Overview of electrons and photons energy calibration at ATLAS experiment

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Fábio L. Alves

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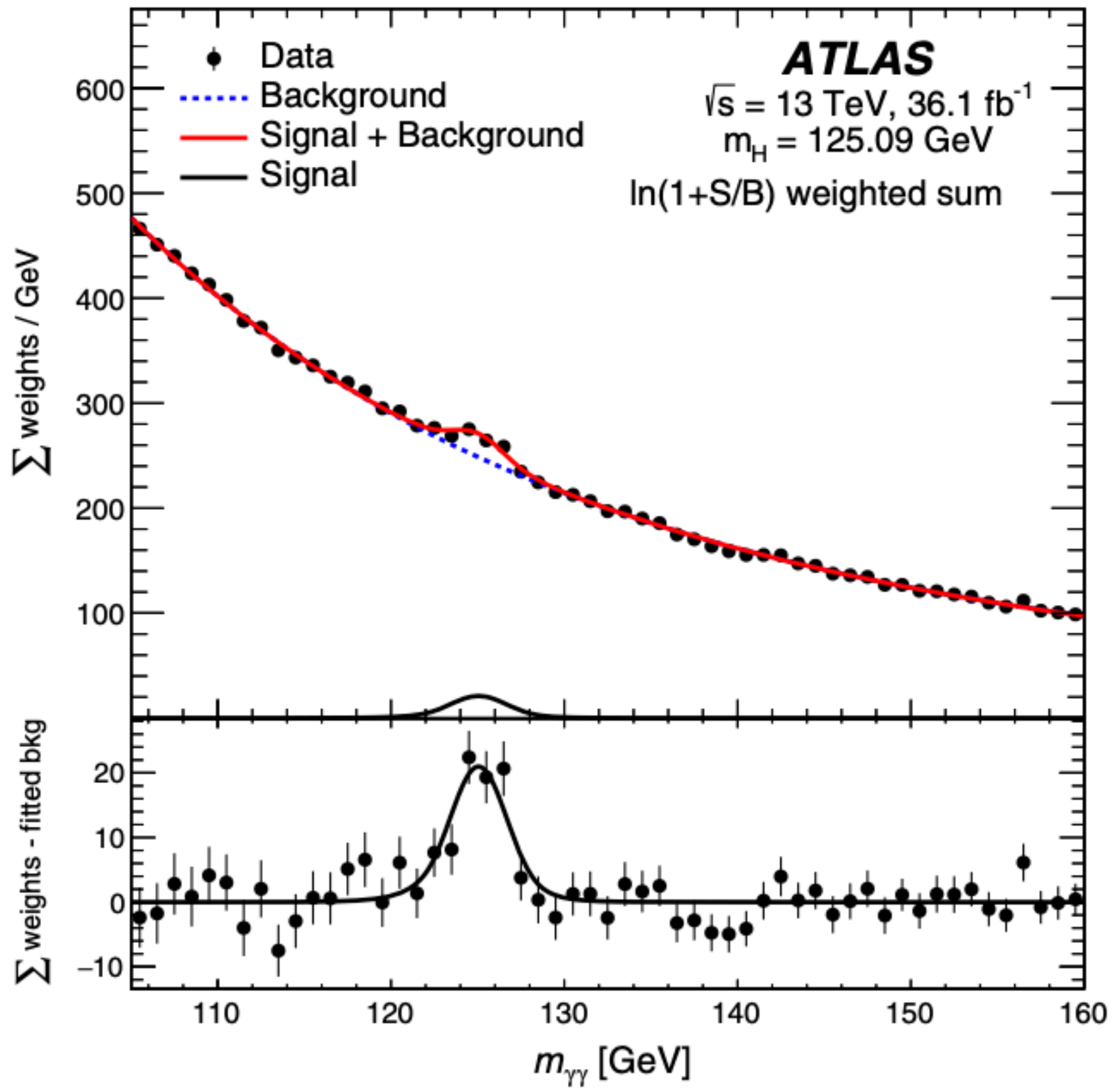
Motivation

