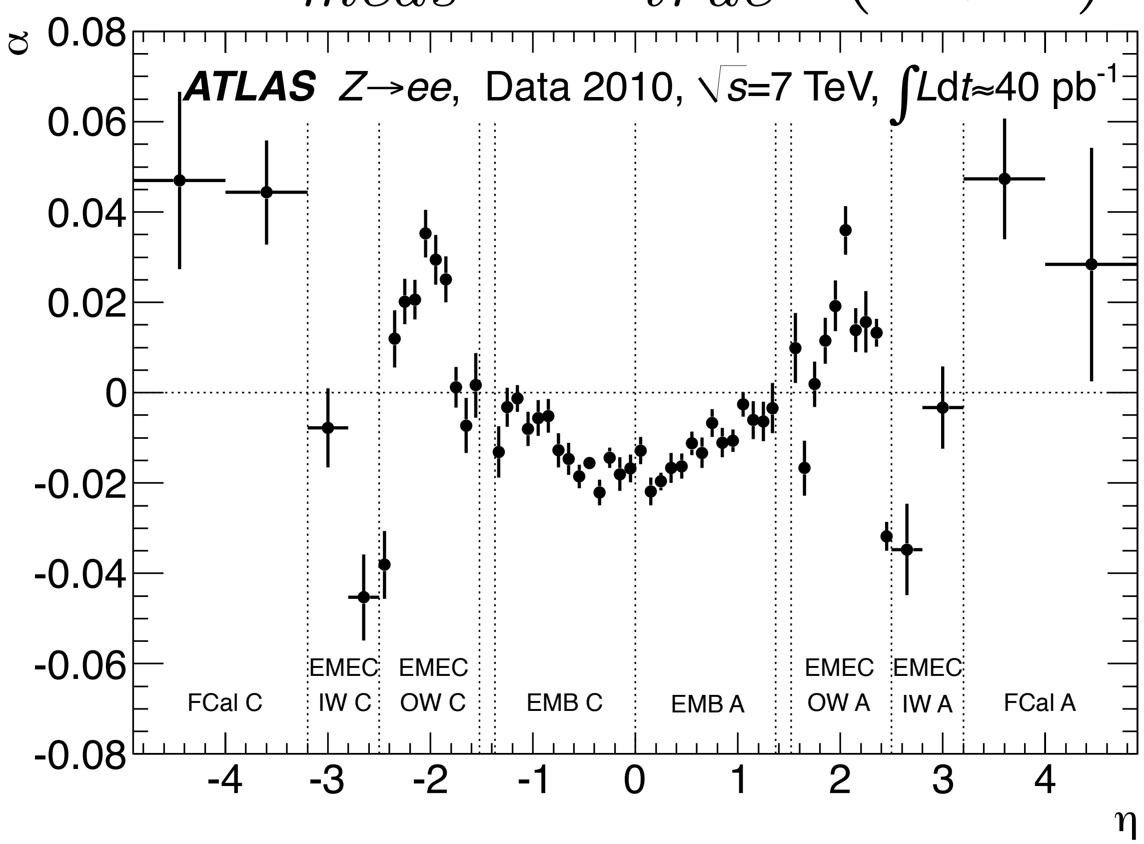
Electrons

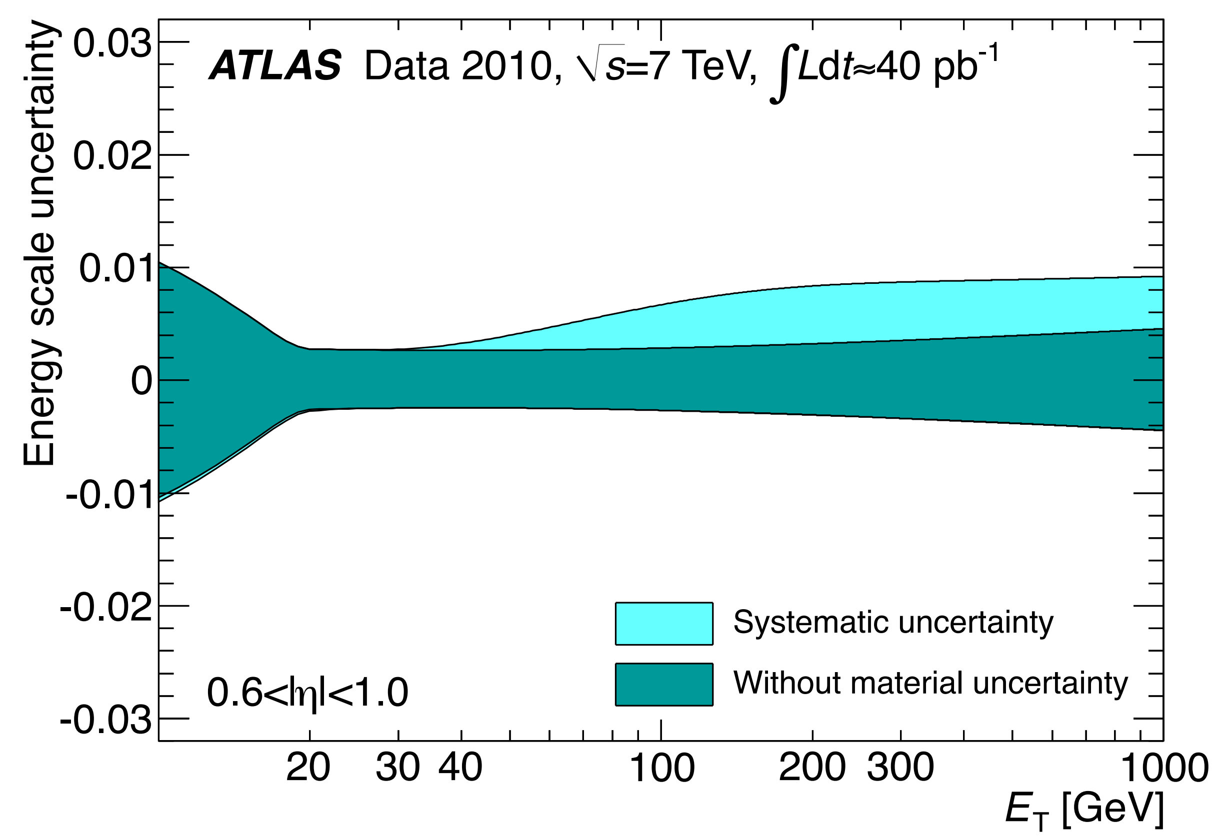
- Cluster energy (from the energies of the cells) is calibrated with MC based methods:
  - Validated with test beam results.
- In-situ calibration with collision data:
  - Electrons from Z are used (cross-checks with W and J/ψ).
- $Z \rightarrow e^+e^-$ lineshape used to extract the resolution constant term in data:
  - 1.2% in the barrel and 1.8% in the endcap.
- $e \rightarrow \gamma$ extrapolation checked with simulation:
  - Differences between electrons and photons for the material effects: ~0.3%.



Eur. Phys. J. C 72 (2012) 1909

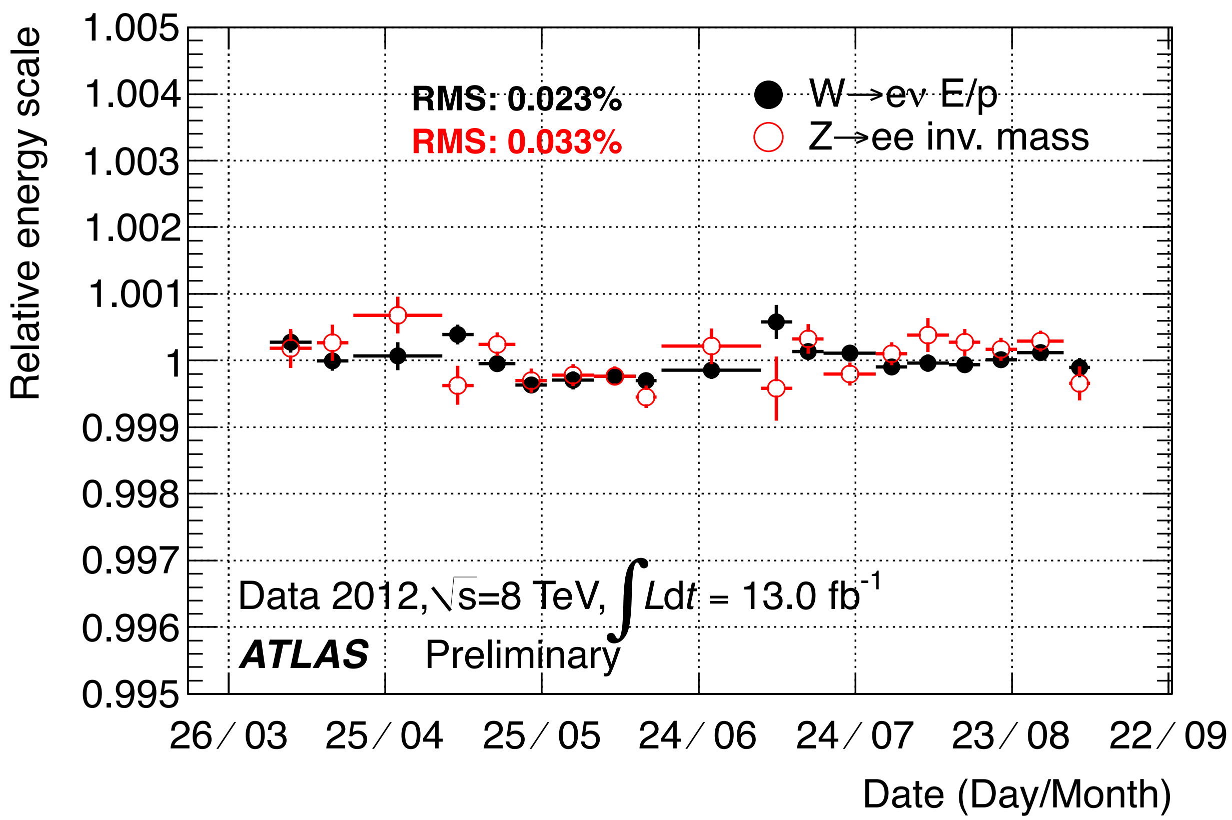
$$E_{meas} = E_{true} \cdot (1+\alpha)$$

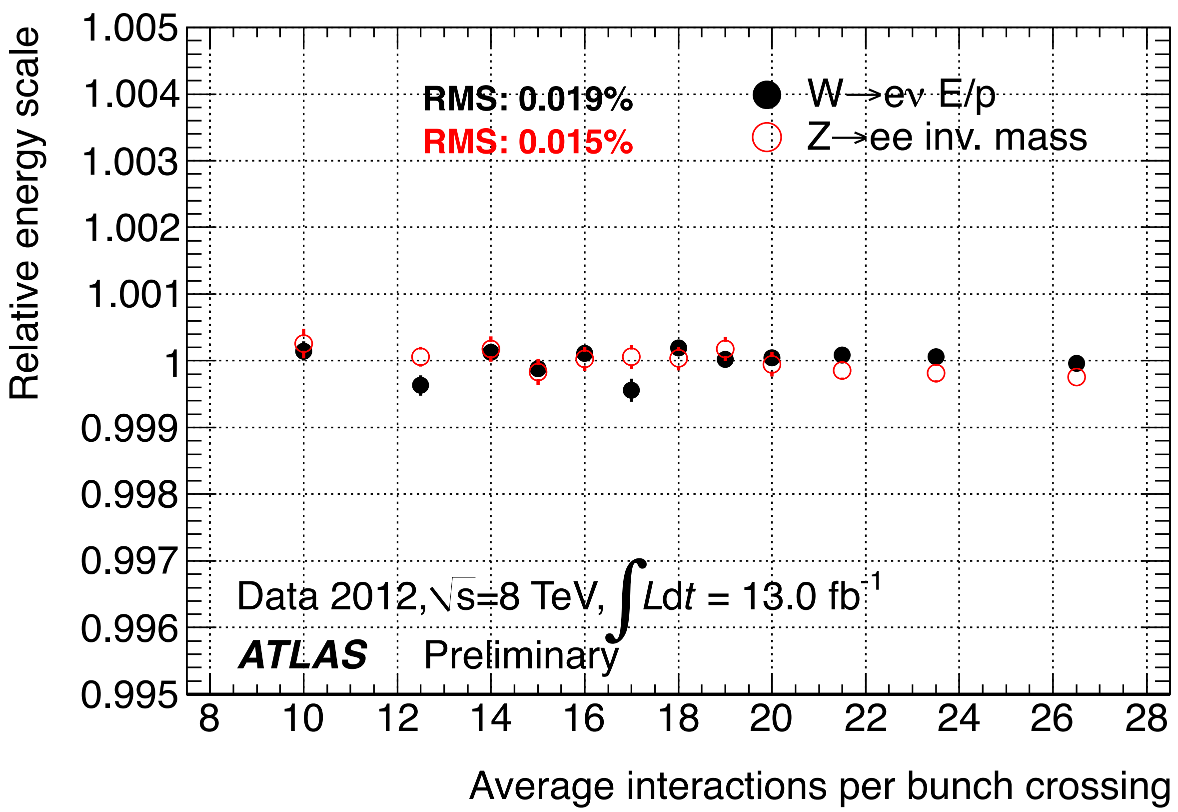




Stability of the calibration

Excellent energy scale stability with time and pile-up.

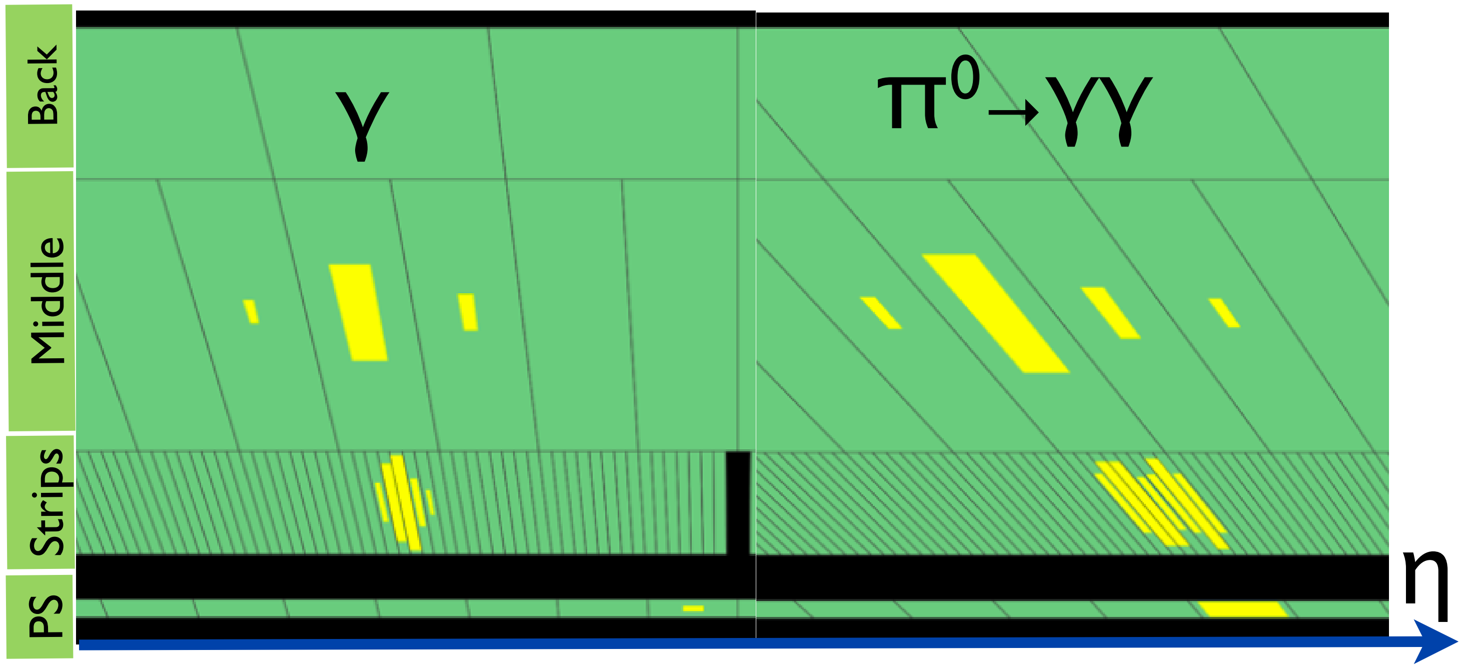




Electron and photon identification strategy

Photons
Electrons

- No leakage in the hadronic calorimeter.
- ECAL to characterise the EM shower shape:
  - Narrow shower in the middle layer.
  - Single maximum in the first layer (rejection of $\pi^0 \rightarrow \gamma\gamma$).

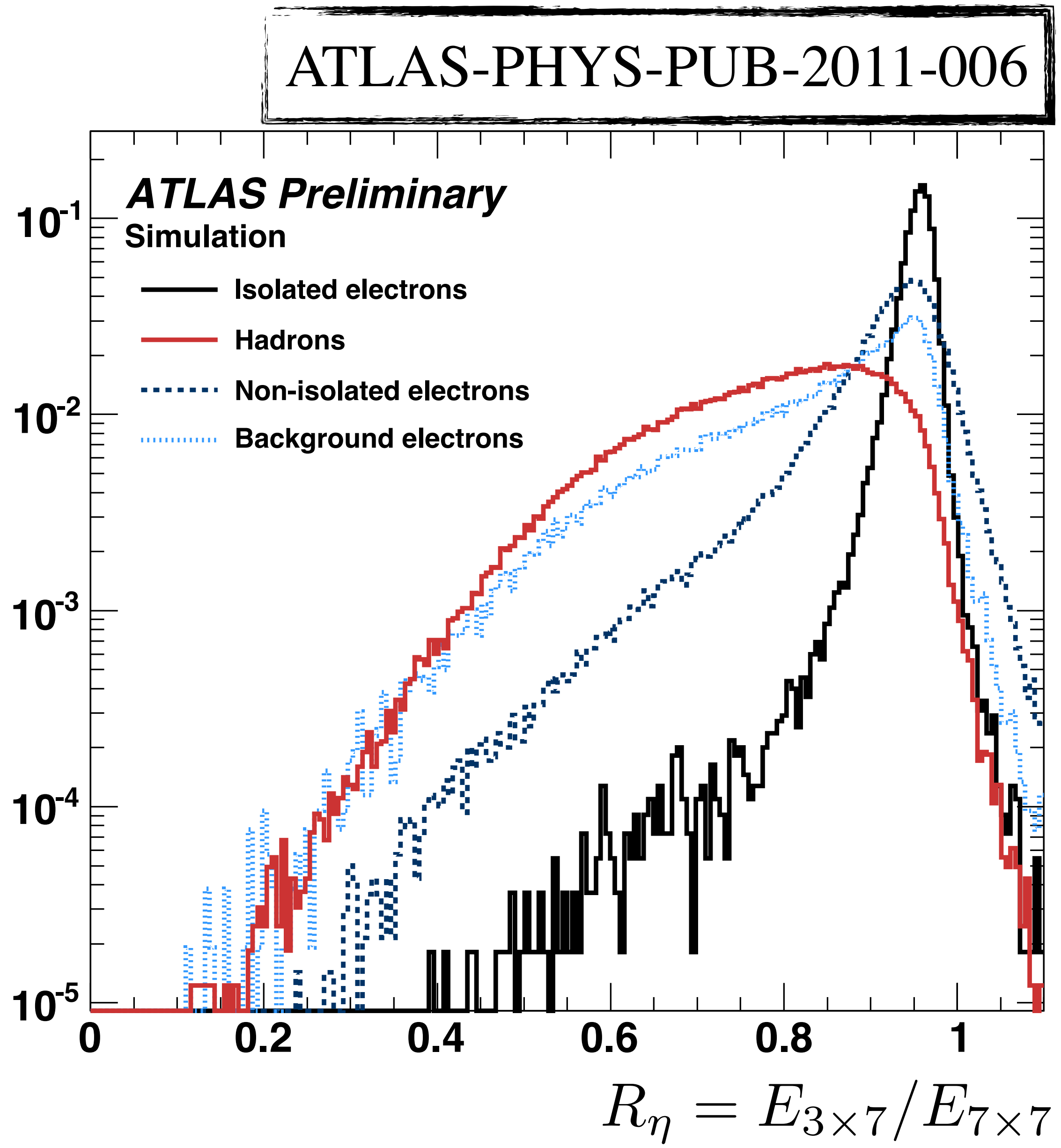


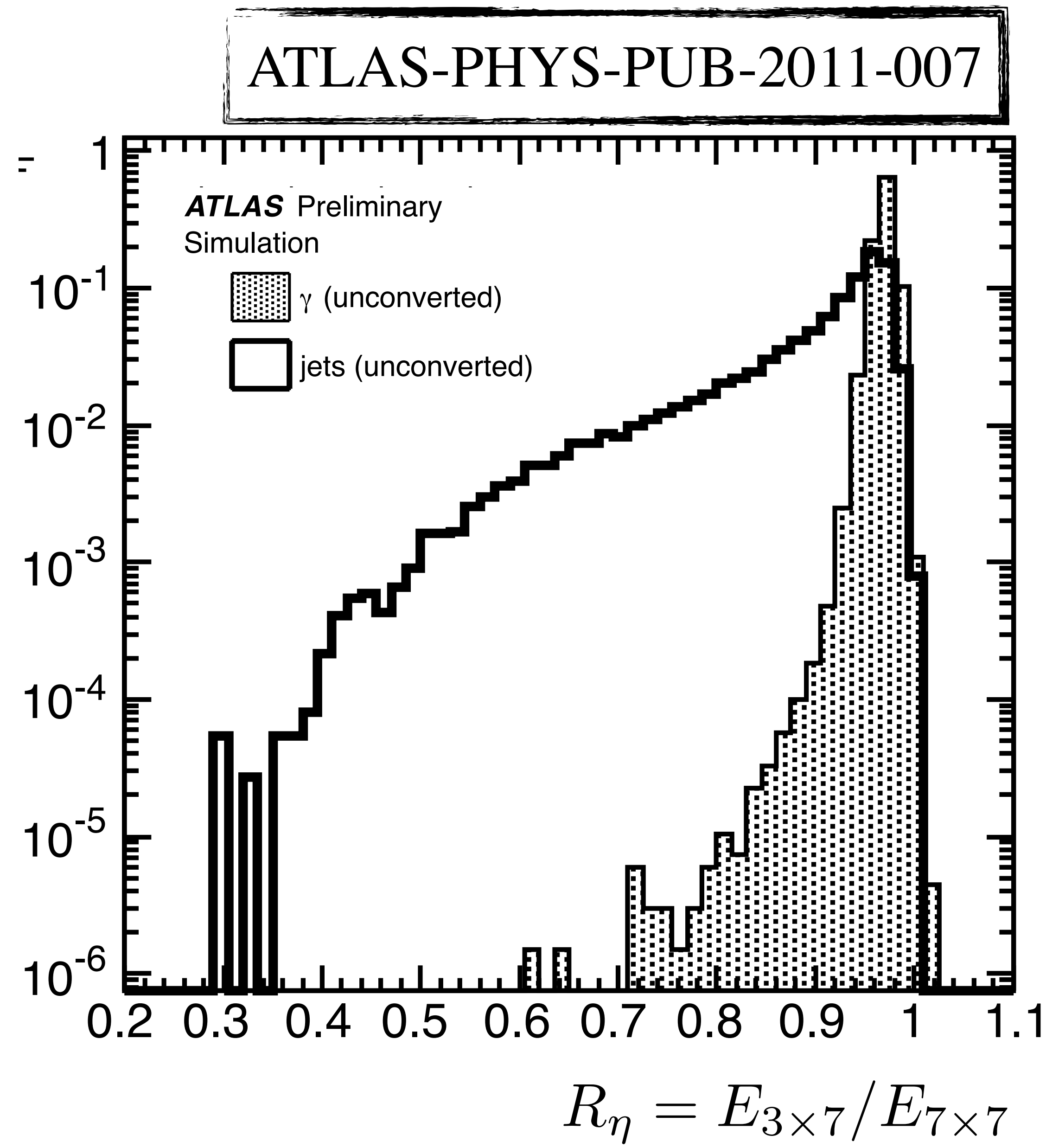
- For electrons, track and track-cluster matching quality:
  - Requirements on the hits in the 3 tracking devices + impact parameter.
  - $\Delta\eta$ and $\Delta\varphi$ requirement between the cluster and the track.

- Different sets of requirements (loose/medium/tight) with increasing background rejection:
  - Optimised in bins of η.
  - Several reoptimisations between 2010 and 2012 to cope with the increase in pileup.
- Developed a multilepton set of requirements:
  - High signal efficiency crucial for $H \rightarrow 4l$.