✦ **Why the precise electron/photon energy calibration is needed?**

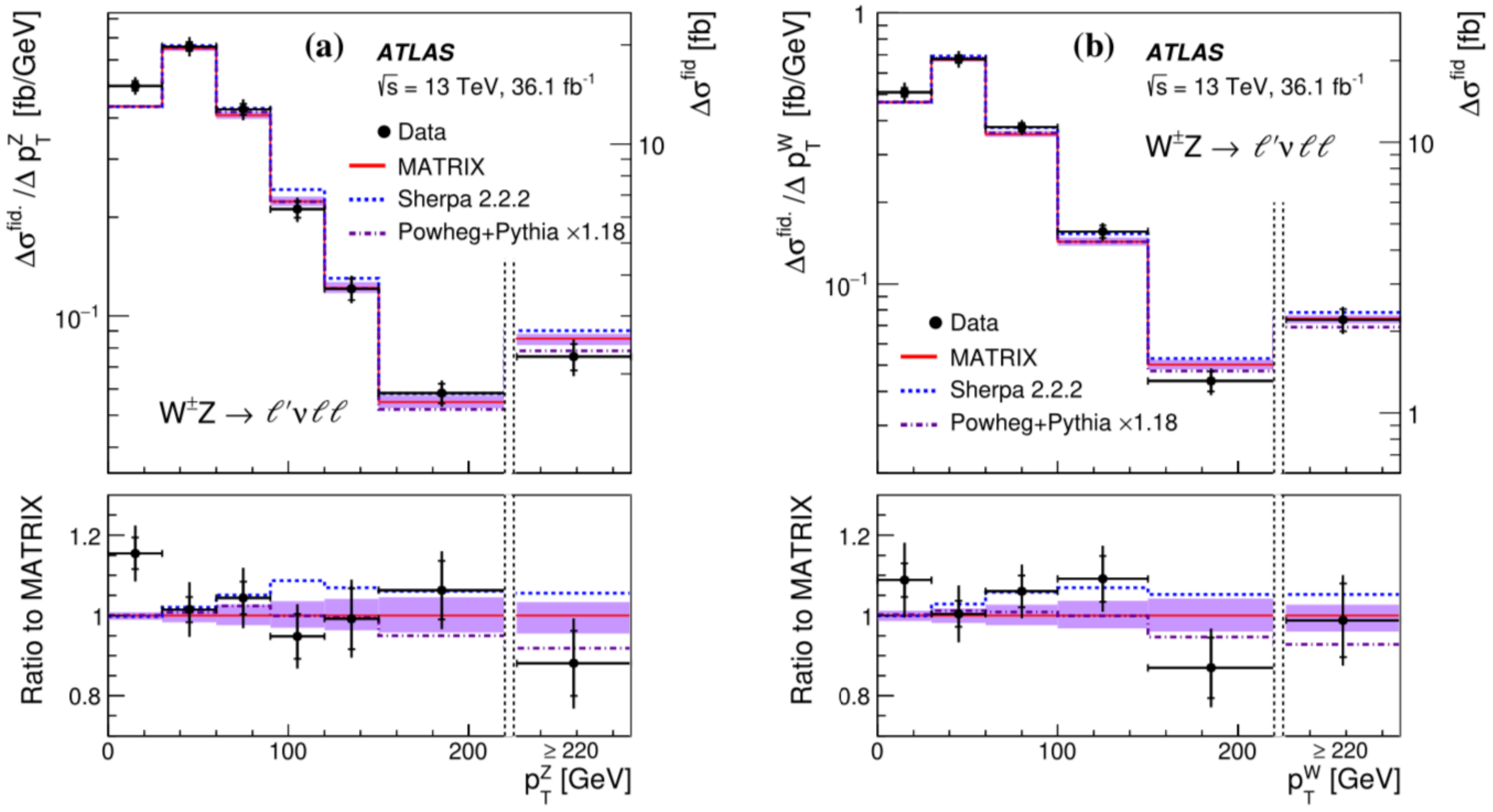
- Very important to be properly estimated for many ATLAS analysis, specially for precise physics measurements:
  - Higgs boson mass measurement, Electroweak processes measurements

Results @ L = 36fb-1 (2015-2016)