Example of discriminating variable

Electrons Photons

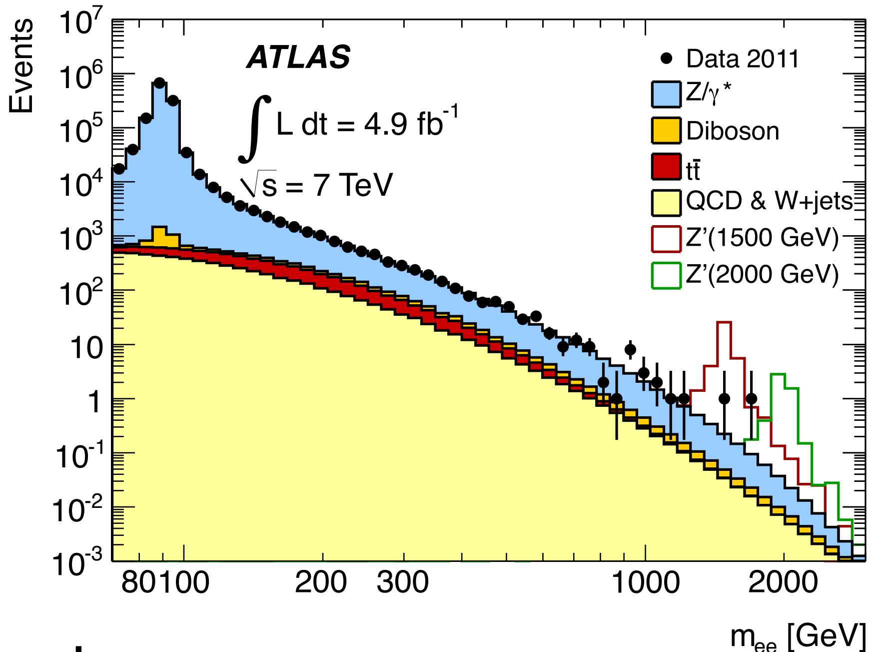


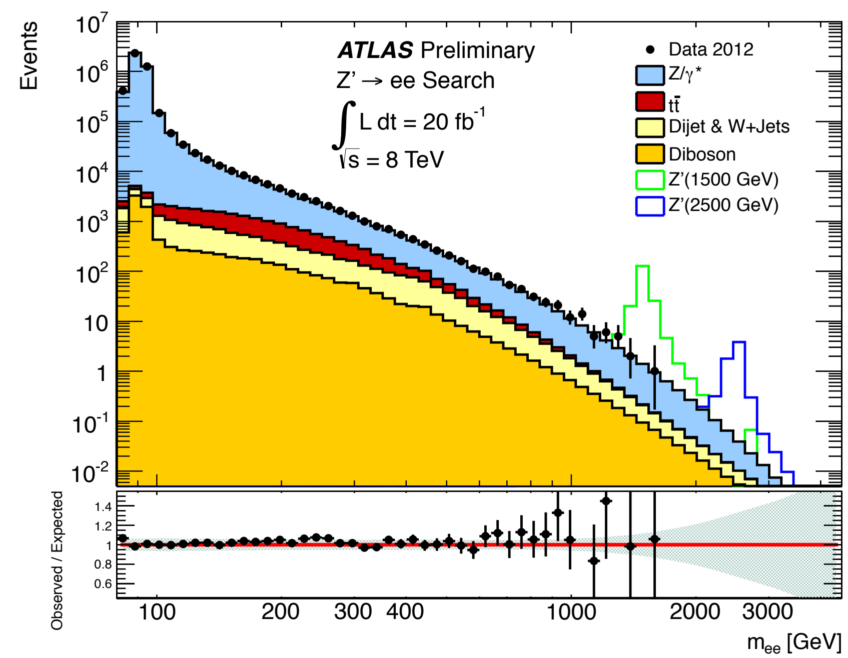


- Clear difference between isolated electrons/photons and jets.
- Need to use multiple variables to get a powerful rejection.

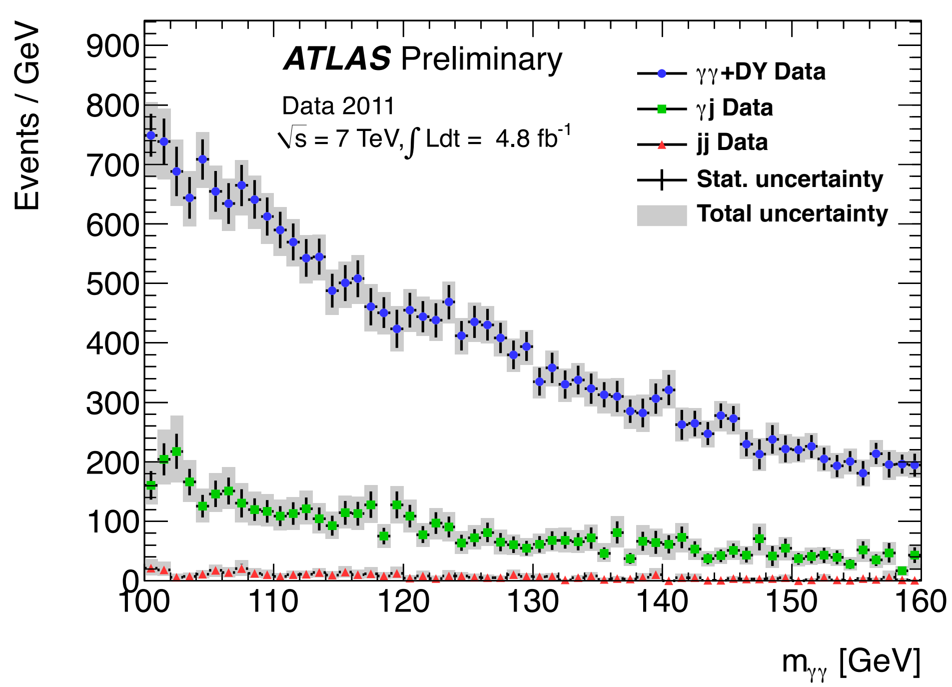
Jet rejection

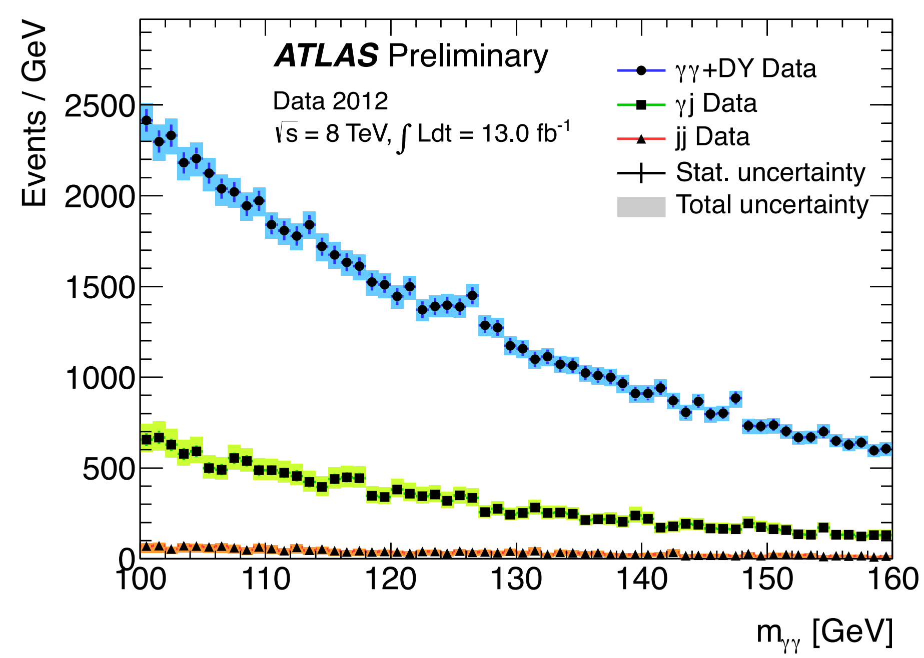
- Searches for dilepton resonances:
  - 6 published analysis from 2010 to 2012.
  - For 110 GeV < m_{ee} < 200 GeV, QCD contribution to the total background less than 10%.





- H→γγ searches:
  - Purity (= $N_{\gamma\gamma}/N_{tot}$) is about 70-80%.
  - No large variations over the three years.





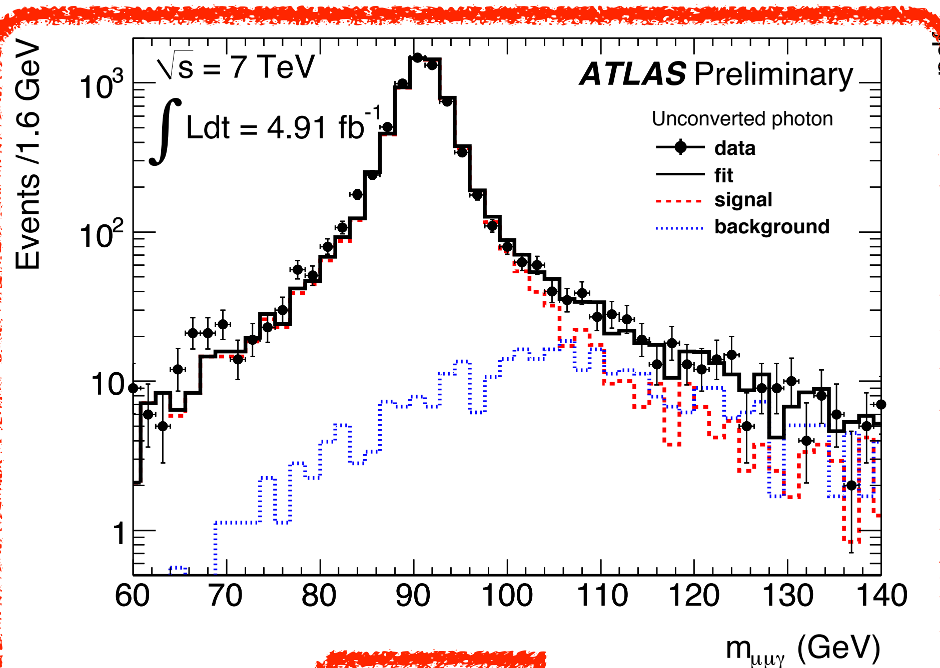
Photons

Measuring the photon identification efficiency

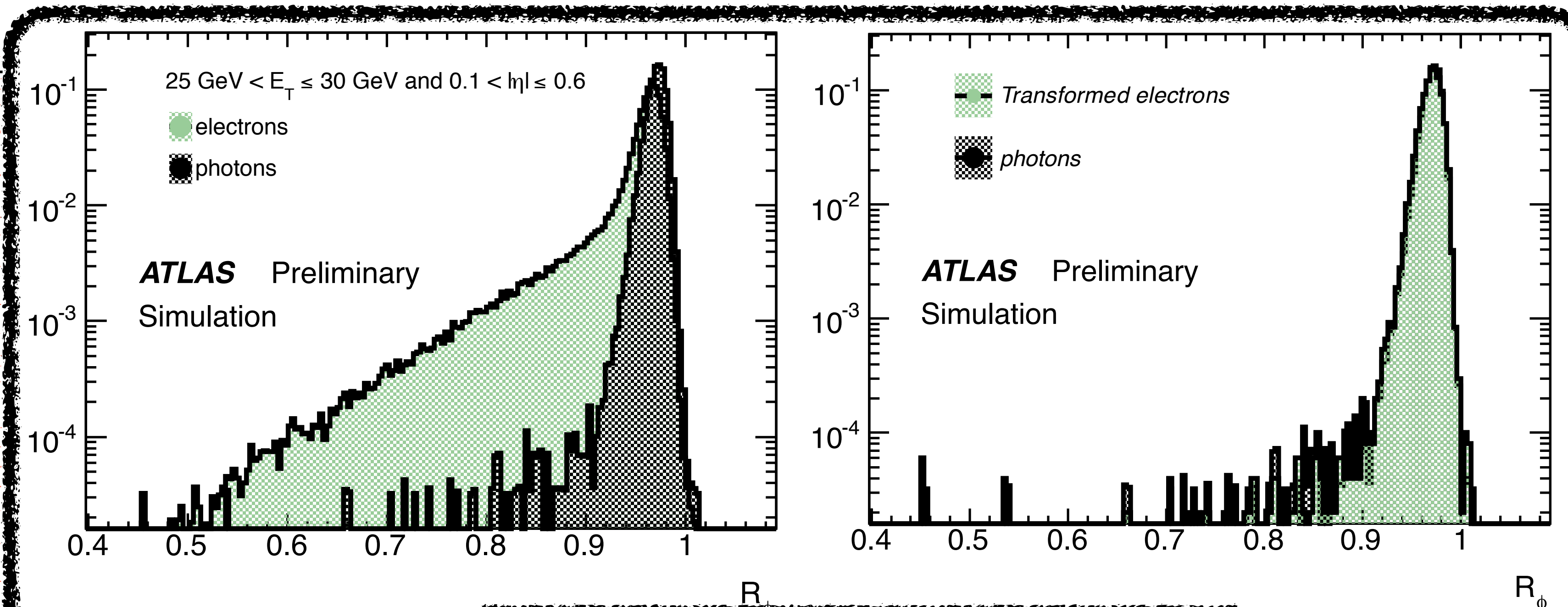
ATLAS-CONF-2012-123

- Shower shape description in the MC is good but not perfect:
  - Gain on the precision by measuring the efficiency directly with data.

- Use three complementary methods to cover a large range of transverse momentum:
  - Pure photon sample from Z→llγ.
  - Extrapolation from electrons (Z→e^+e^- events).
  - Inclusive sample of photon candidates:
    - "Matrix method": Track isolation to determine background and signal components before and after applying the id requirements.



Z→llγ

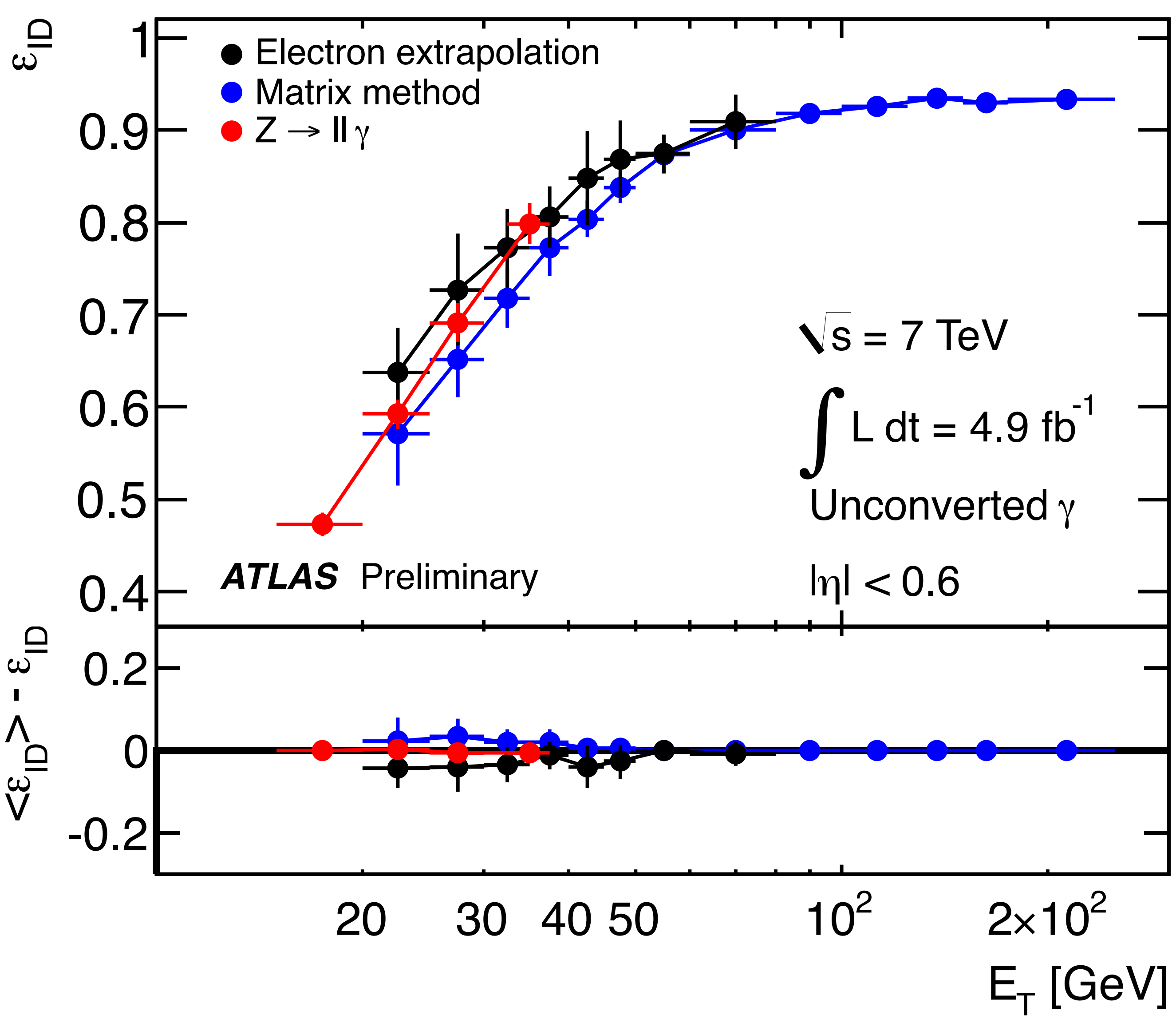


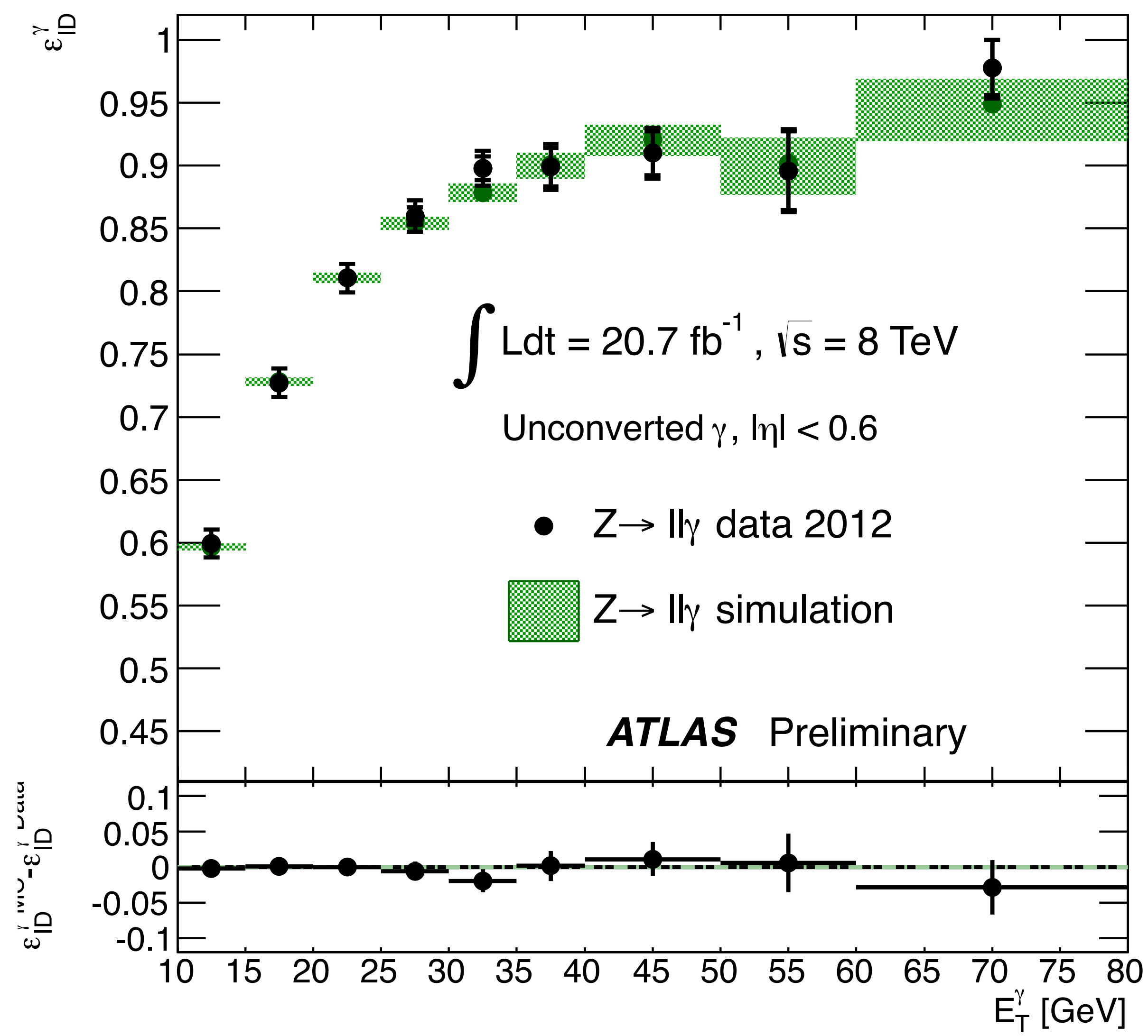
Extrapolation from electrons

Photon identification efficiency measurement

ATLAS-CONF-2012-123

- Measurement performed in bins of $|\eta|$ separately for converted and unconverted photons.
- Good agreement of the three methods in the overlapping regions.
- Combination to reduce the uncertainties: ~5% to ~1-2% decreasing with p_T.
- Special treatment of correlations among photons to reduce the uncertainty on the event efficiency for multi-photons events:
  - Large impact on $H\rightarrow\gamma\gamma$ signal strength evaluation.



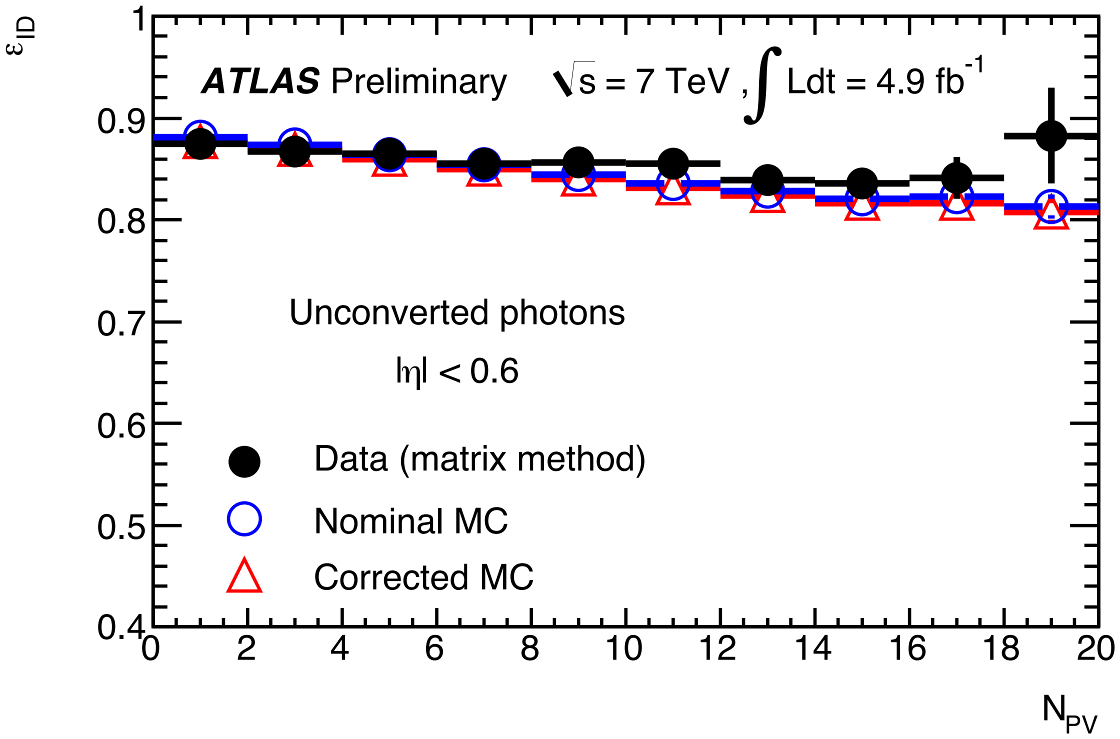


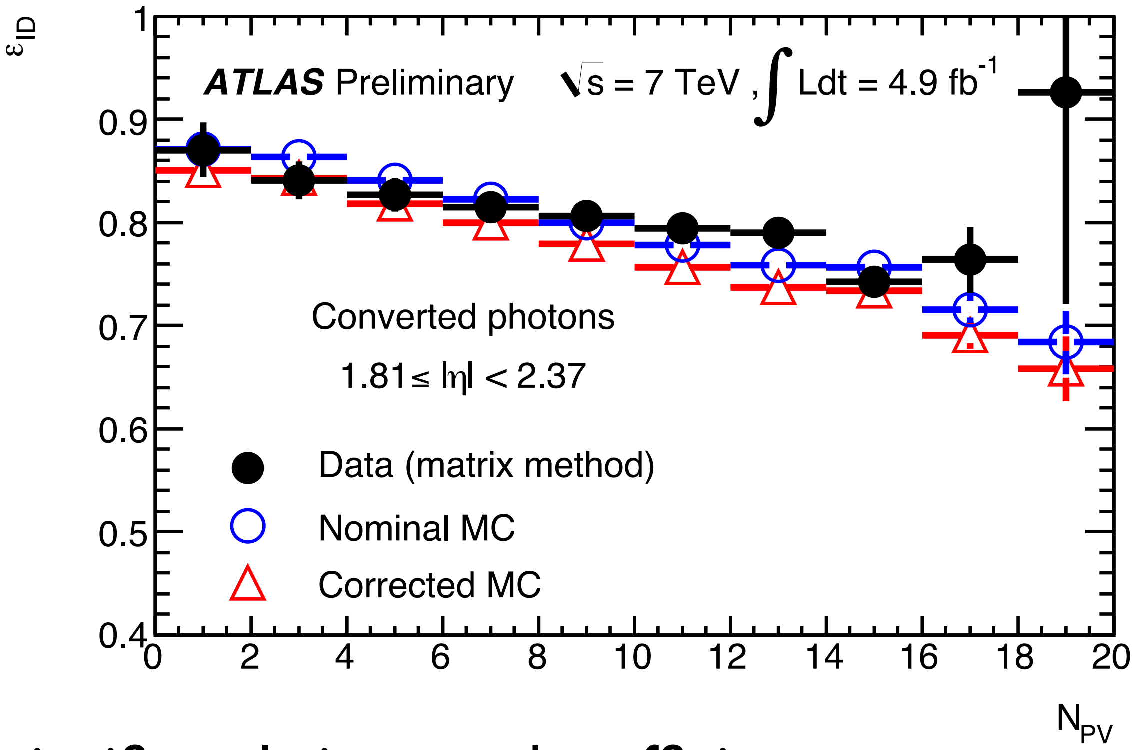
Stability of the photon identification efficiency measurement

Photons

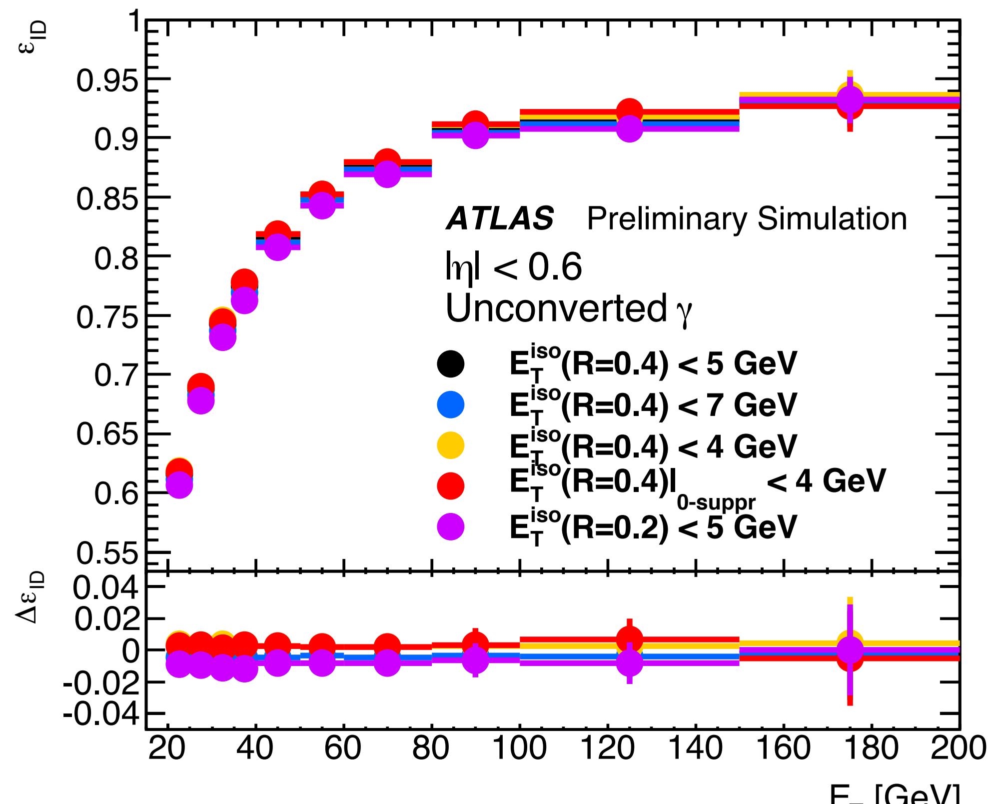
ATLAS-CONF-2012-123

- Pileup dependency well reproduced in the simulations.





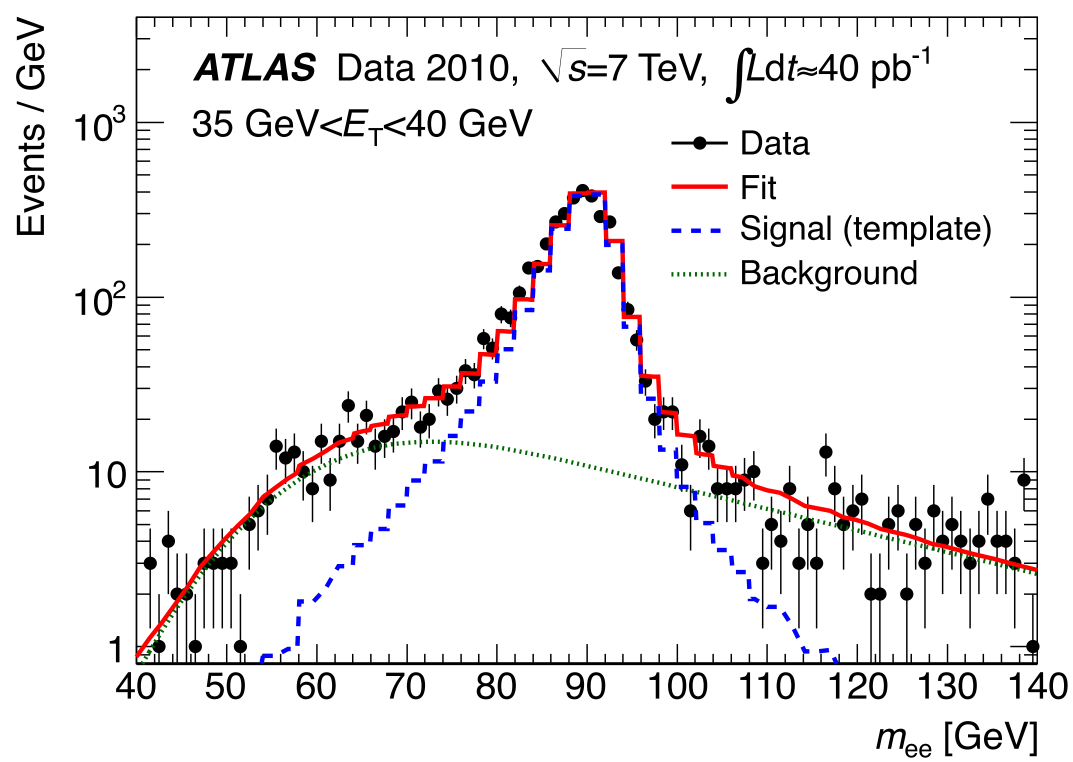
- Variations of the isolation criteria does not significantly impact the efficiency.

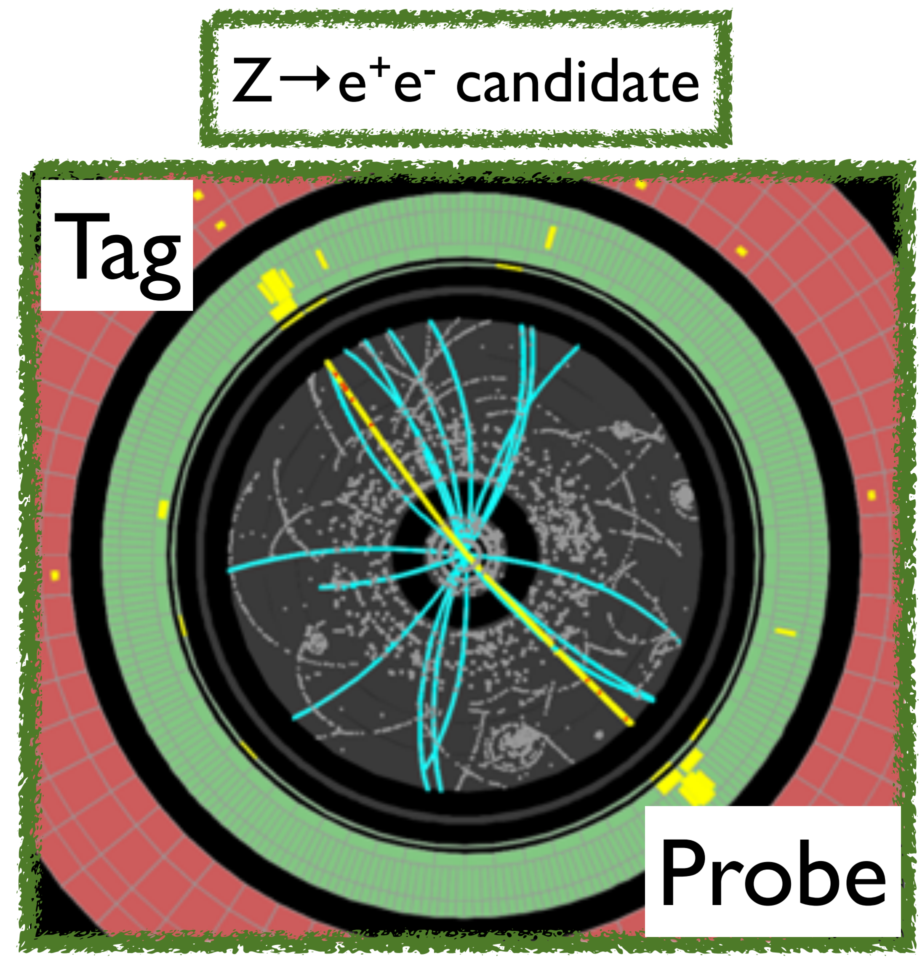


Measuring electron efficiencies: Tag and Probe method

1. Select (Tag) clean sample of unbiased (probe) electrons:
   - Invariant mass and id requirement on only 1 electron for $Z \rightarrow e^+e^-$ and $J/\psi \rightarrow e^+e^-$.
   - Missing transverse energy and transverse mass requirements for $W \rightarrow e\nu$.

2. Estimate the background contamination using a variable uncorrelated with the quantity of interest:
   - Dilepton invariant mass for Z and J/ψ.
   - Calorimeter isolation for Z and W.

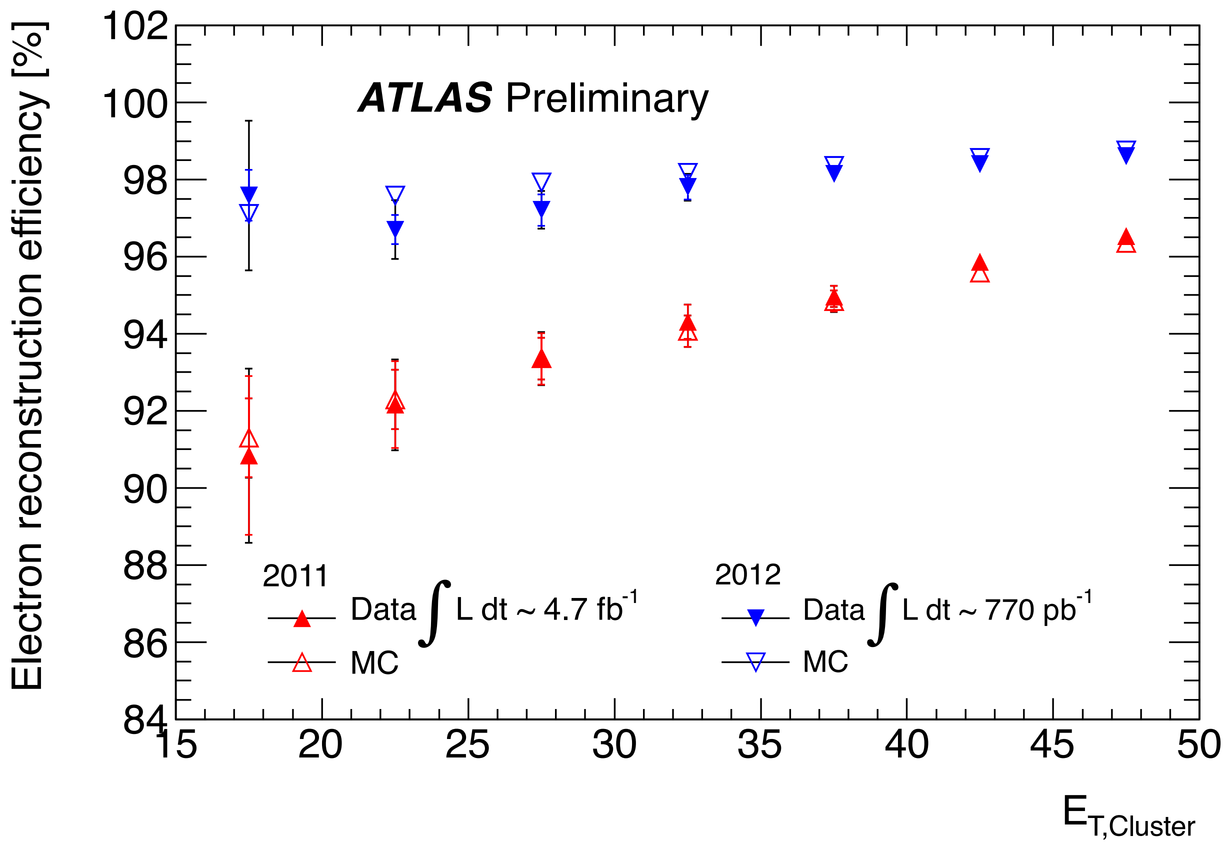


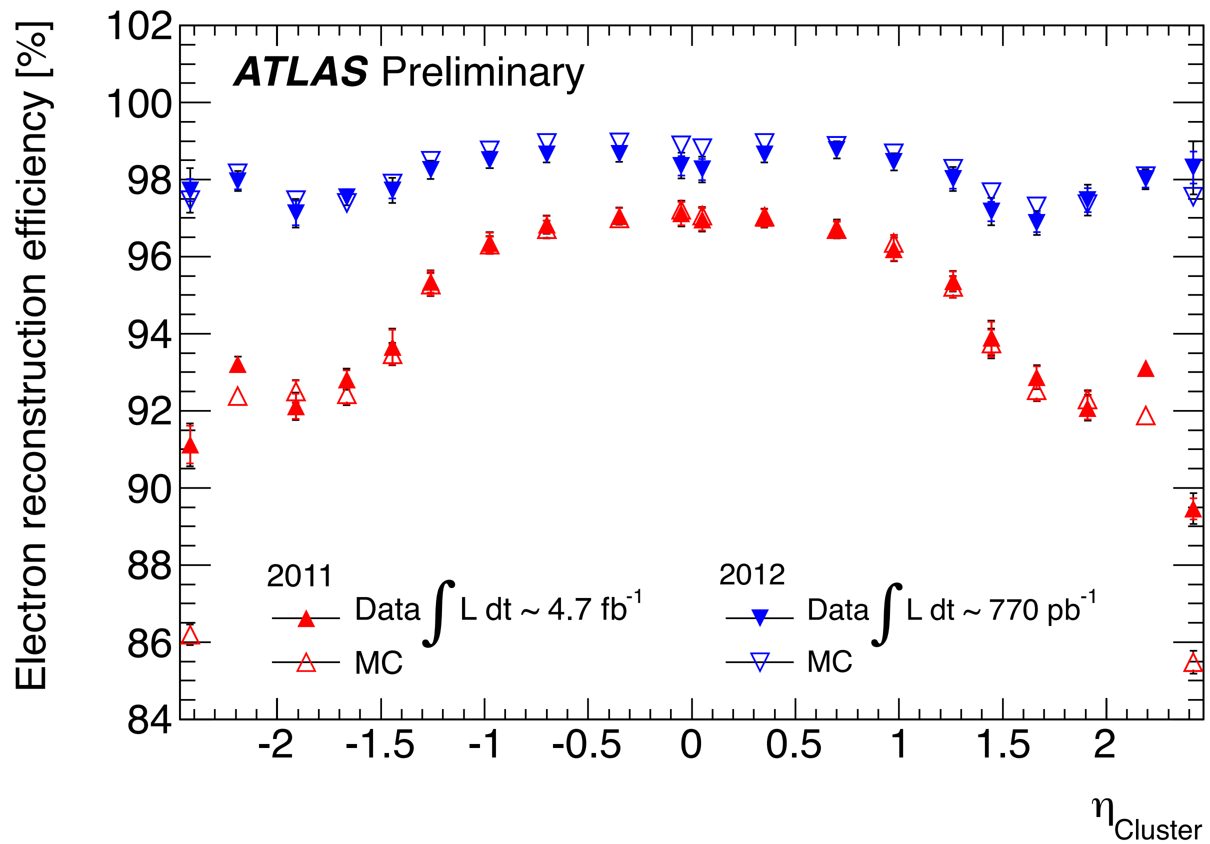


3. Use the probe object in the tagged events to estimate:
   - Cluster-Track matching efficiency.
   - Identification efficiency.
   - Charge misidentification efficiency.
   - ...

Cluster-Track matching efficiencies

T&P Method Electrons





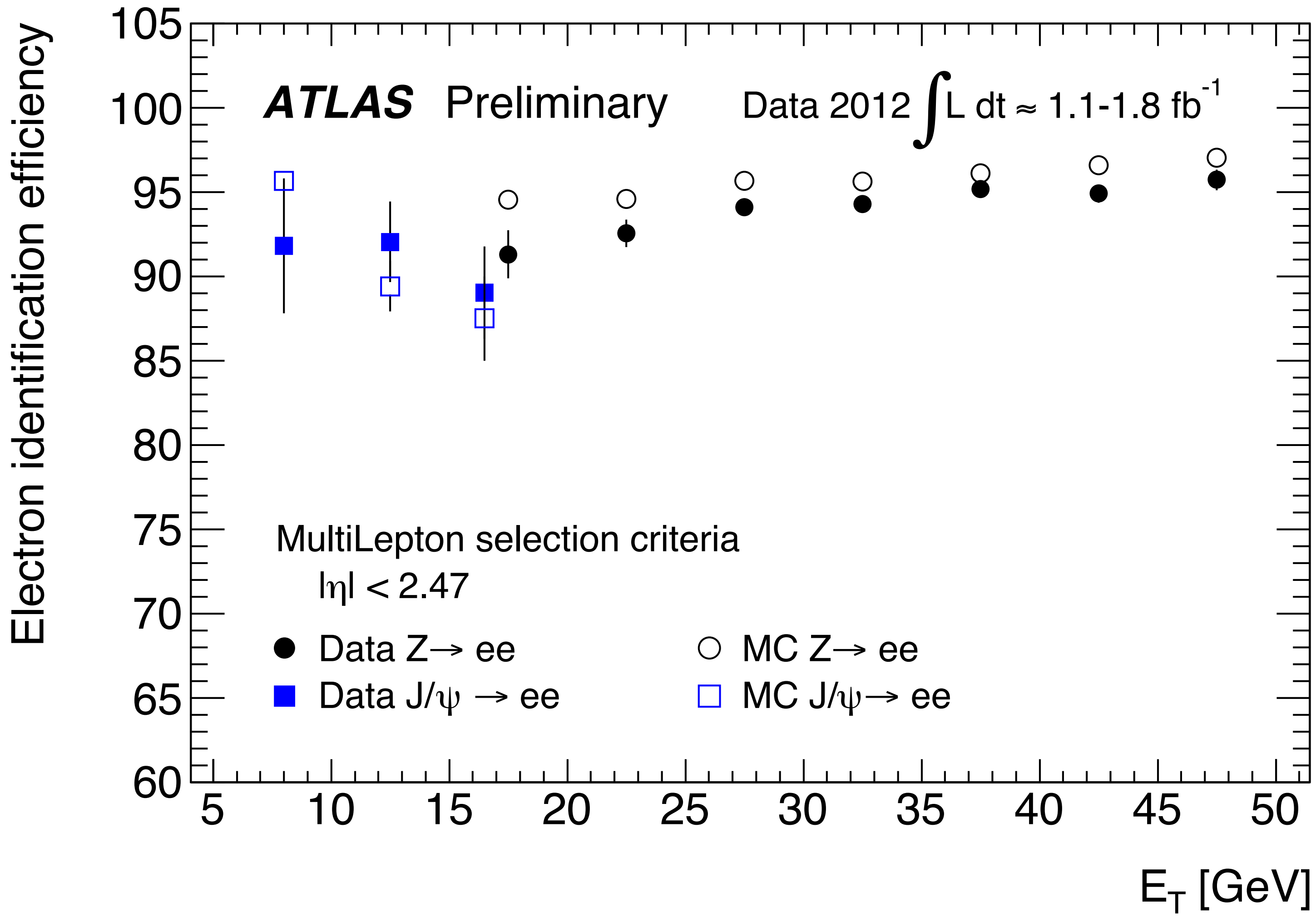
- Bremsstrahlung losses in track pattern recognition added in 2012 reconstruction:
  - Up to 8% gain in the efficiency.
  - Flatter behaviour w.r.t the pseudorapidity.

Electron identification efficiency

Eur. Phys. J. C 72 (2012) 1909

T&P Method Electrons

- Measurement performed with Z,W and J/ψ:
  - Overall good agreement between the three samples.
  - Overall good agreement with the simulation.

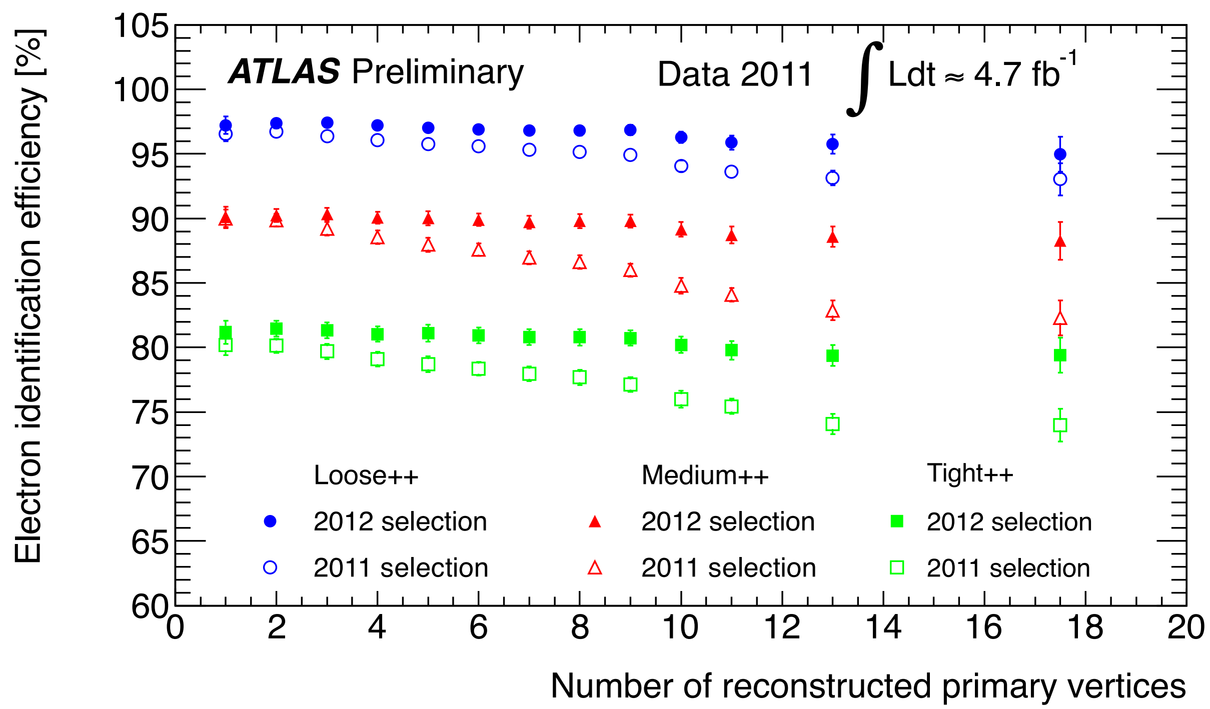


Electron identification efficiency

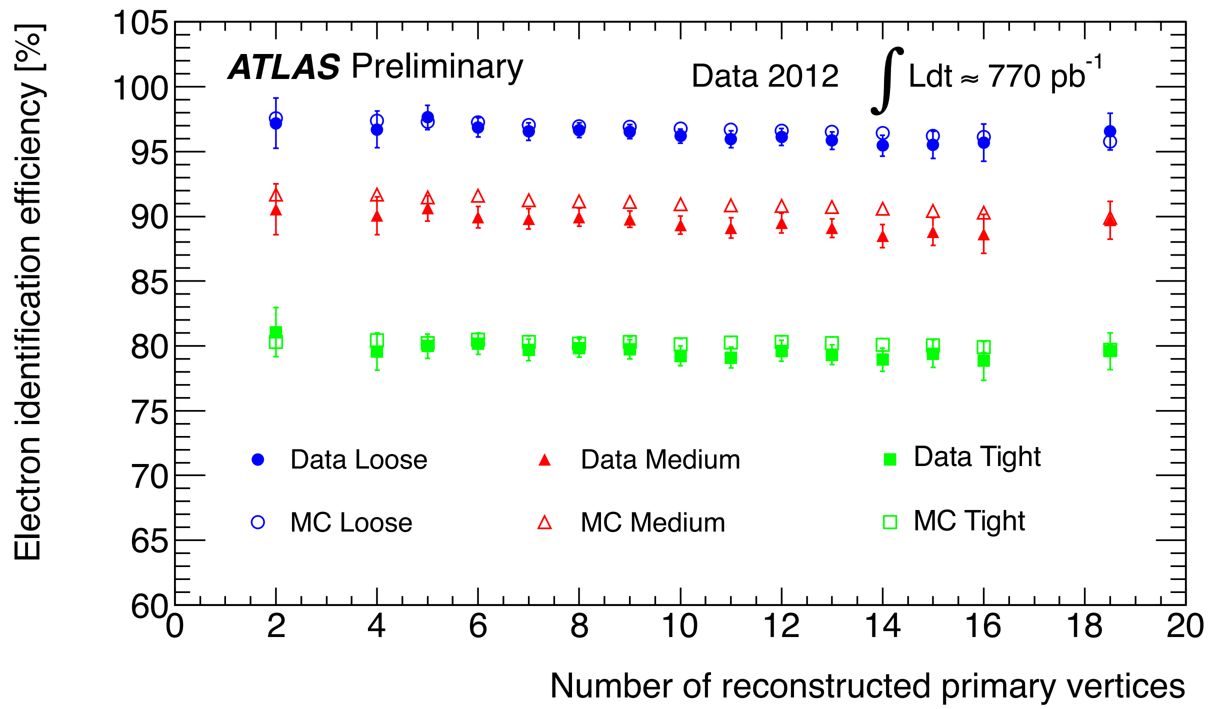
• Identification strategy (cut optimisation) has been revisited several times to cope with the evolution of the data-taking conditions:

- Keep a ~flat efficiency as a function of the pileup.