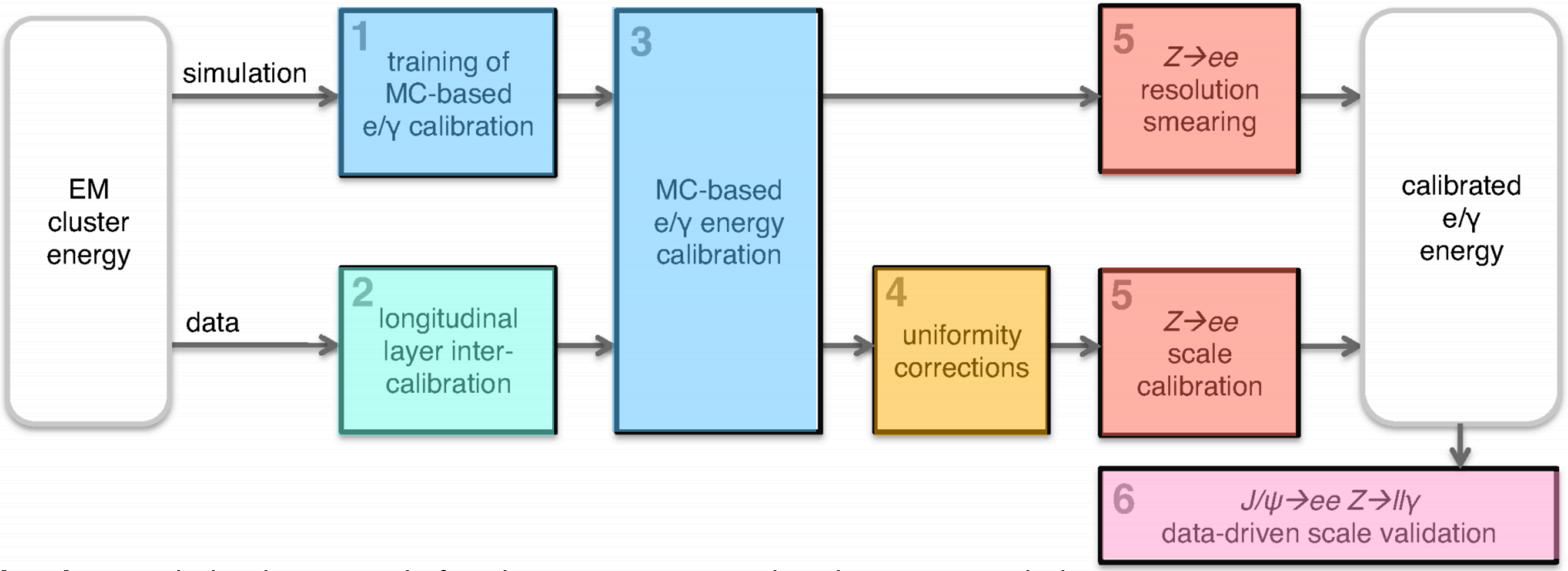
H(yy) mass measurement



Measurement of W(+/-)Z production cross sections



Electrons & photons calibration scheme



1,3	**MC-based calibration**: optimised separately for electrons, converted and unconverted photons • assumes that the detetor geometry and material are well described in simulation
2	**Layer-intercalibration (E1/E2)**: equalization of the energy scale in data with respect to MC due to the segmented EM longitudinally • probed with Z(mumu) decays and cross-checked with electrons (Z(ee) decays)) + Pre-sampler energy scale estimation
4	**Uniformity and Stability corrections**: corrections for residual non-uniformities modeled by the simulation • e.g: non-optimal HV regions, inter-module widening (IMW),…
5	**Correction for residual Data/MC differences**: applying energy scale and resolution factors to Data and MC • Z peak comparison for factors extraction
6	**J/psi(ee) and Z(ee)y**: sample processes used as cross-checks