DATA 2011



DATA 2012

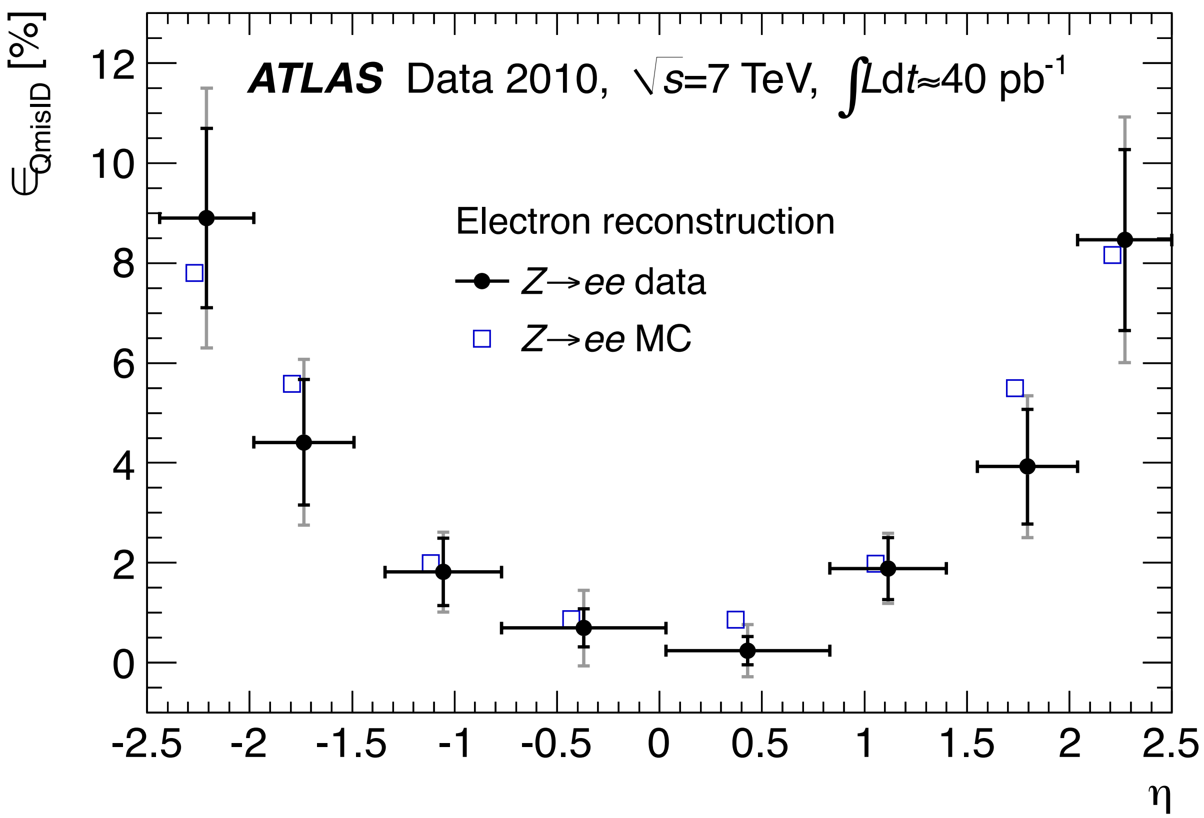


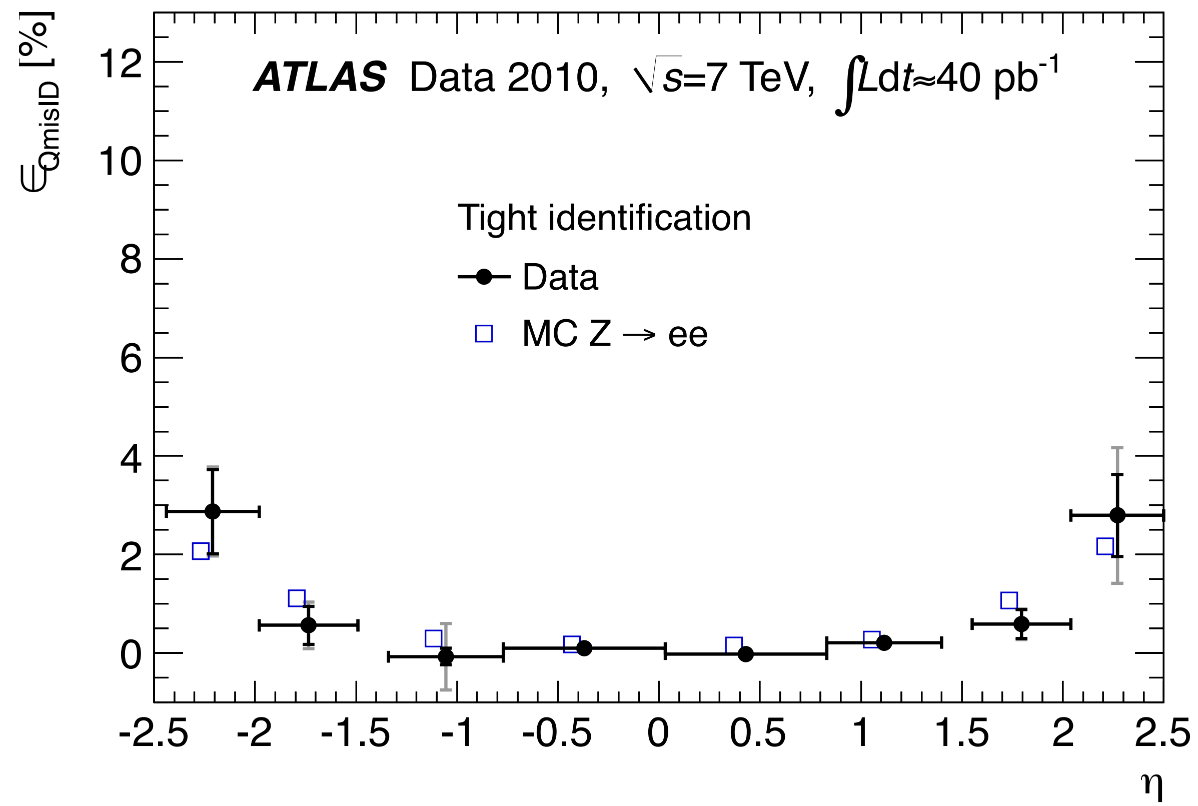
Charge misidentification rate

Eur. Phys. J. C 72 (2012) 1909

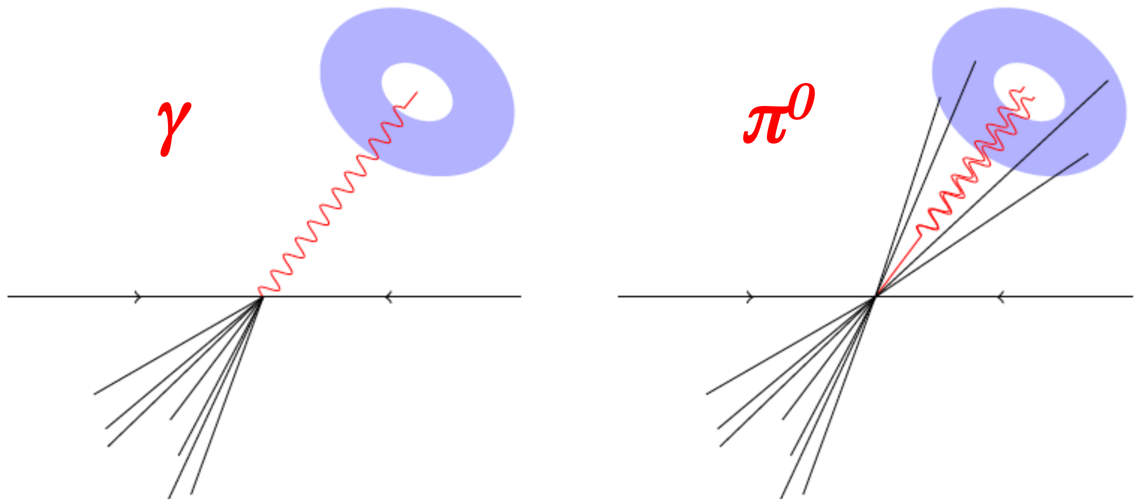
T&P Method Electrons

- Wrong charge can be assigned to electron/positron candidate:
  - The rate depends on the quality of the track.





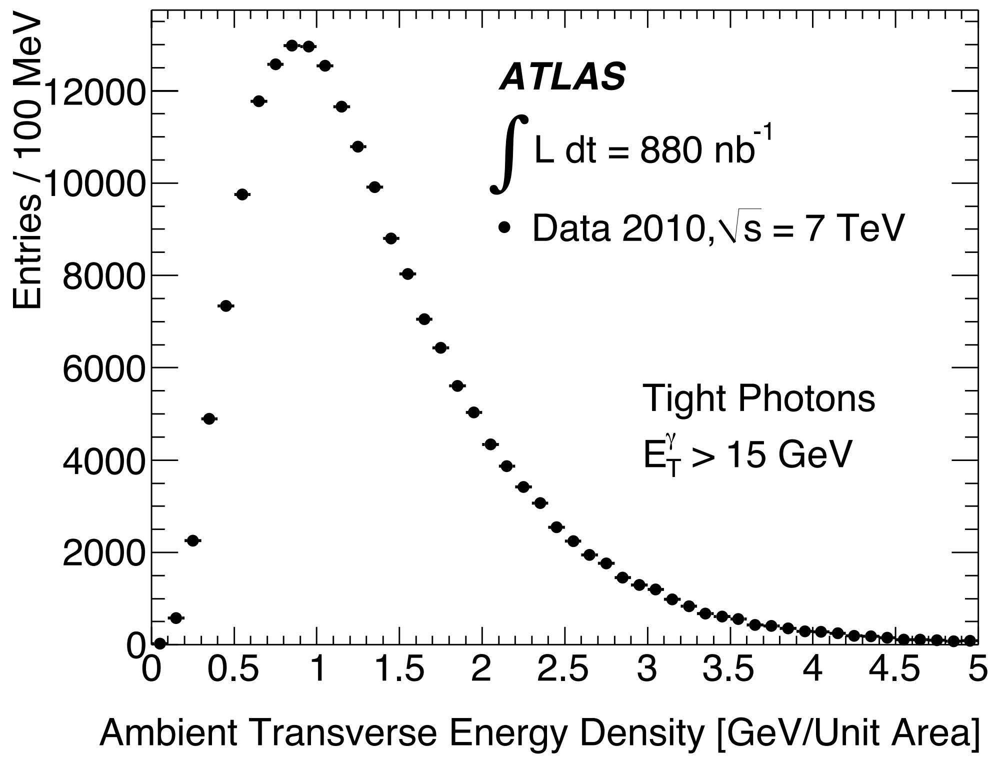
Isolation

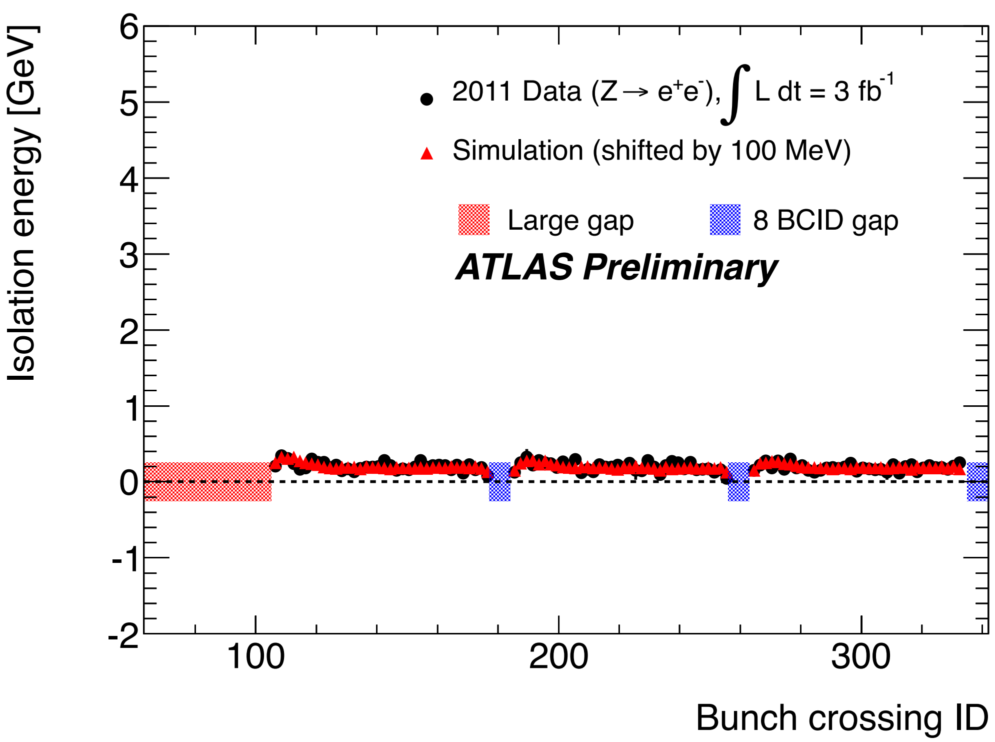


- Track-based isolation:
  - Measure p_T of tracks around the direction of the object.
- Calorimeter-based isolation:
  - Measure energy in a ring around the cluster
  - Correct for the leakage of the candidate itself and soft contributions from pile-up and underlying events.

- Good data/MC agreement.
- Good stability w.r.t the pile-up effect.

Phys.Rev. D83 (2011) 052005

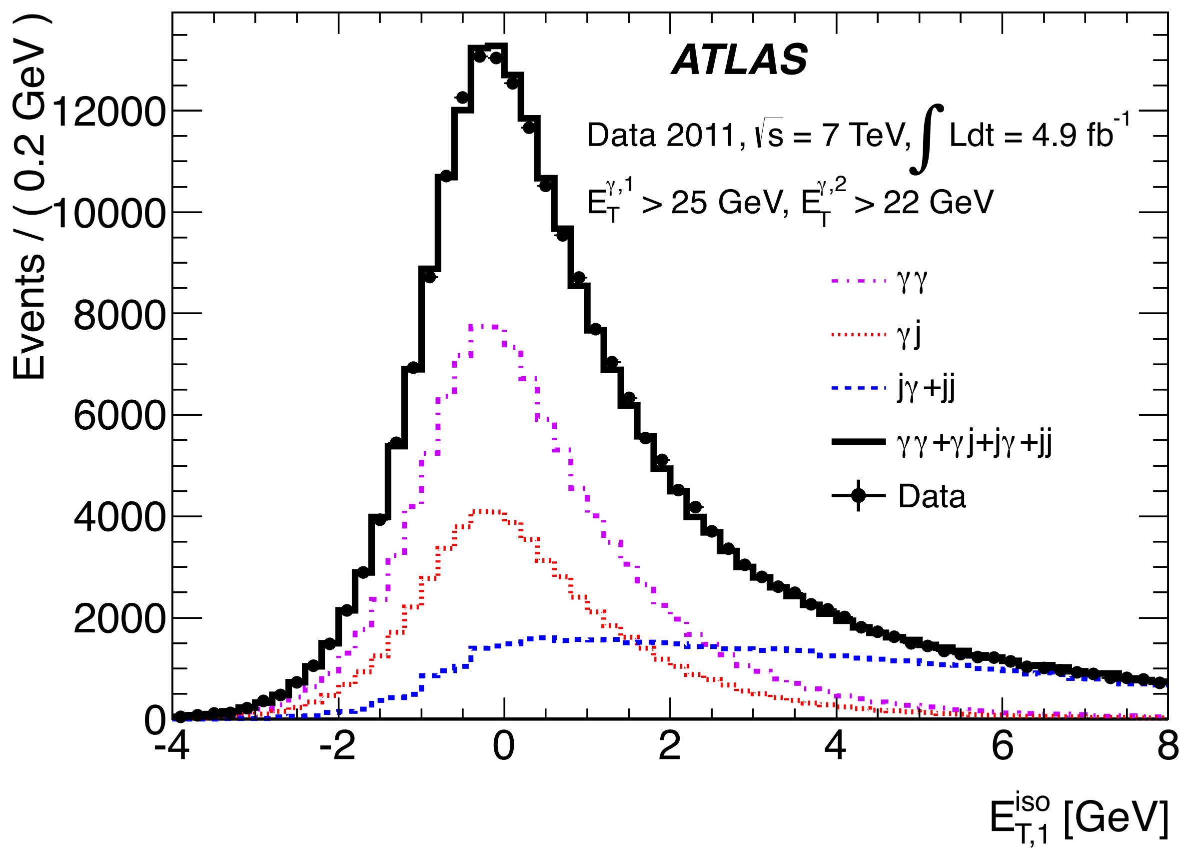


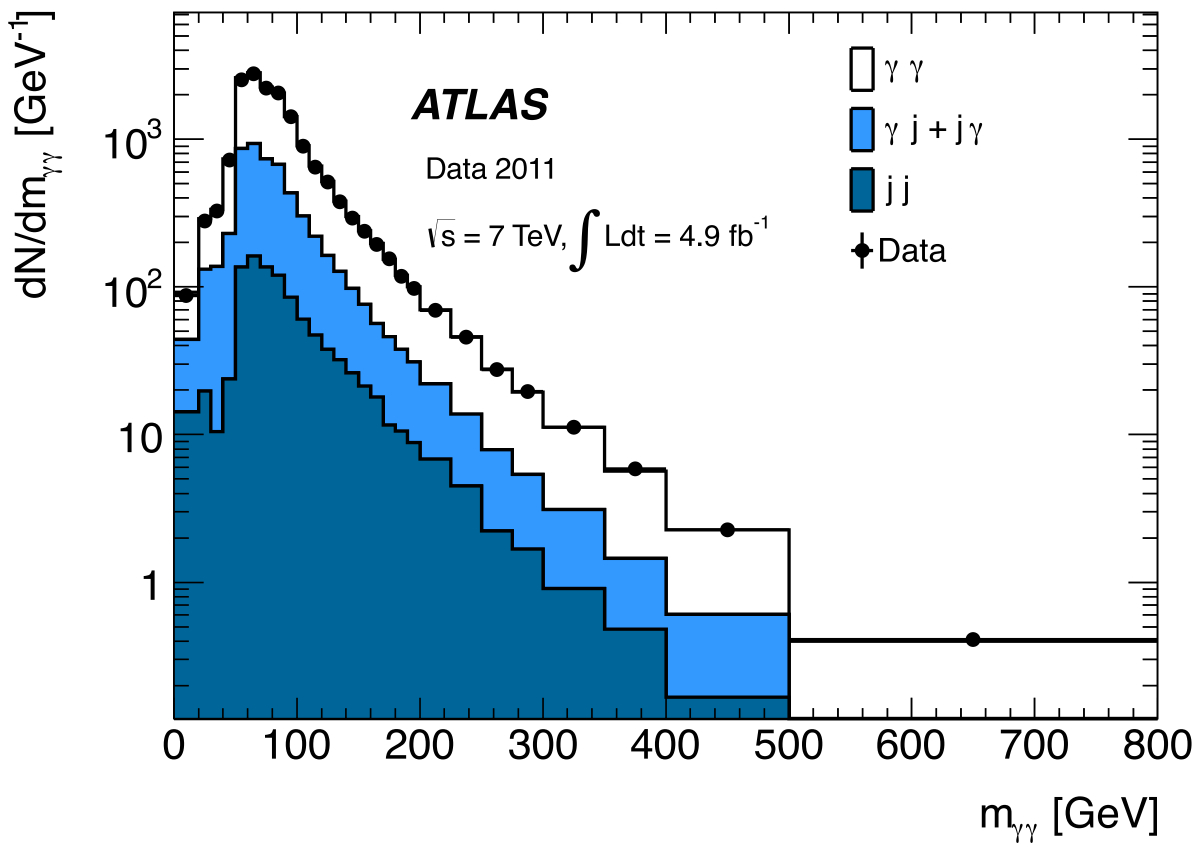


Isolation

JHEP01(2013)086

- Key variable in several analysis.
- Measurement of the production cross-section of diphoton events:
  - Isolation is used to determine the composition of the data sample.

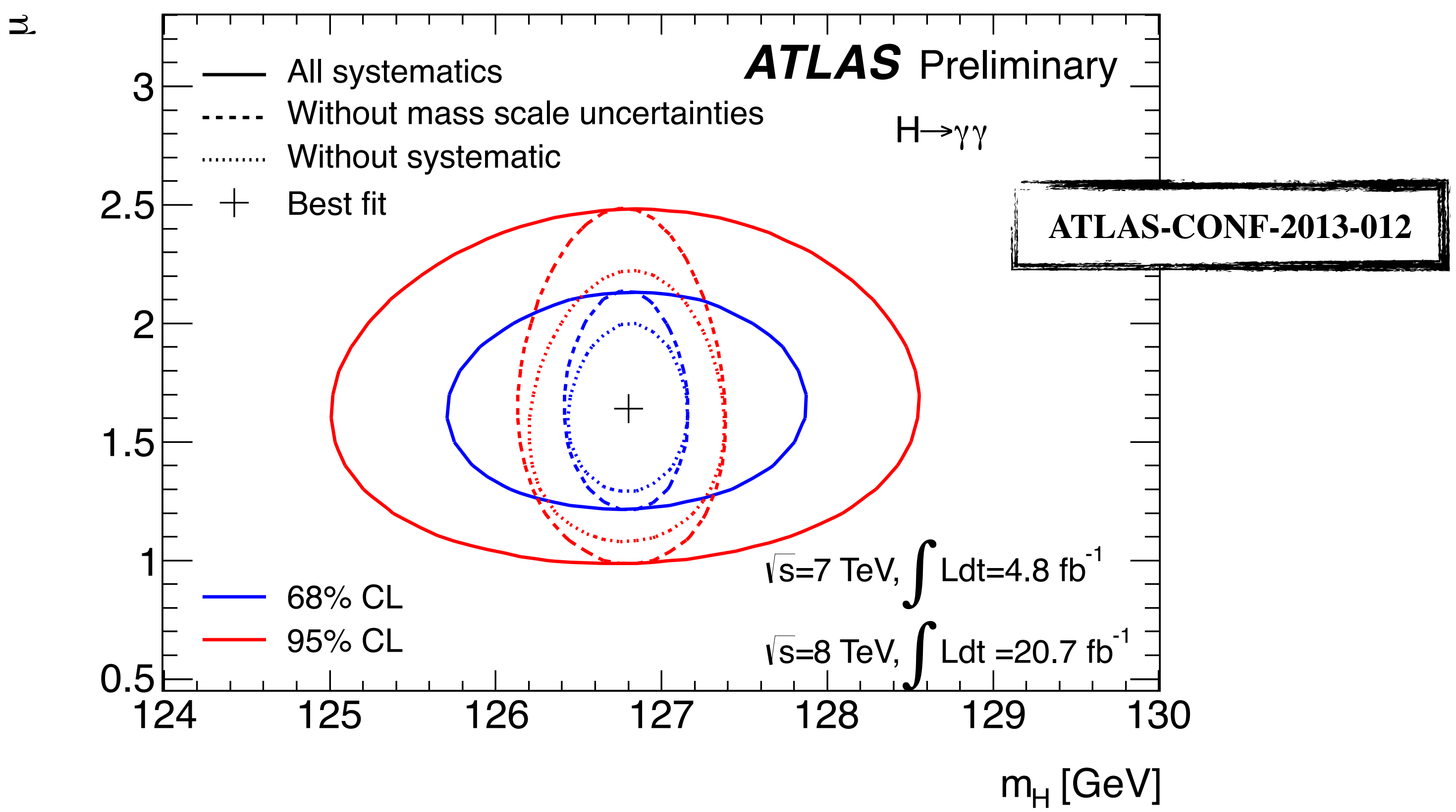




Conclusions

- Excellent performances of ATLAS to detect and measure the properties of electrons and photons.
- Excellent energy scale stability with time and pileup.

- Crucial measurements for the ATLAS physics program:
  - The EM energy scale is the dominant systematic uncertainty on m_H in the $\gamma\gamma$ channel.



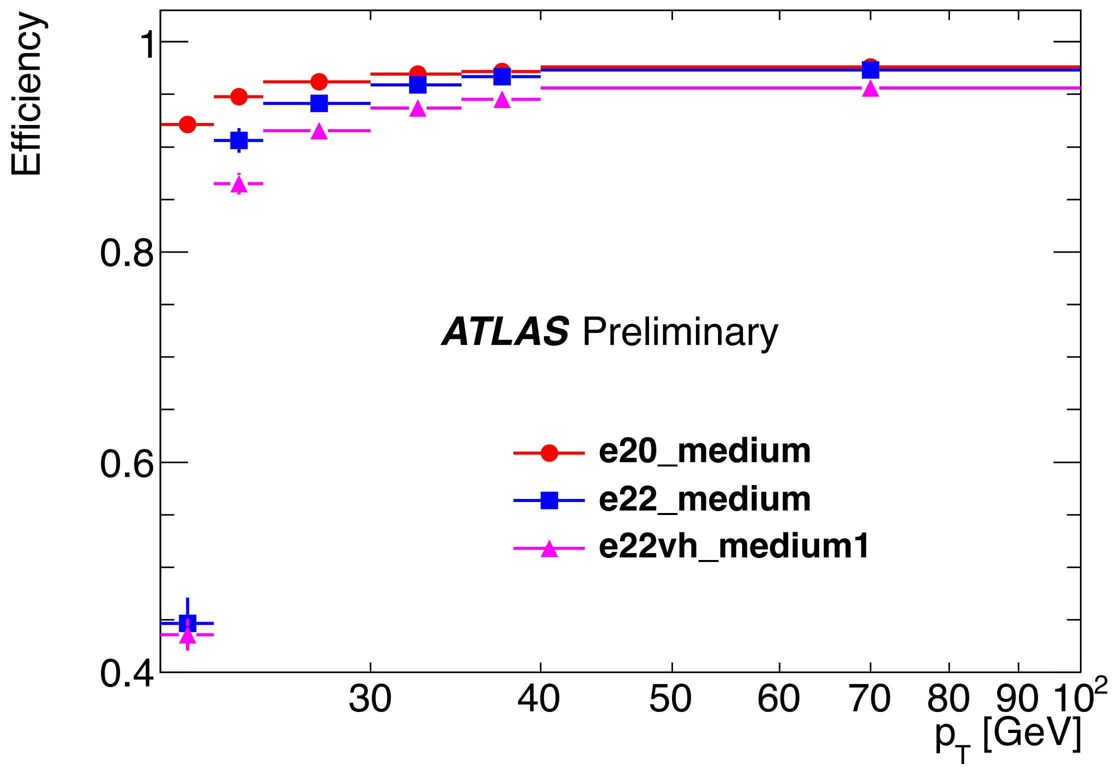
- The measurements of the performances with 2012 data are preliminary:
  - There is still room for improvements !
- Start preparing run II:
  - If the LHC bunch spacing stays at 50ns, <μ>~80 (for Run I, <μ> < 40). We will have to revisit the strategy. For example: e/γ ambiguity, identification strategy, ...

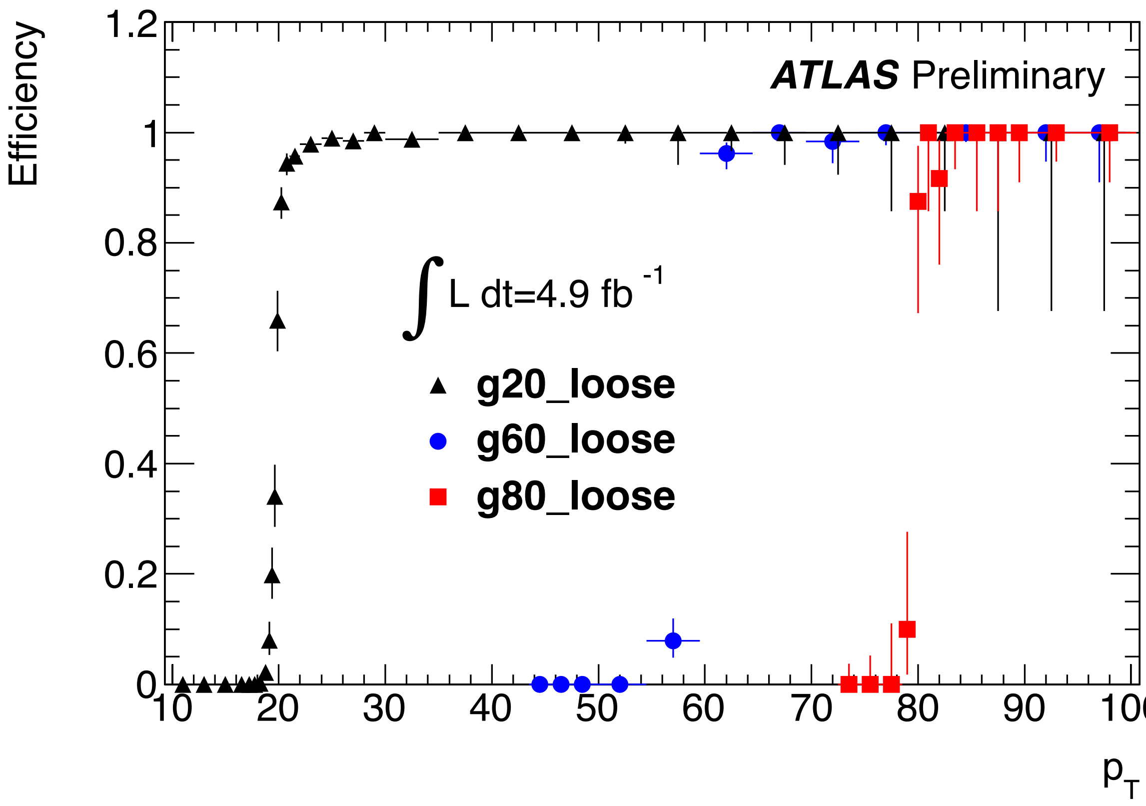
Backup

Electron and Photon trigger

Photons
Electrons

- L1 trigger based on energy deposit in regions of interests (RoIs) in the calorimeter.
- HLT trigger uses the granularity of the calorimeter in the RoIs and the tracker information.
  - Photon triggers fully efficient within a few GeV from the threshold.
  - Scale factors needed for electron triggers.





Electron identification efficiency

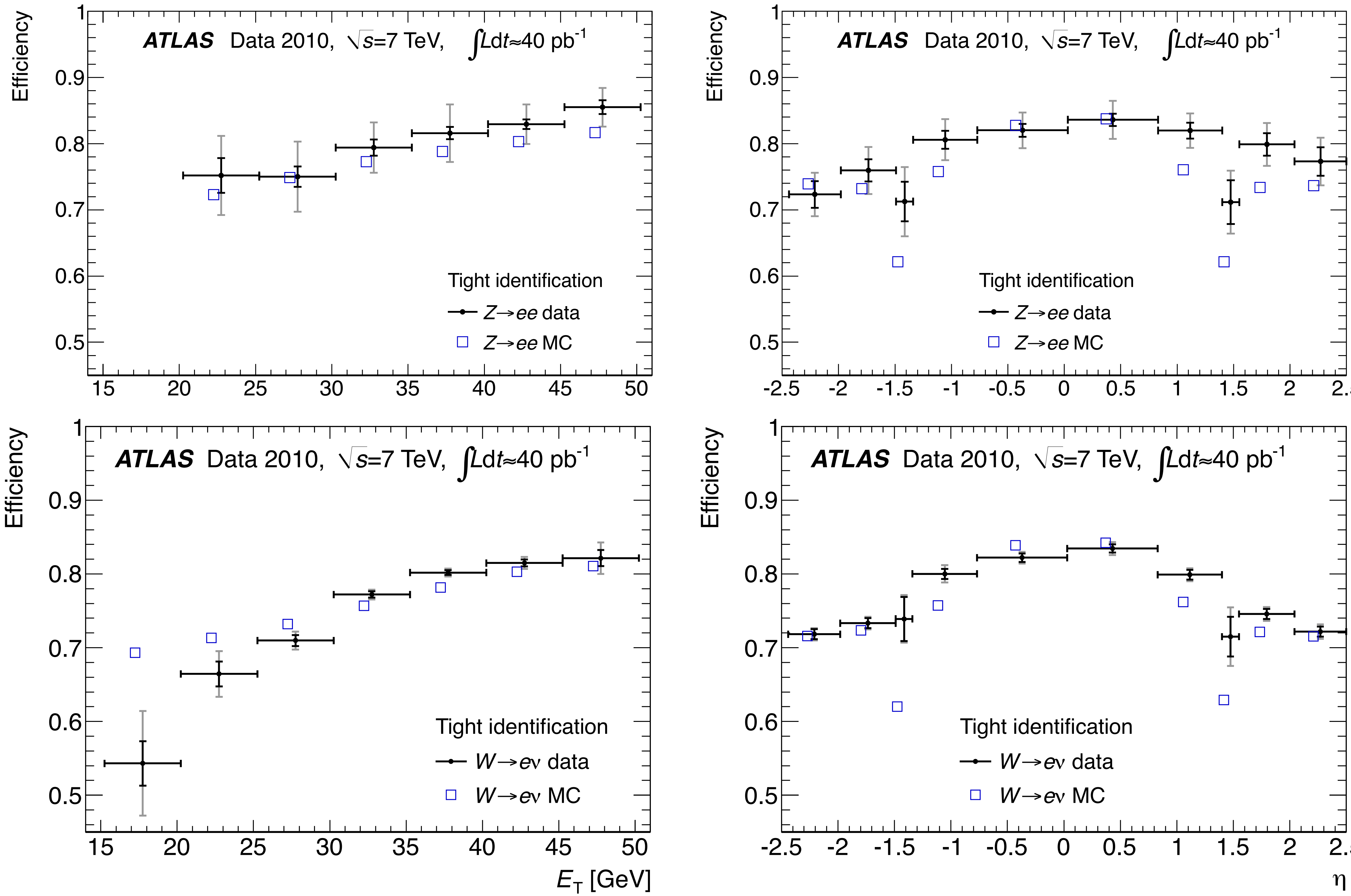
- Measurement performed with Z,W and J/ψ:
  - Overall good agreement between the three samples.
  - Overall good agreement with the simulation.

[Eur. Phys. J. C 72 (2012) 1909]

T&P Method Electrons

Z

W



Expected photon id efficiency and jet rejection

ATLAS-PHYS-PUB-2011-007

$$\epsilon = \frac{N_{\gamma}^{reco,\, pass\; cut}}{N_{\gamma}^{truth}}$$

		loose selection efficiency (%)			*tight* selection efficiency (%)		
		all	unconverted	converted	all	unconverted	converted
γ/j	$E_T > 20$ GeV	95.45 ± 0.01	97.80 ± 0.01	91.73 ± 0.01	82.88 ± 0.02	85.04 ± 0.03	79.44 ± 0.04
	$E_T > 25$ GeV	95.96 ± 0.01	98.08 ± 0.01	92.58 ± 0.03	85.31 ± 0.02	87.16 ± 0.03	82.35 ± 0.04
	$E_T > 40$ GeV	96.37 ± 0.02	98.40 ± 0.02	93.17 ± 0.04	89.21 ± 0.03	90.76 ± 0.04	86.76 ± 0.05
$H \to \gamma\gamma$	$E_T > 20$ GeV	96.15 ± 0.05	97.93 ± 0.04	93.00 ± 0.10	88.45 ± 0.08	89.81 ± 0.09	86.05 ± 0.14
	$E_T > 25$ GeV	96.25 ± 0.05	97.99 ± 0.04	93.16 ± 0.10	88.92 ± 0.08	90.22 ± 0.09	86.61 ± 0.14
	$E_T > 40$ GeV	96.46 ± 0.05	98.16 ± 0.04	93.42 ± 0.11	90.06 ± 0.08	91.27 ± 0.09	87.92 ± 0.14
$G \to \gamma\gamma$	$E_T > 100$ GeV	95.91 ± 0.01	97.70 ± 0.01	92.55 ± 0.01	90.89 ± 0.01	91.73 ± 0.01	89.29 ± 0.01

Table 8: Expected total photon identification efficiencies (reconstruction + identification) for loose and tight selections. The quoted uncertainties are statistical.

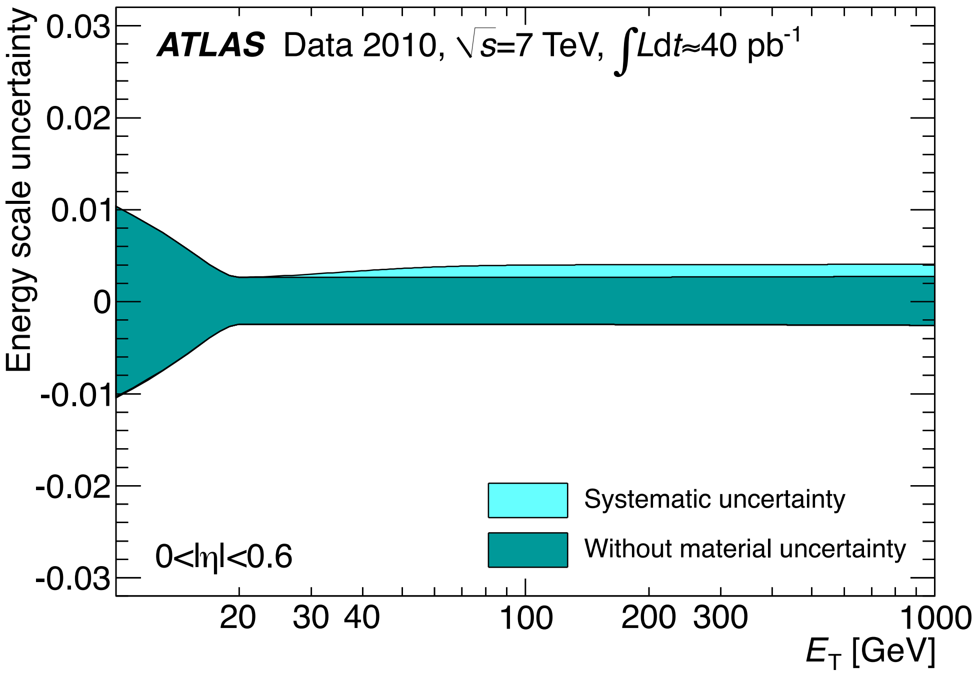
$$R = \frac{N_{jet}}{N_{\gamma}^{fake}} \cdot \frac{N_1}{N_2} \cdot \frac{1}{\epsilon_{filter}}$$

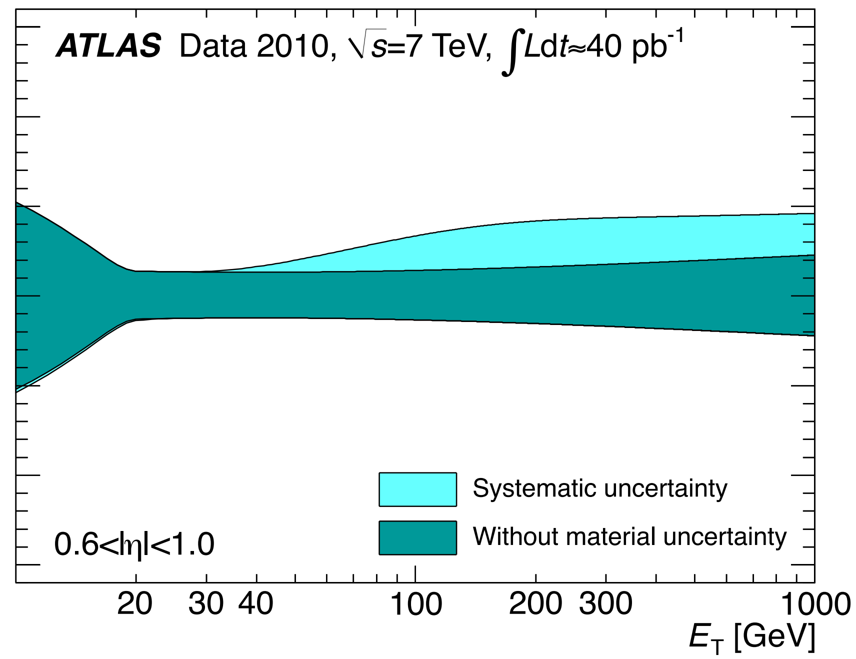
	loose rejection			tight rejection		
	all jets	quark jets	gluon jets	all jets	quark jets	gluon jets
$E_T > 20$ GeV	898 ± 4	323 ± 2	2220 ± 20	4780 ± 40	1630 ± 20	13600 ± 200
$E_T > 25$ GeV	1030 ± 6	365 ± 3	2670 ± 30	5290 ± 70	1740 ± 30	16800 ± 500
$E_T > 40$ GeV	940 ± 10	368 ± 6	2210 ± 60	5100 ± 200	1680 ± 60	20100 ± 1500

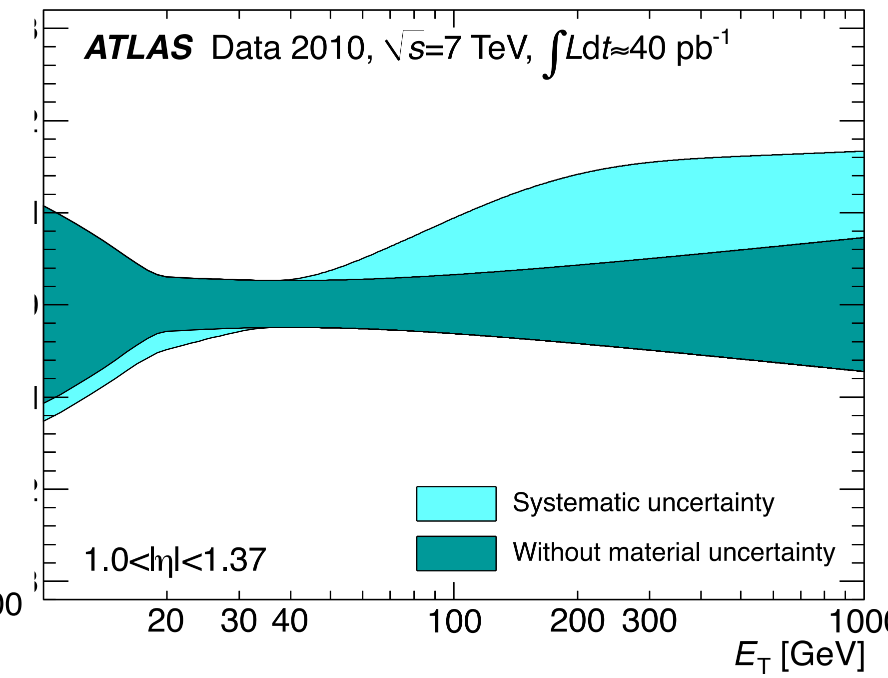
Table 9: Expected jet background rejections for loose and tight selections. The quoted uncertainties are statistical.

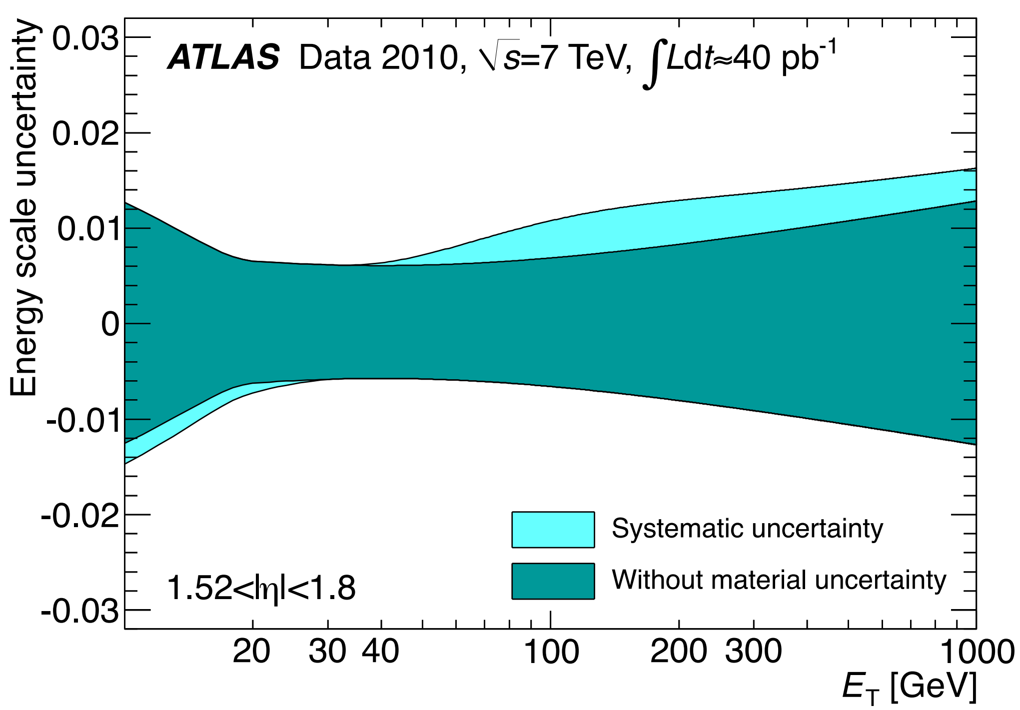
Energy scale uncertainties

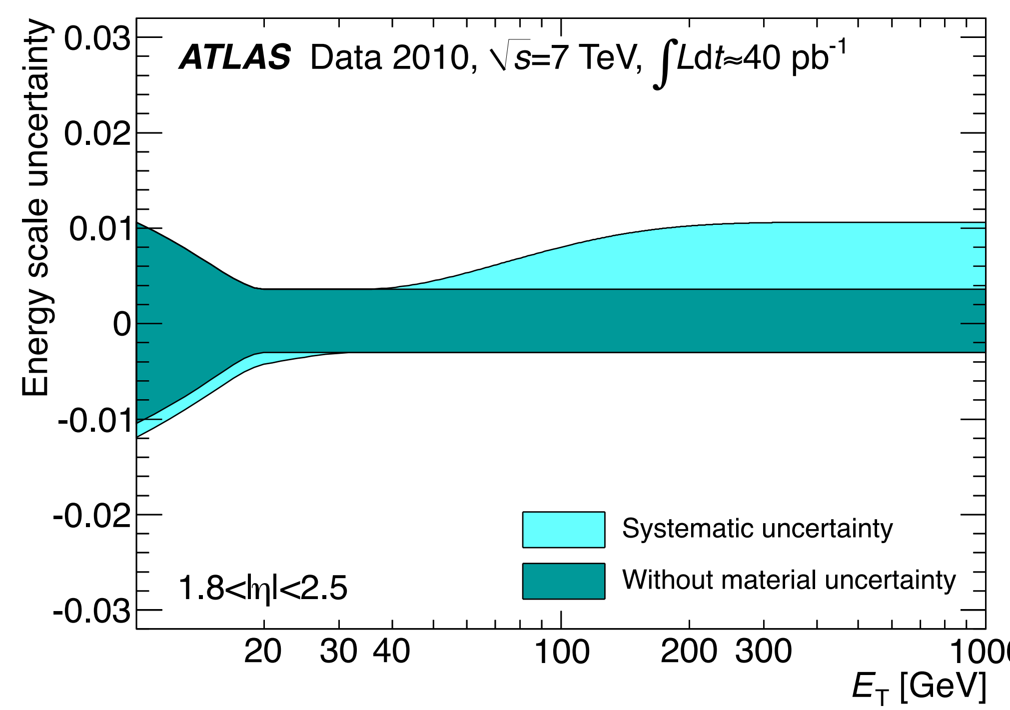
- Energy scale uncertainty: material, comparison with J/ψ, PS energy scale, elect. calib. and crosstalk.