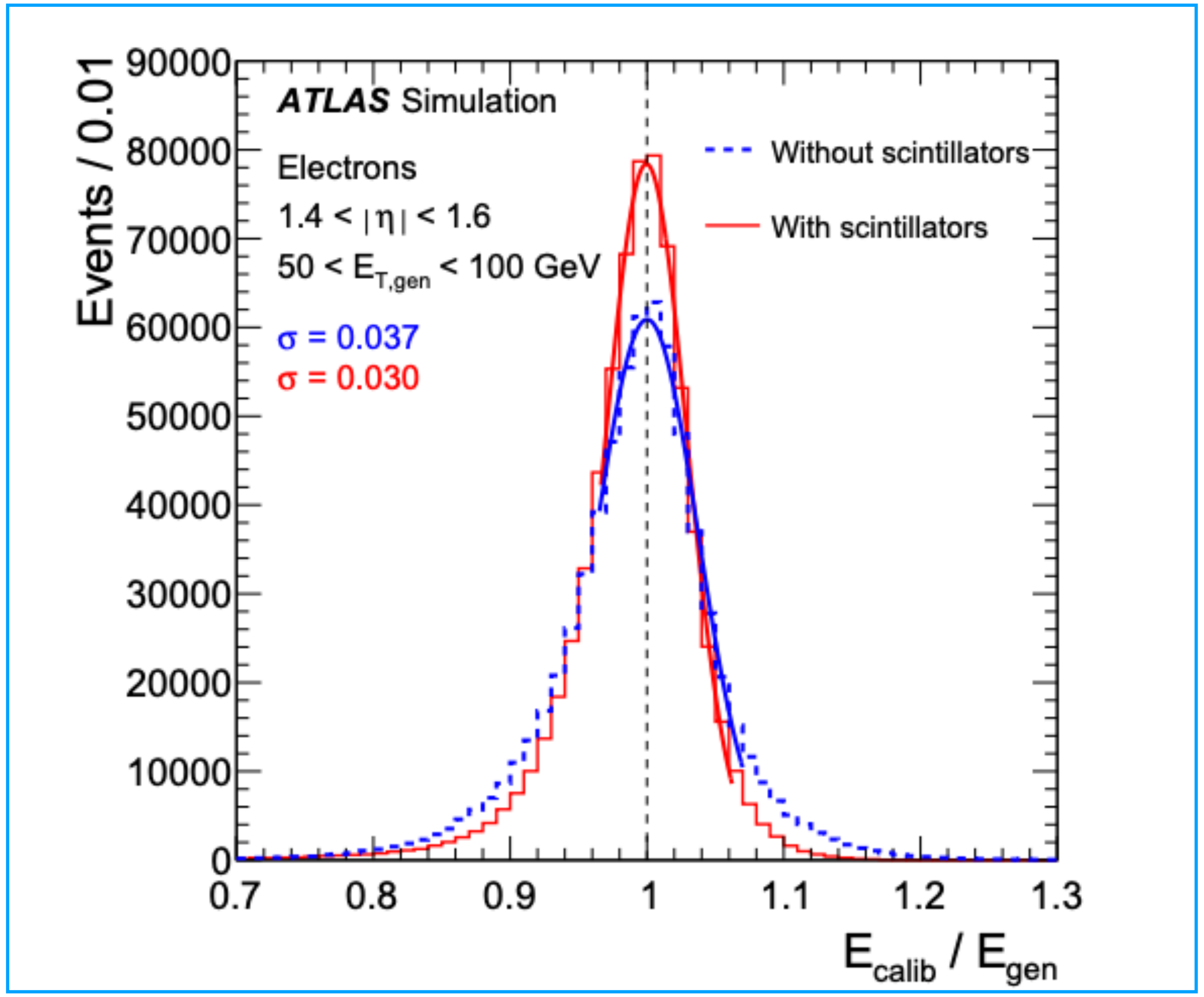
MC-based calibration

✦ **Electron/photons energy measured from the EM reconstructed clusters**

- energy loss due to: material upstream in the EM, neighboring cells and energy deposition beyond the EM

✦ **Single correction derived with Multivariate Technique Algorithm (MVA)**

- Boosted Decision tree (BDT) using as input variables:
  - energy deposited in the calorimeter and Pre-sampler (PS), ratio of the energy deposited in E1 and E2 layers of EM, eta, cell index, eta and phi positions with respect to cell edge
  - Converted photons: radius of the photon conversion in the transverse plane and track properties associated to the conversion
  - Transition region (1.4 <|eta|<1.6):E4 scintillators informations are used
  - **Input samples for training**: MC single electrons, converted and unconverted photons