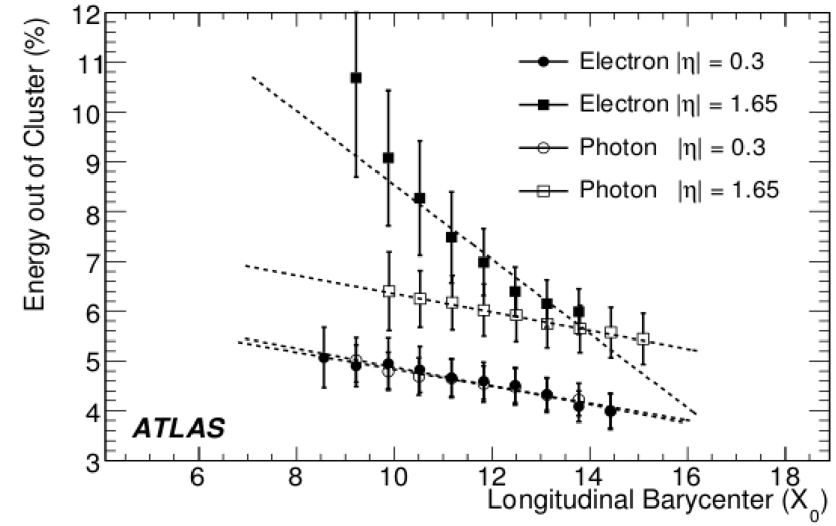
Cluster energy reconstruction

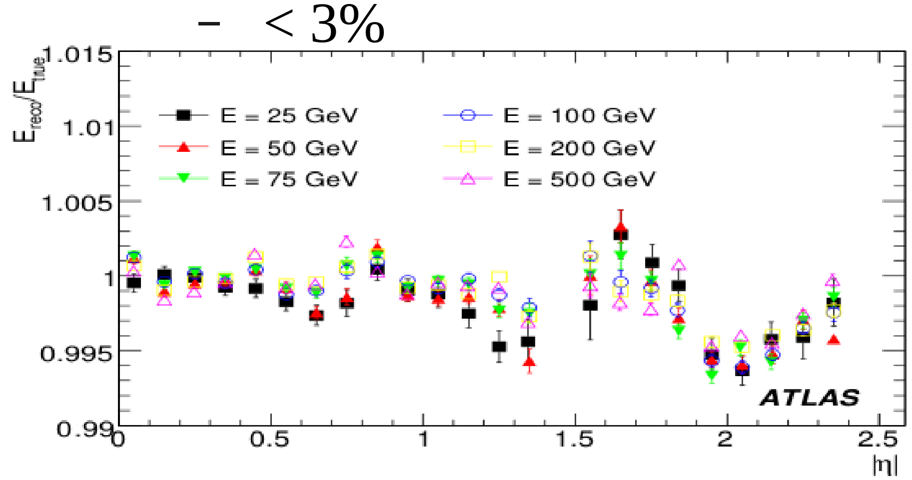
Electrons Photons

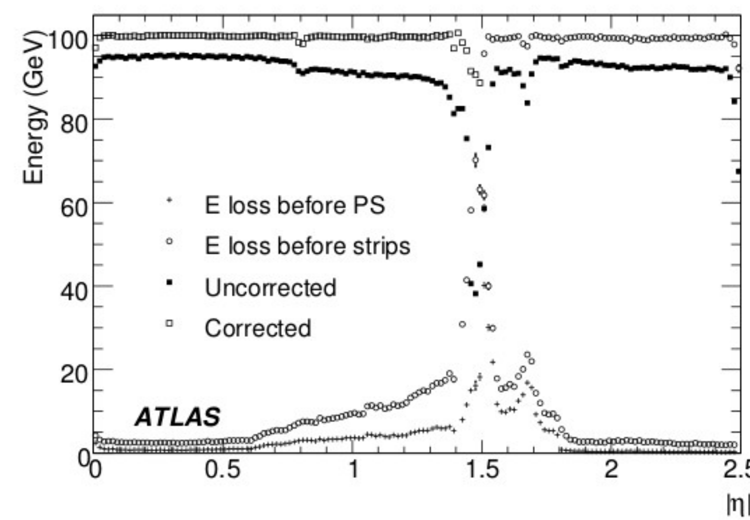
Slide from E. Petit
LHC France 2013

- $E_\gamma = E_{front} + E_{calo} + E_{back}$
- $E_{calo} = C_{cal}(X,\eta)(1+f_{out}(X,\eta))\sum_{i=1}^{3} E_i$
  - X: longitudinal barycentre
  - η: cluster barycenter
  - f_{out}: fraction of energy deposited outside cluster (<7%)
  - C_{cal}: calibration factor (0.98-1)
- $E_{front} = a(E_{cal},\eta) + b(E_{cal},\eta)E_{PS} + c(E_{cal},\eta)E_{PS}^2$
- $f_{leak} = E_{back}/E_{cal} = f_0^{leak}(\eta)X + f_1^{leak}(\eta)e^X$
  - < 3%

$$X = \frac{\sum_{i=1}^{3} E_i X_i + E_{PS} X PS}{\sum_{i=1}^{3} E_i + E_{PS}}$$



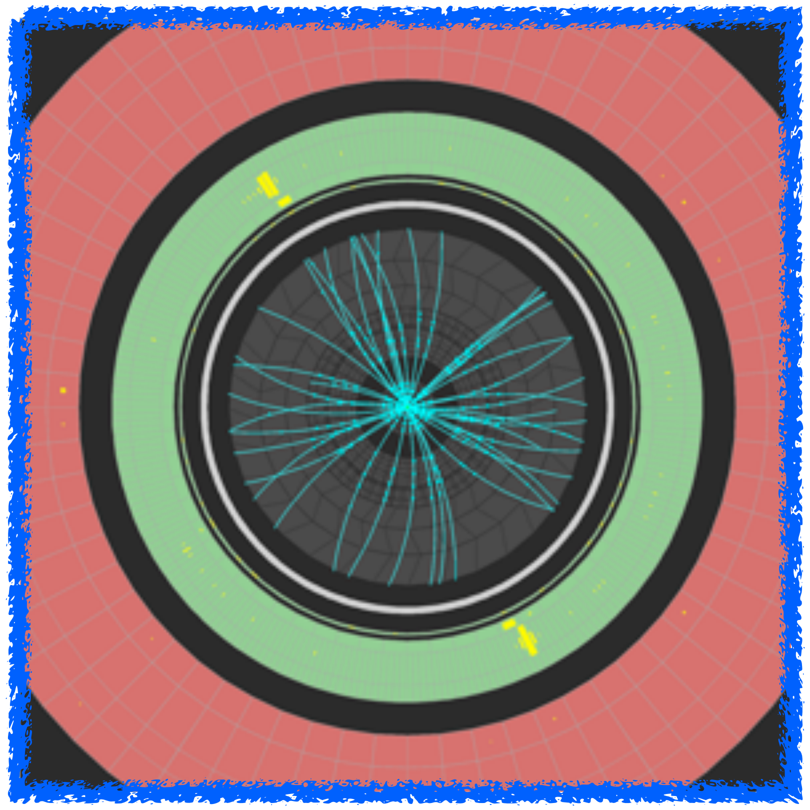




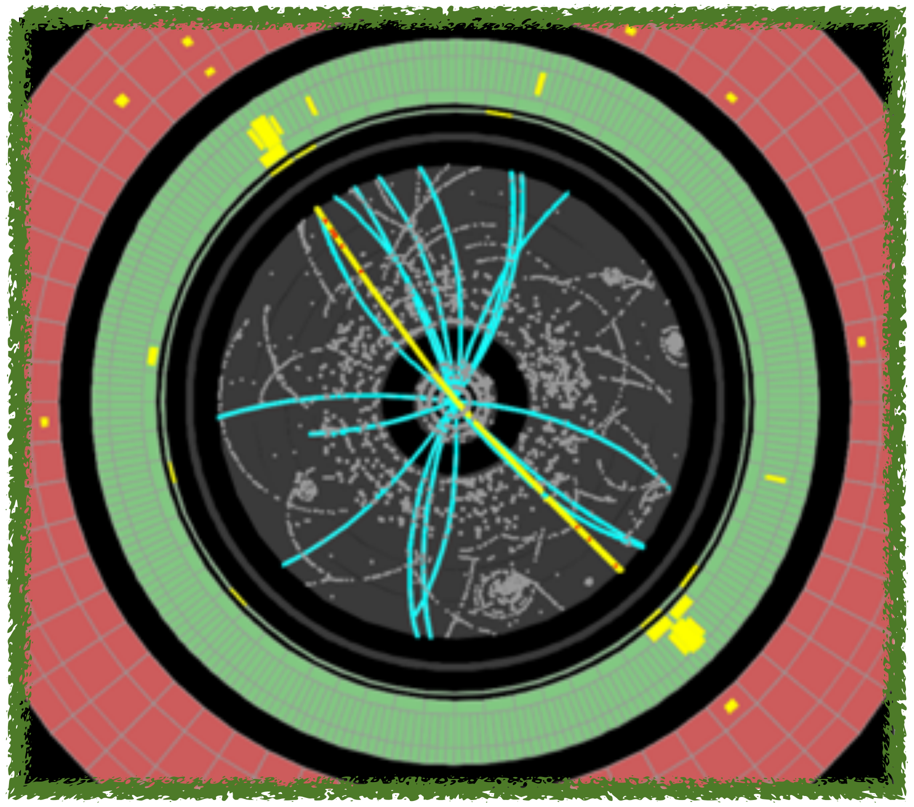
25

Event displays

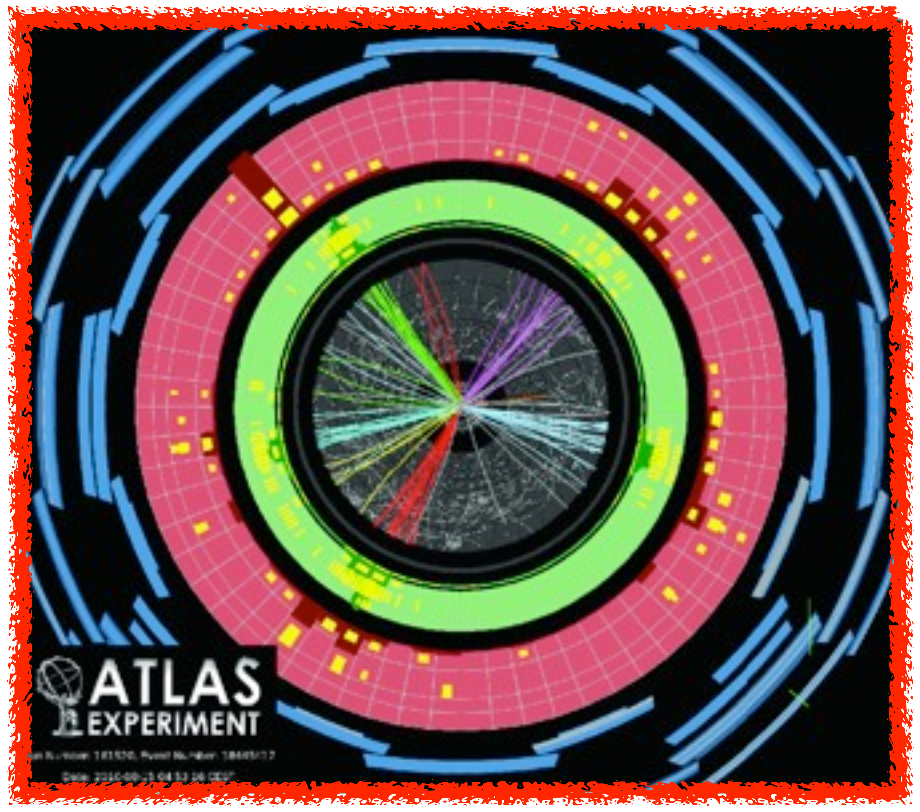
Diphoton candidate



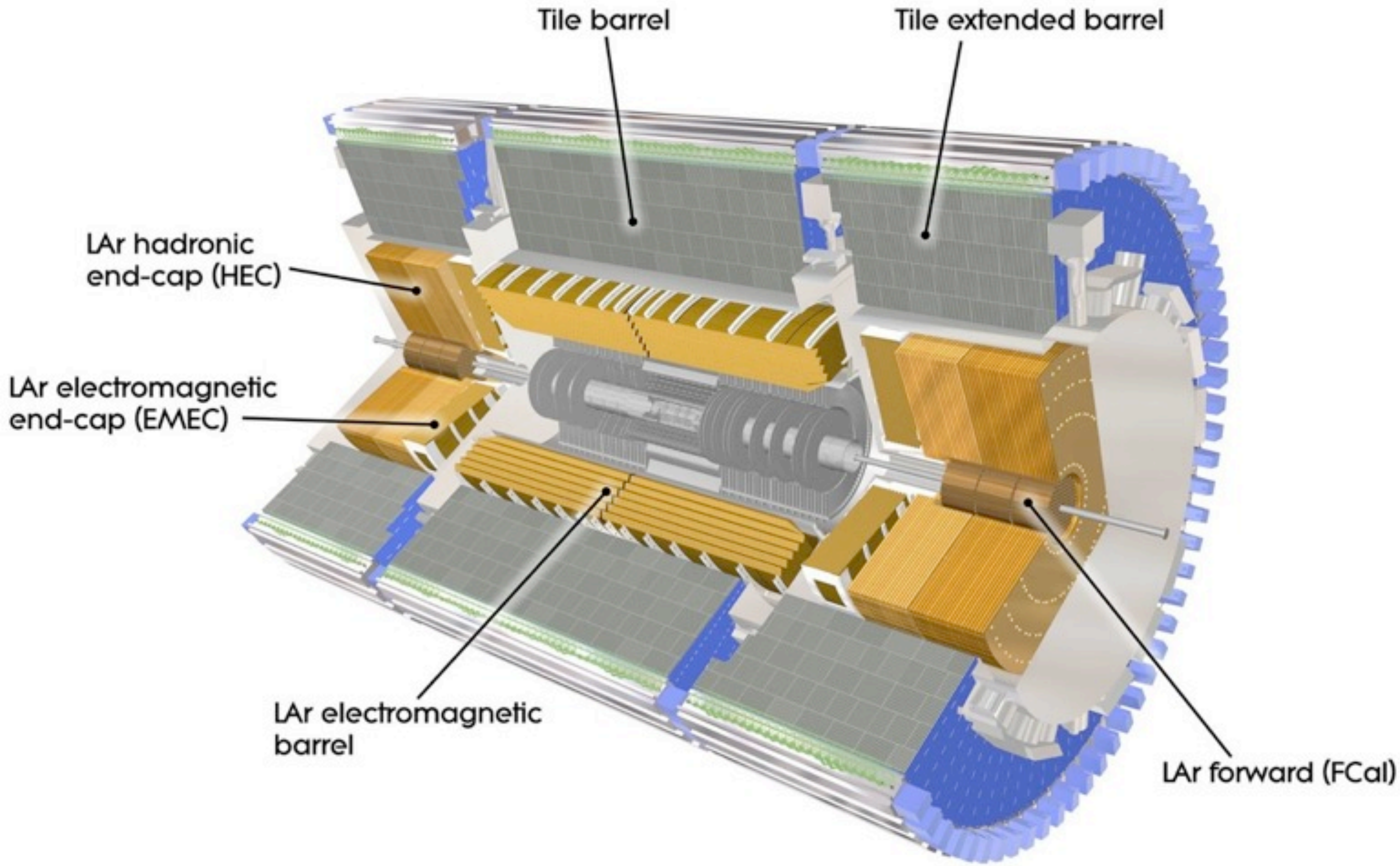
Z→e⁺e⁻ candidate

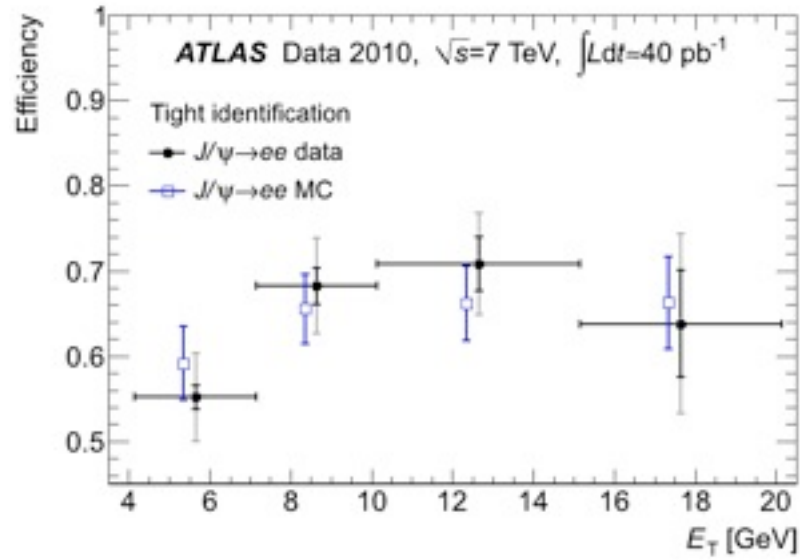


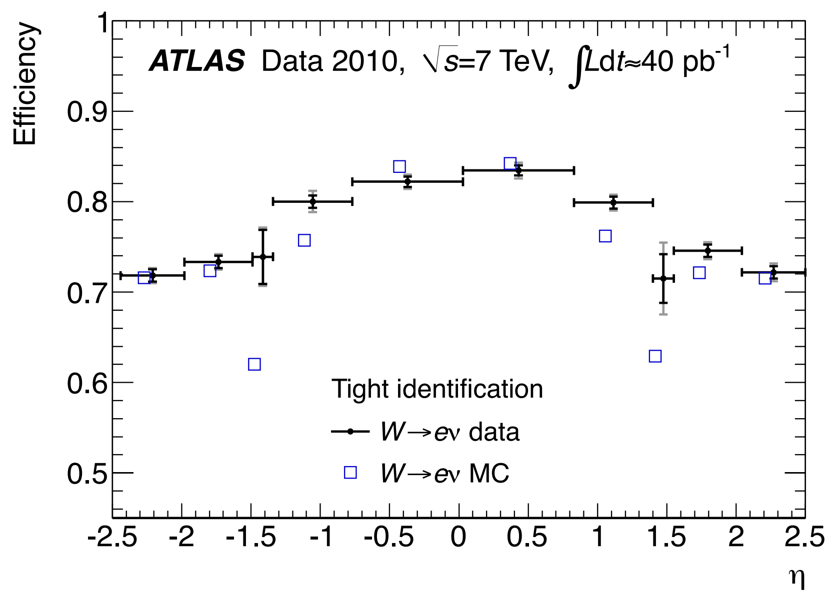
Multi-jets candidate

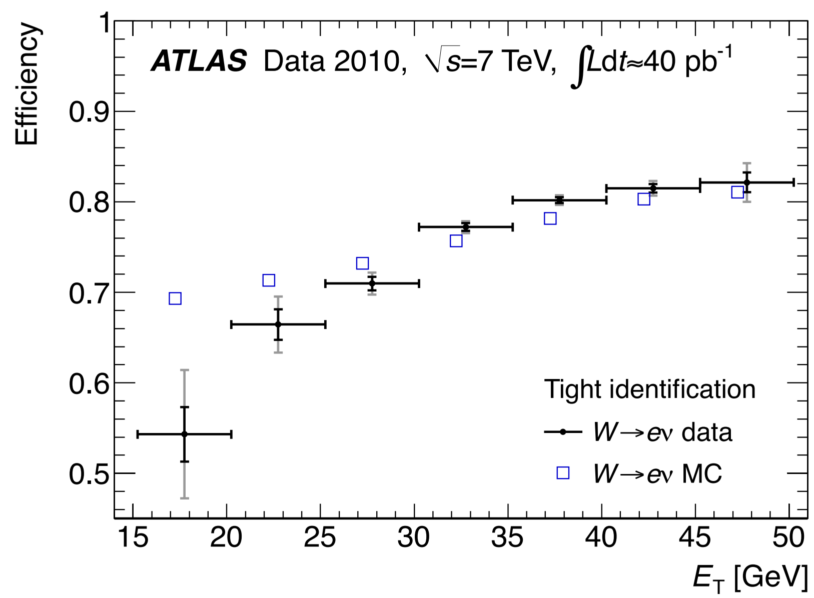


Calorimeters

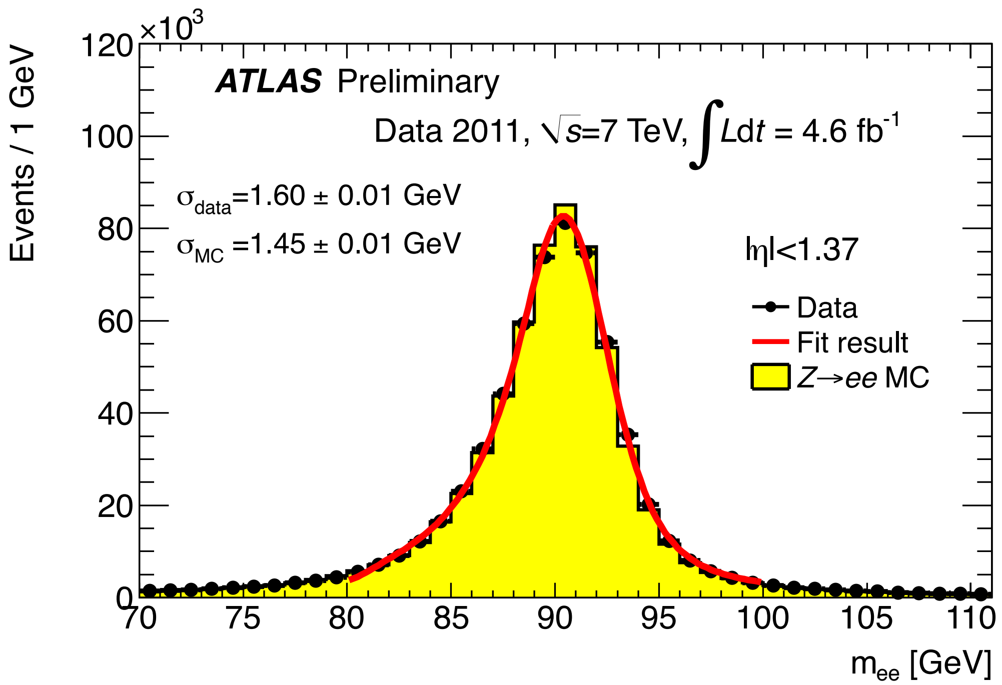


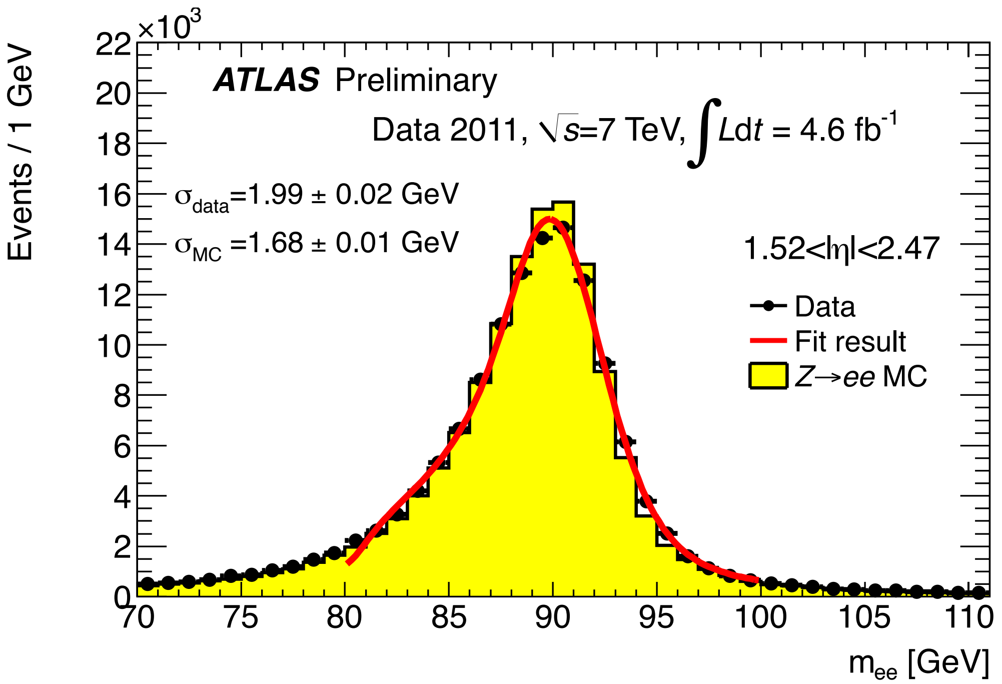

ATLAS Data 2010, √s=7 TeV, ∫Ldt≈40 pb-1
Tight identification
J/ψ→ee data
J/ψ→ee MC
Efficiency
E_T [GeV]