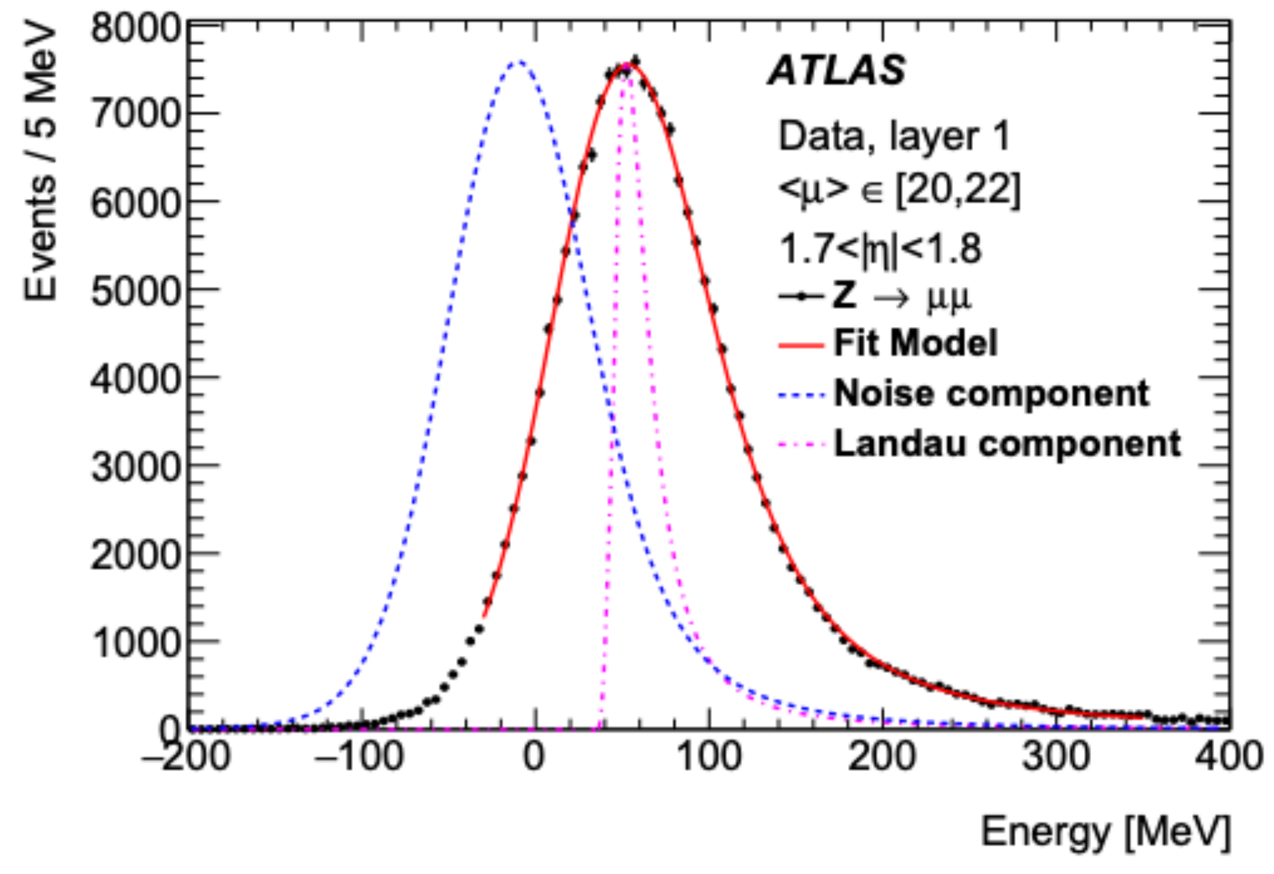
✦ *Energy resolution performance is verified with the ratio between Ecalib (calibrated electron energy) and Egen (generated electron energy):*