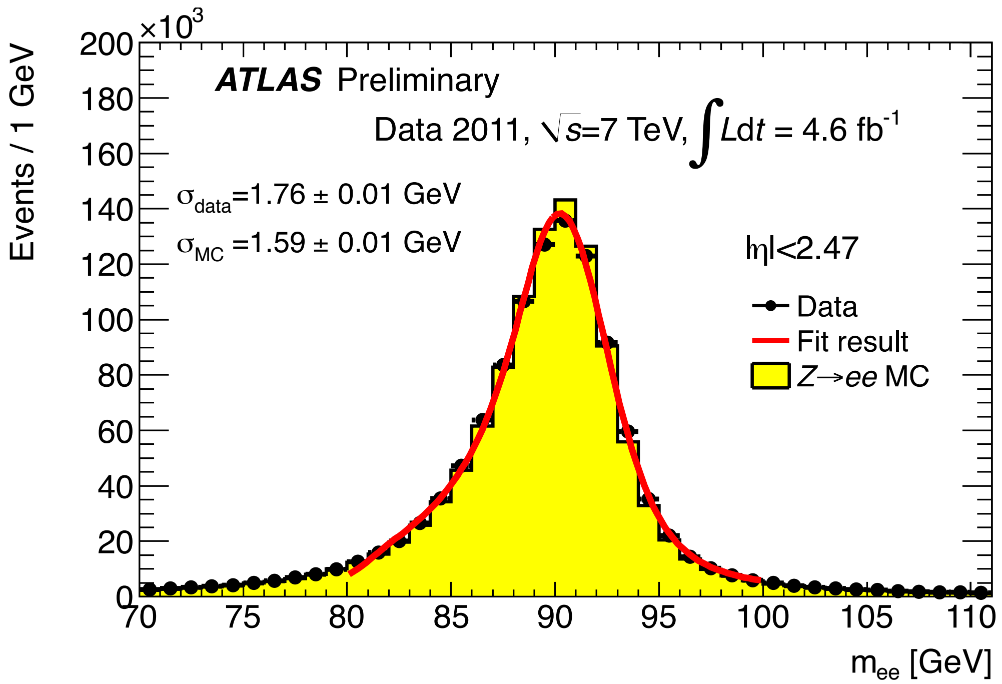

ATLAS Data 2010, √s=7 TeV, ∫Ldt≈40 pb-1
Tight identification
W→eν data
W→eν MC
Efficiency
η


ATLAS Data 2010, √s=7 TeV, ∫Ldt≈40 pb-1
Tight identification
W→eν data
W→eν MC
Efficiency
E_T [GeV]

Calibrated Z->e+e- mass with 2011 data

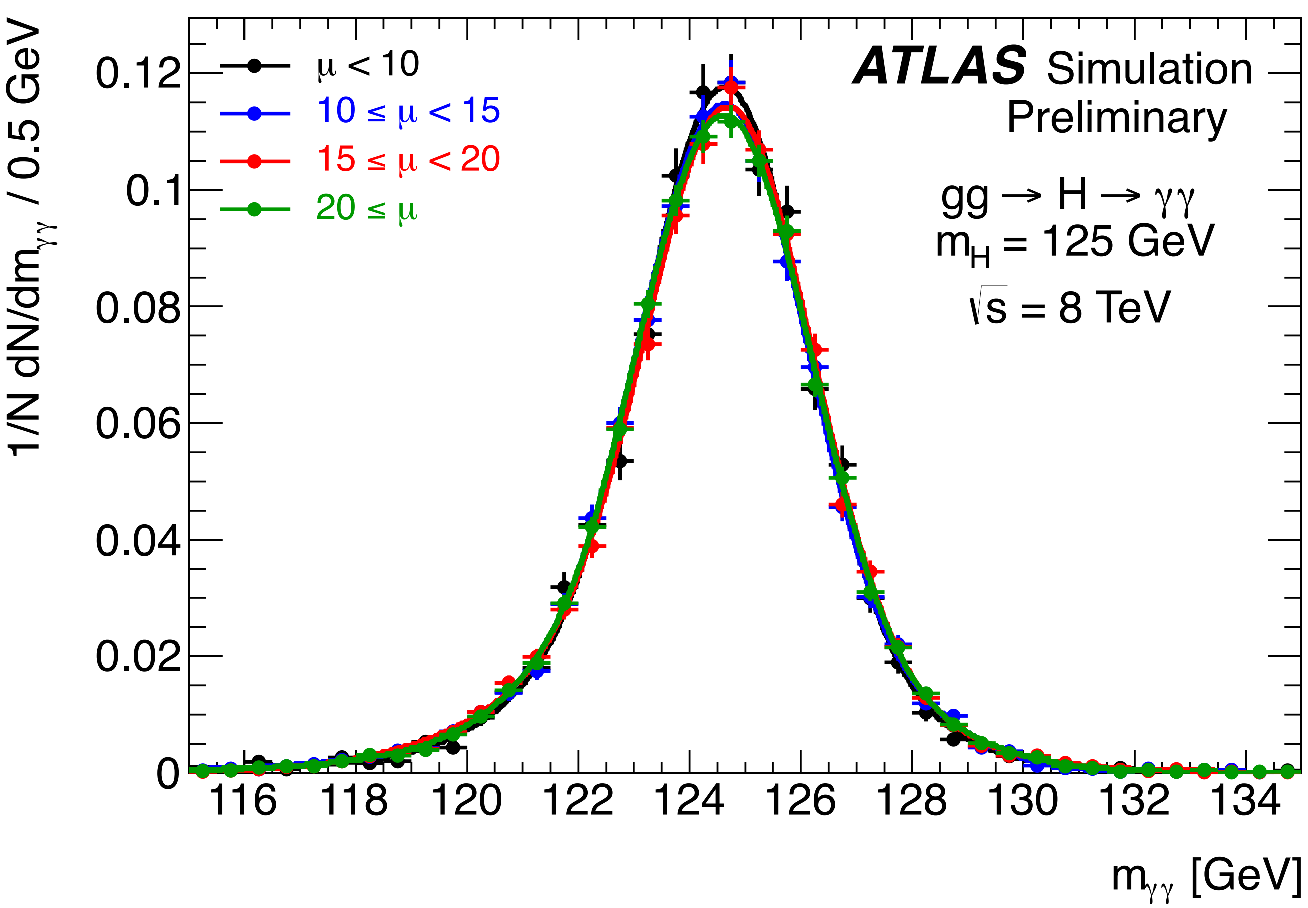


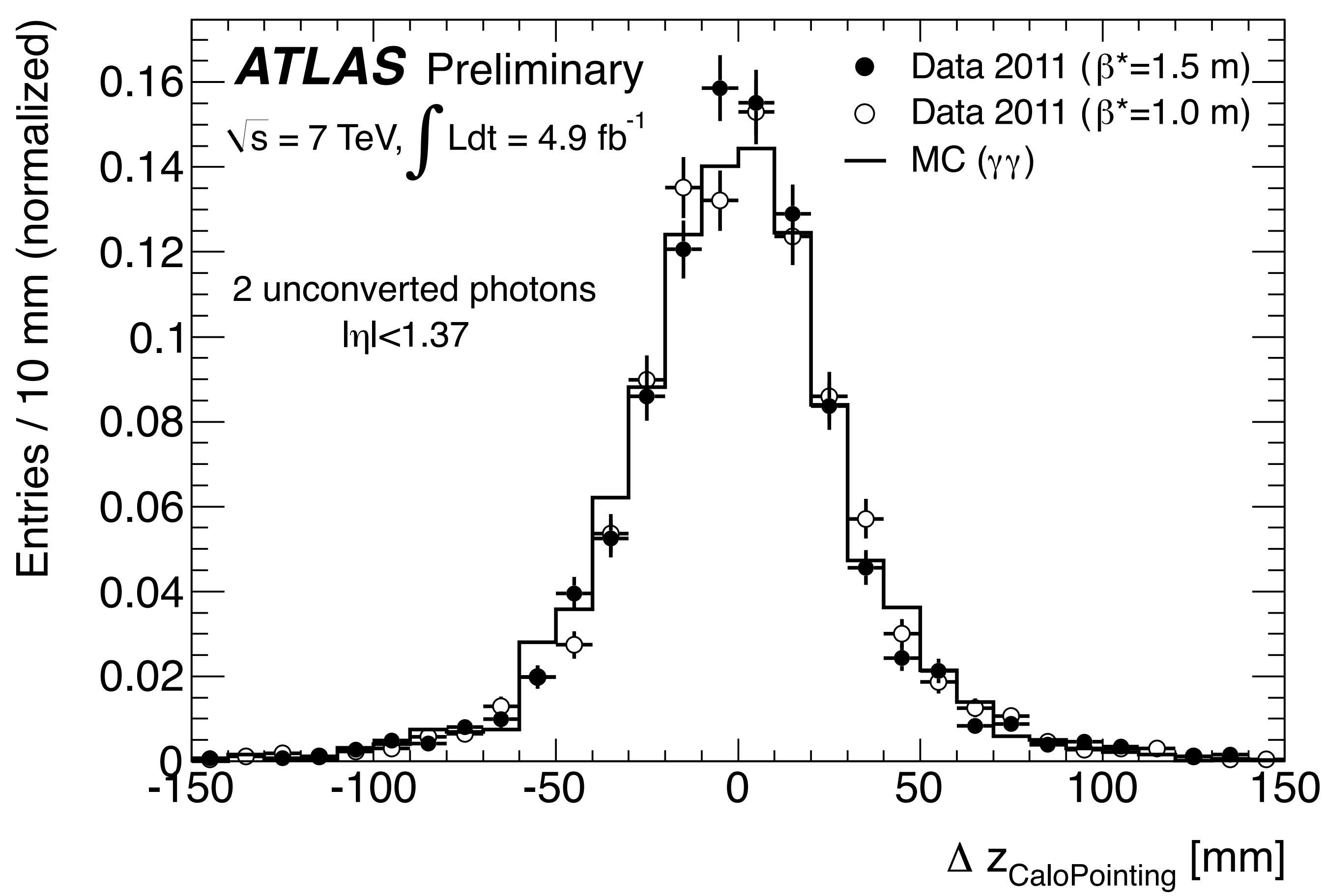




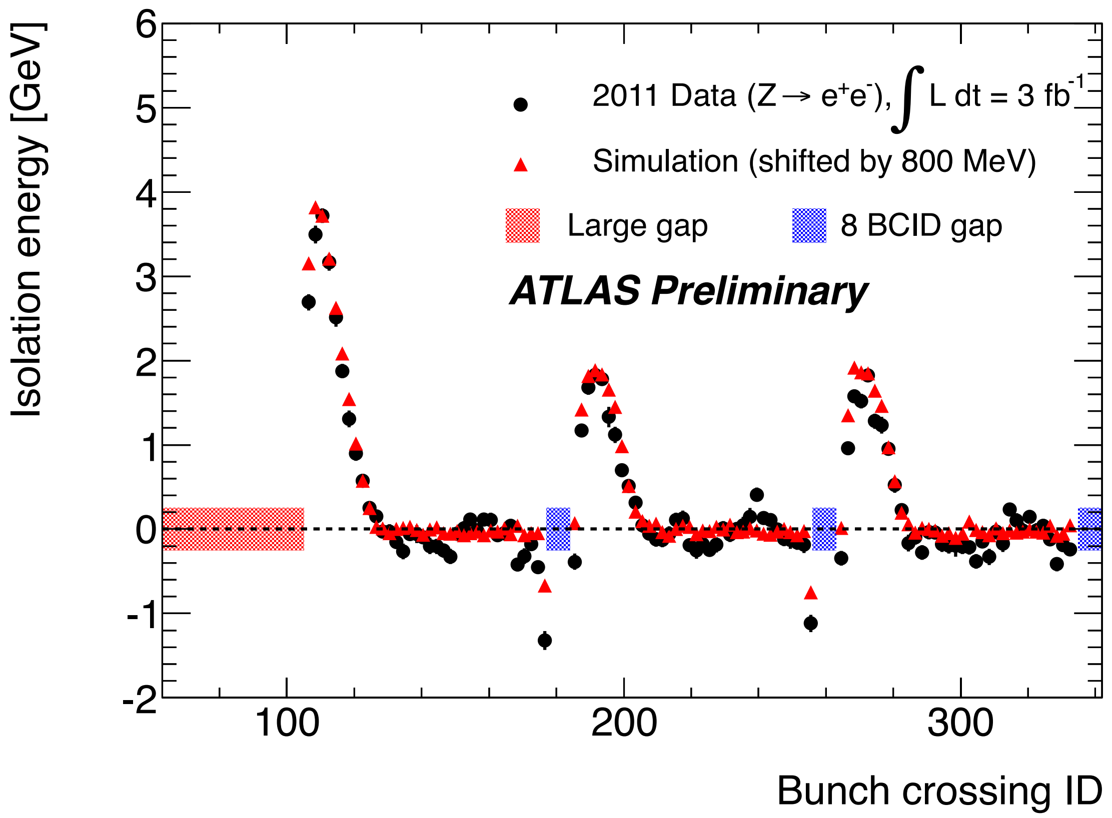
Pile-up impact on calorimeter pointing

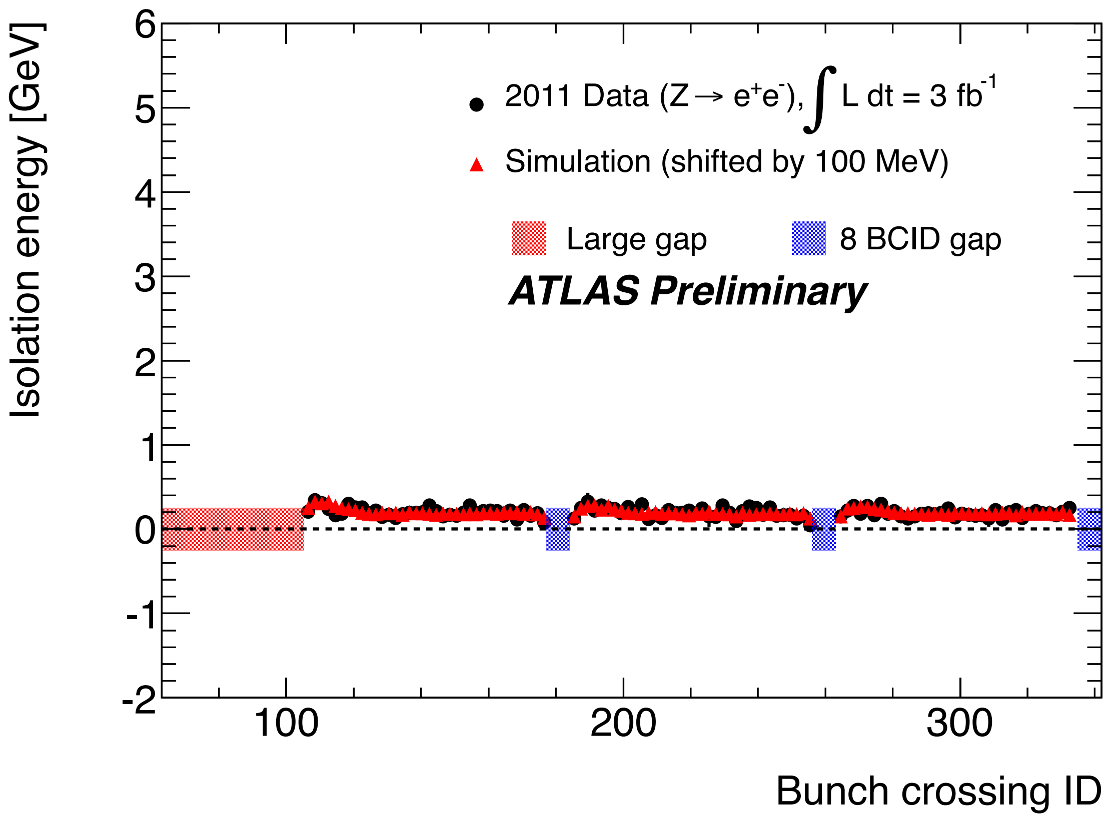
ATLAS-CONF-2012-091



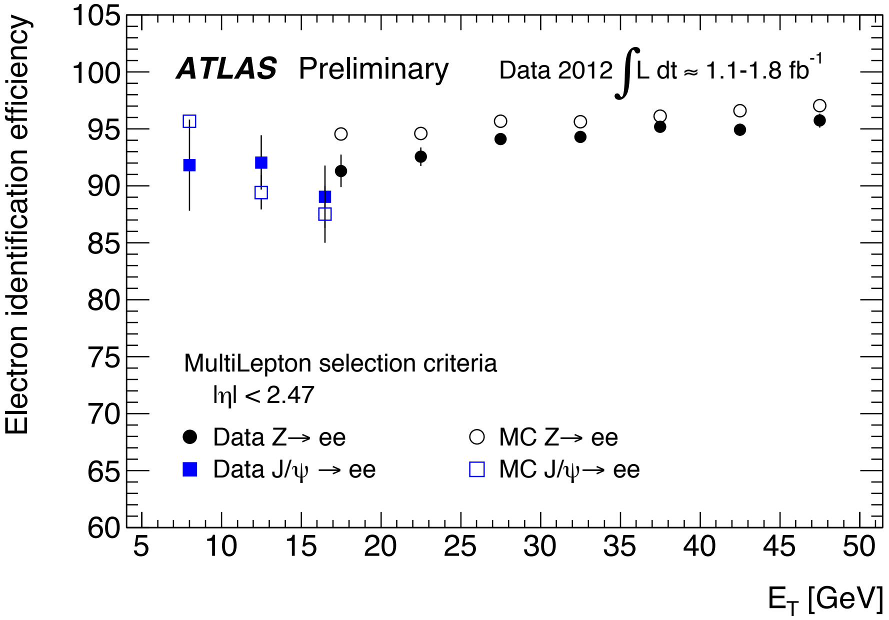


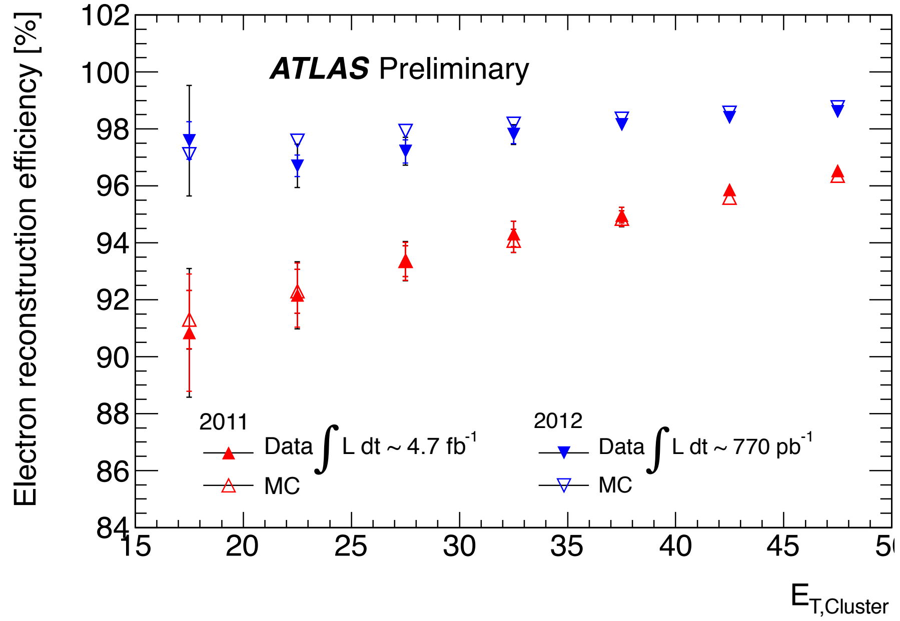
Calorimeter isolation versus out-of-time pile-up

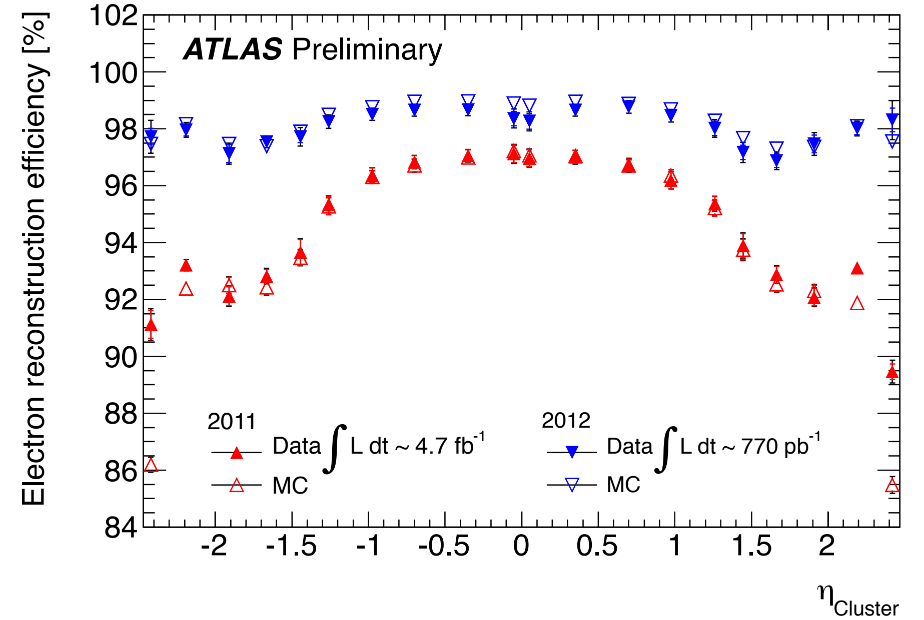


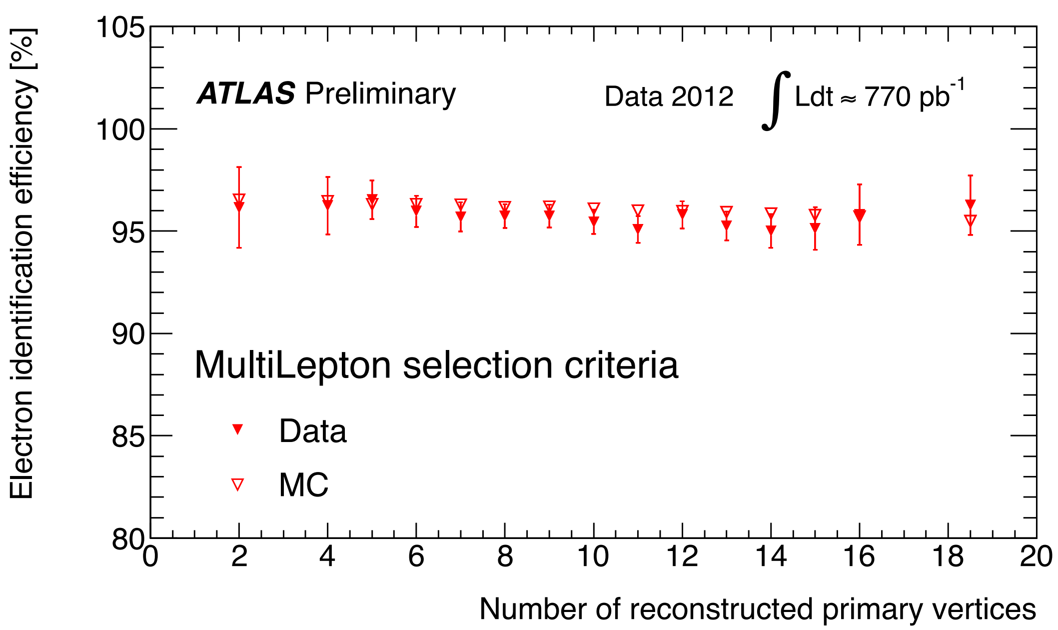


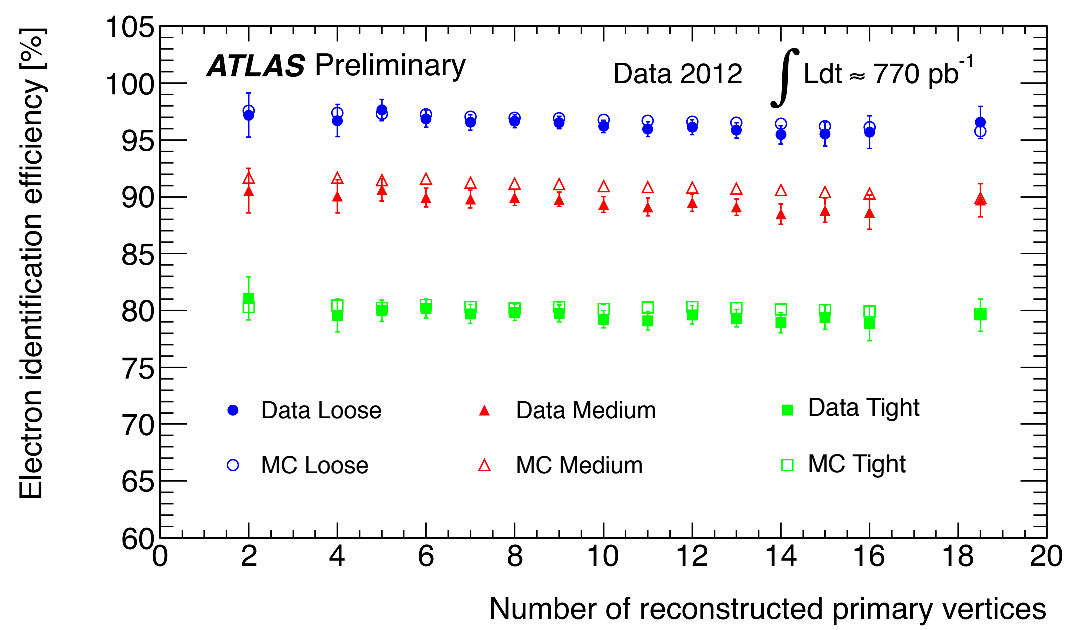
Electron efficiency measurements in early 2012 data