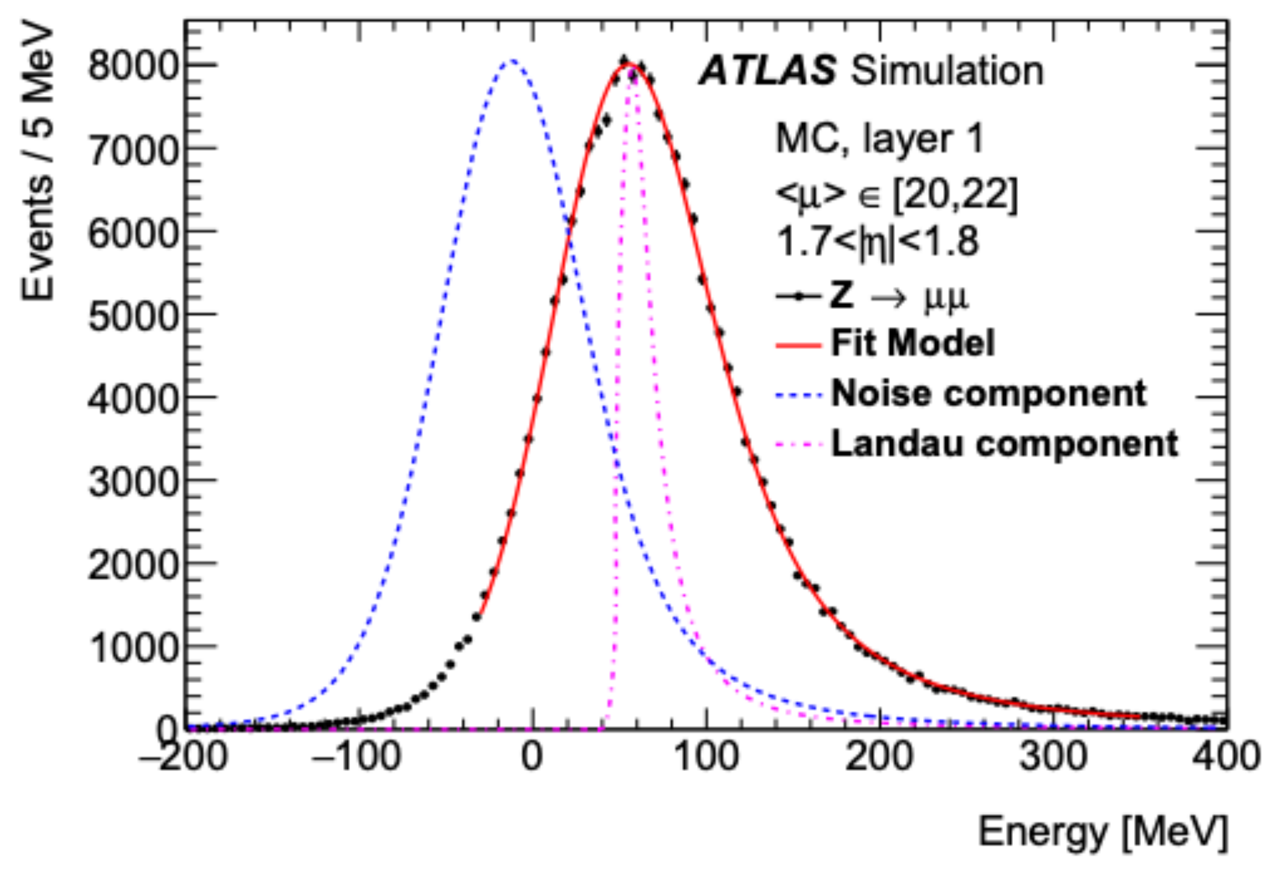
- **ET range (50-100) GeV**:
  - largest improvement for electrons (~20%)
  - improvement of ~5% to unconverted photons