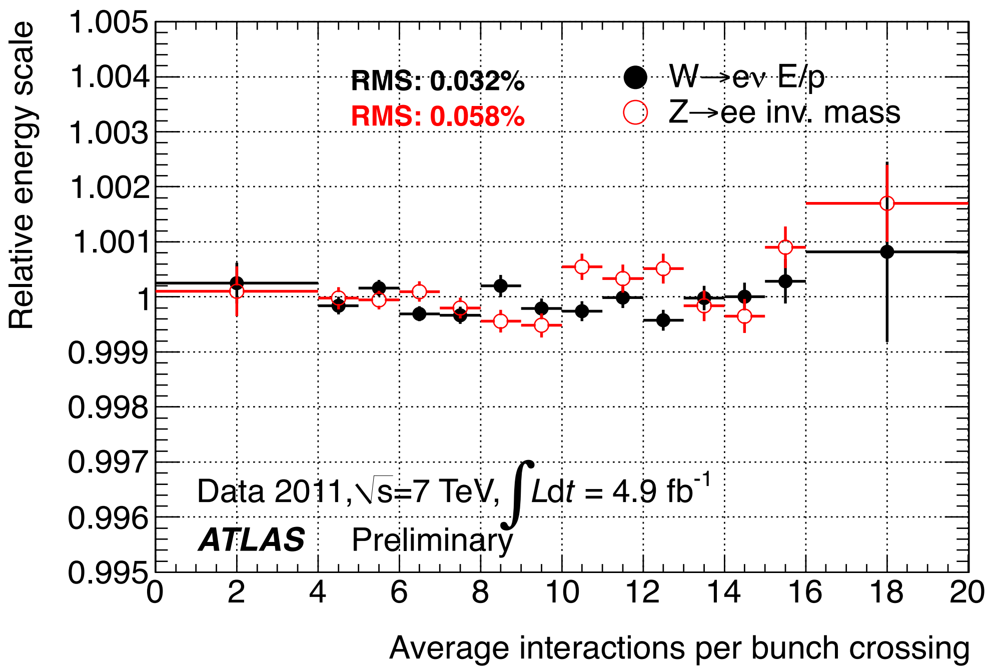


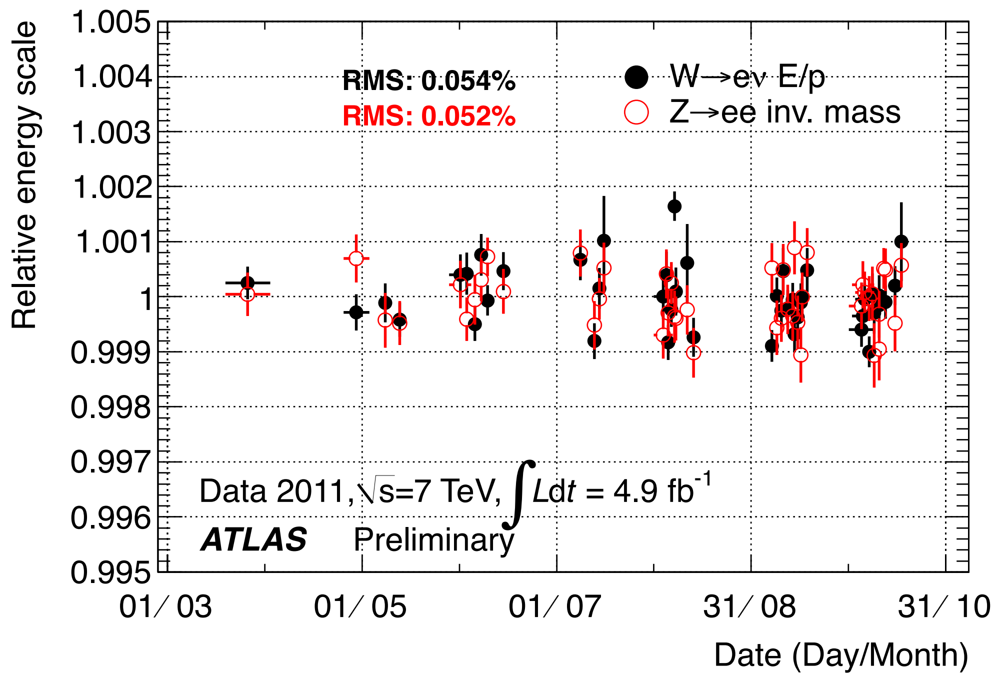




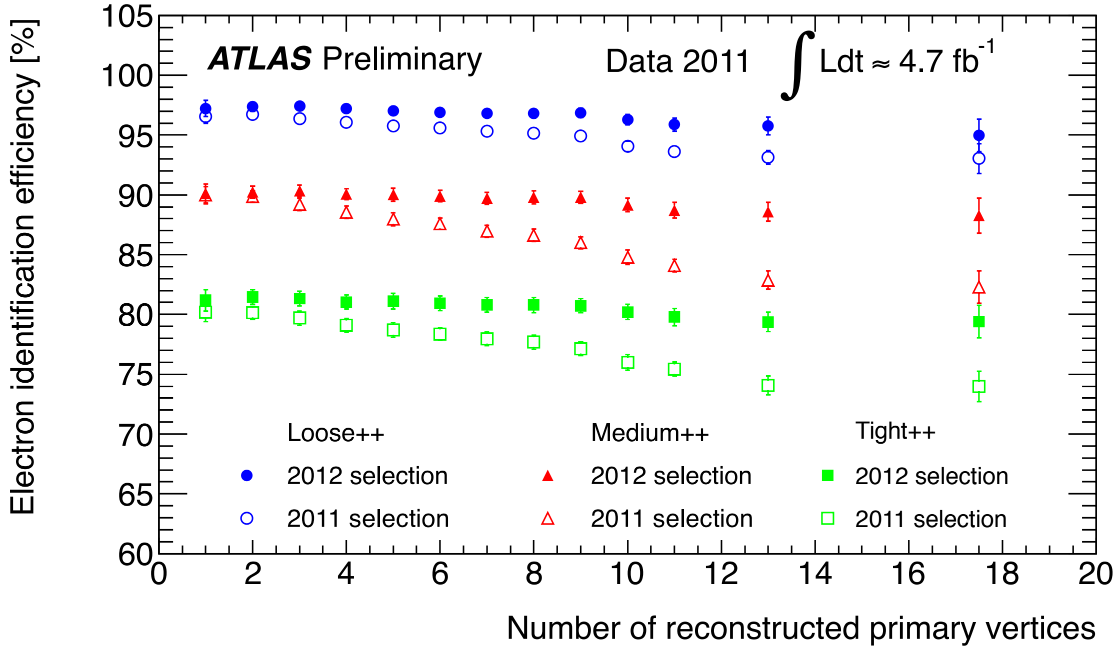


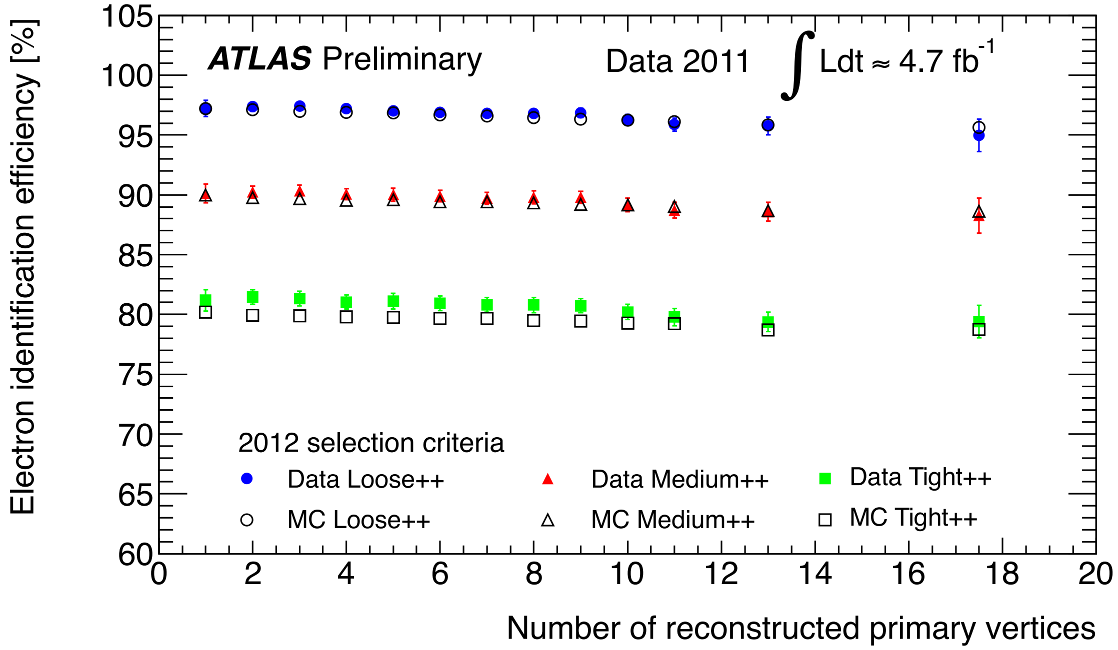
Electron energy response stability with time and pile-up: data 2011



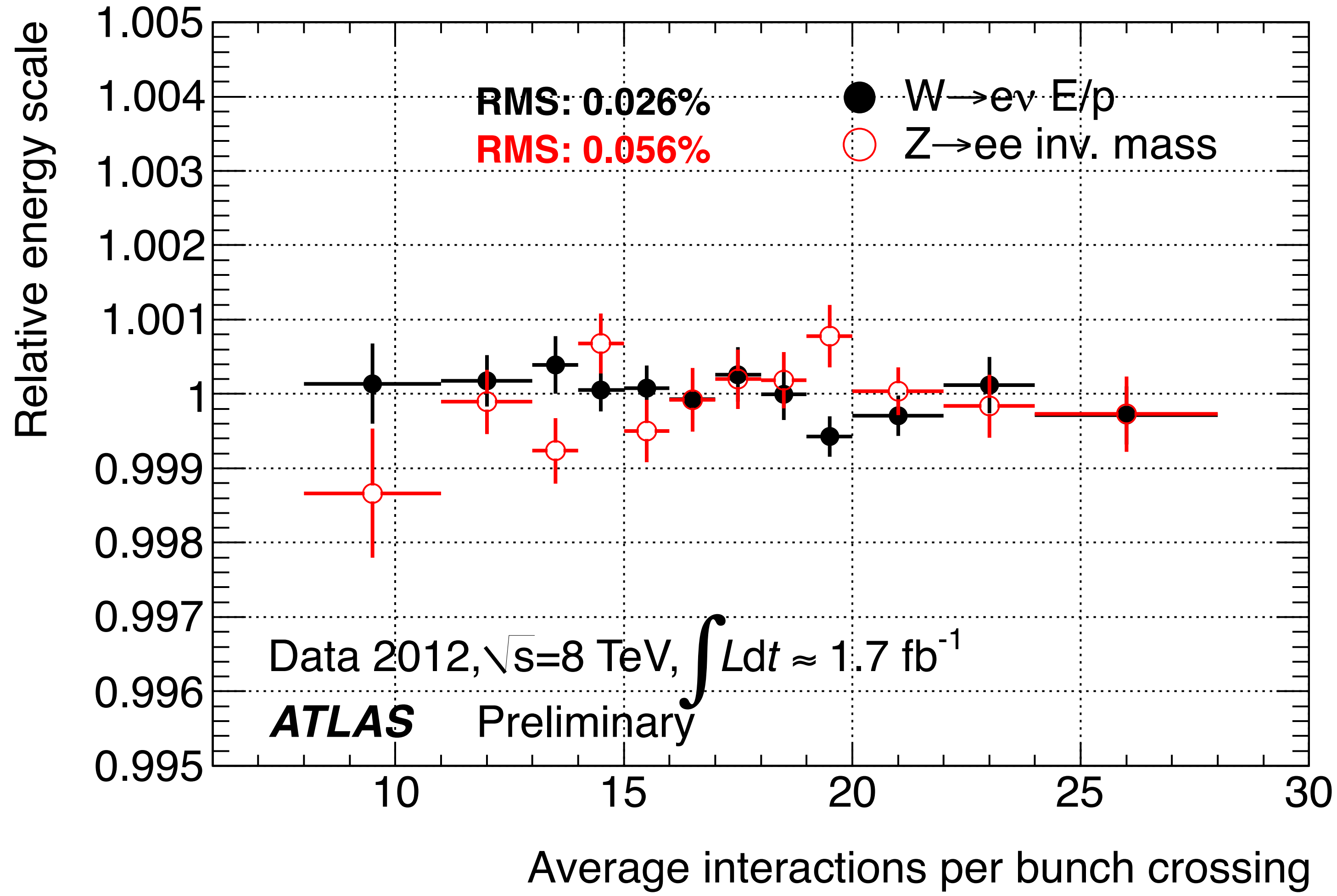


Electron identification efficiency dependence on pileup (update)

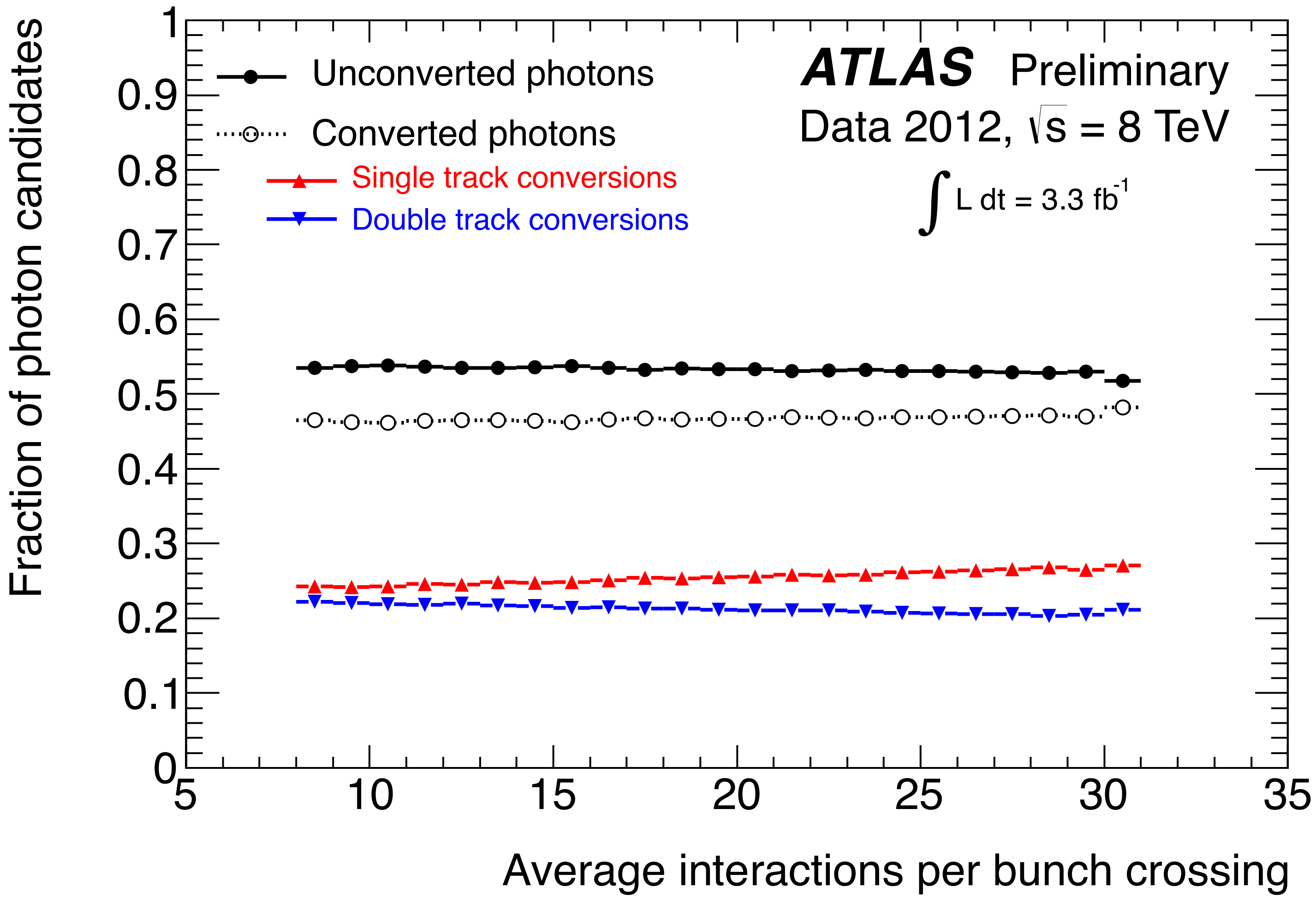




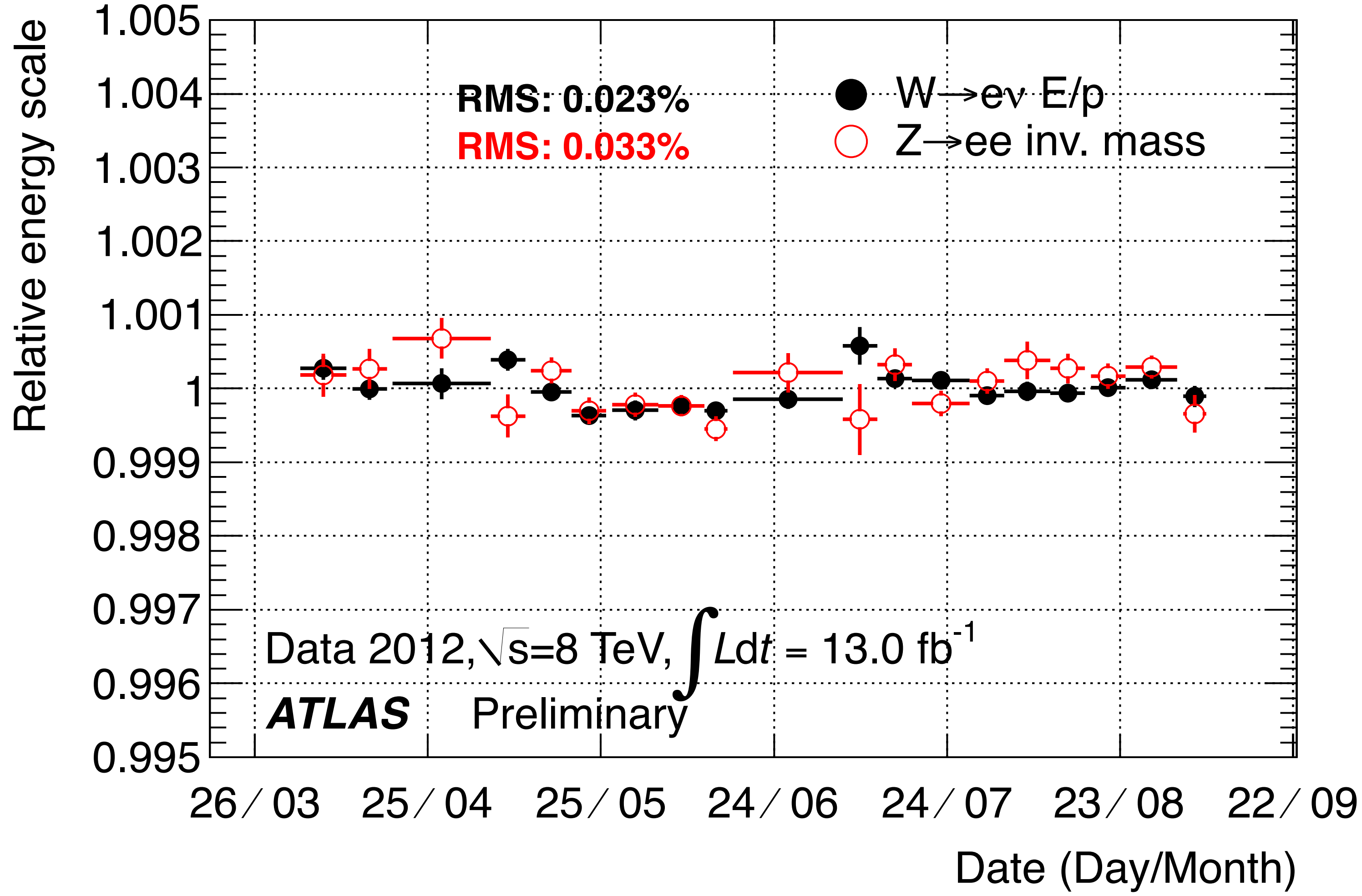
Electron energy response stability with pile-up in 2012 data



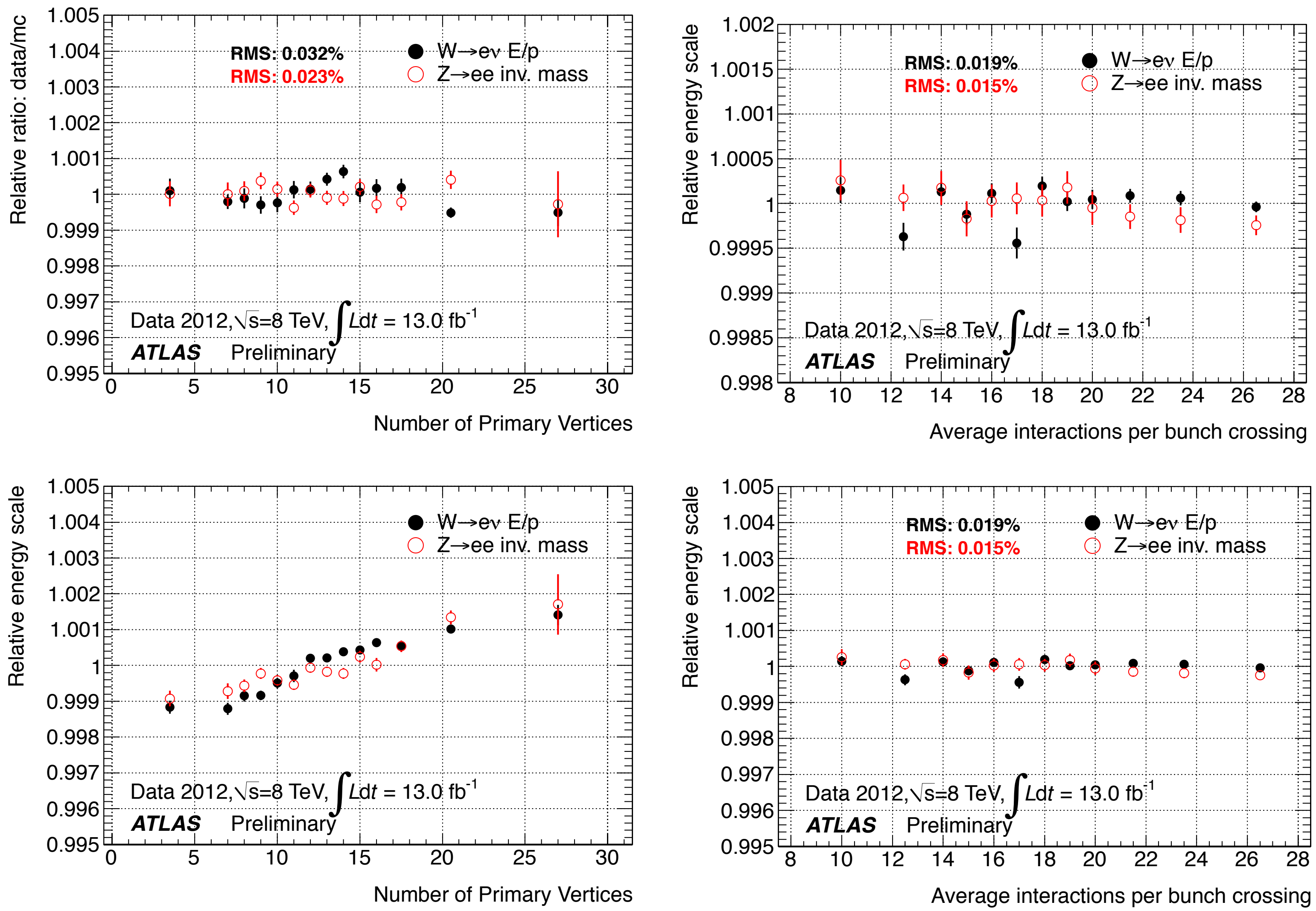
Stability of photon conversion reconstruction with pile-up



Electron energy response stability with time in 2012 data with 13 fb-1



Electron energy response stability with pile-up in 2012 data with 13 fb-1



Z->llgamma 2012 plots