Correction on data: E1/E2 layer inter-calibration

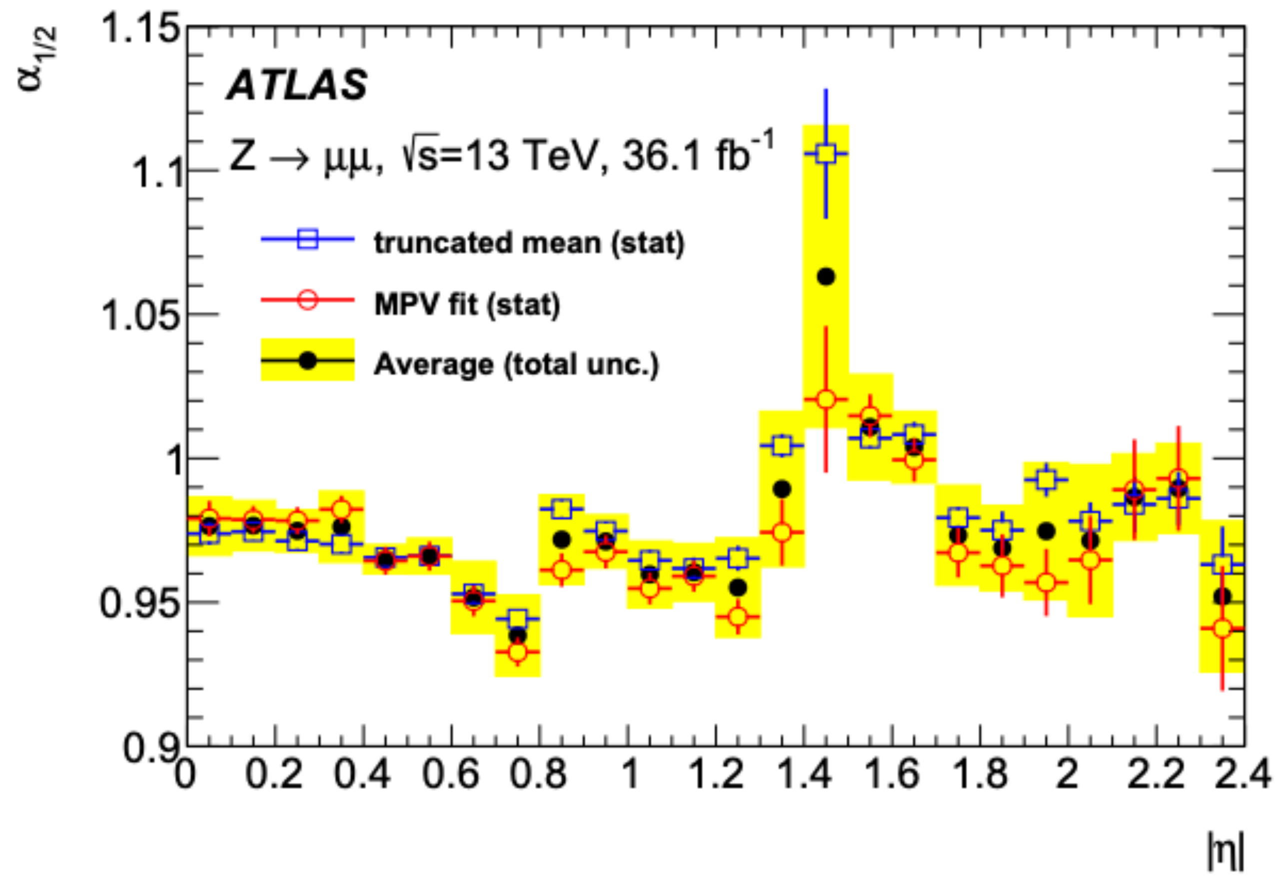
- **E1/E2 layer inter-calibration is performed with muons**
  - Muons energy deposition are insensitive to the amount of passive material upstream of the EM calorimeter
    - direct probe for the energy response estimation
  - Calibration factor estimation:

$$\alpha_{1/2} = \frac{E_{1/2}^{Data}}{E_{1/2}^{MC}}$$





- **Fit Method (Most Probable Value) and Truncated Mean Method (TMT)**
  - Fit method:
    - Muon energy distribution is parametrized with a convolution function between Landau distribution + noise distribution
      - noise distribution is estimated on samples (Data and MC) on zero bias events (dependency on <mu> and |eta| are checked)
  - Truncated Mean Method:
    - mean extracted in restricted window to minimize the sensitivity to the tails of the distribution
- **Cross-checks are performed using two additional methods with Z(ee) decays:**
  - invariant mass in di-electron decays and E/p (reco cluster energy over momentum of associated track) distributions



- ***Uncertainty range on measurement with muons*:**
  - Barrel region: 0.7% to 1.5%
  - End-cap region: 1.5% to 2.5%
    - with exception of the transition region between barrel and end-cap EM calorimeter regions

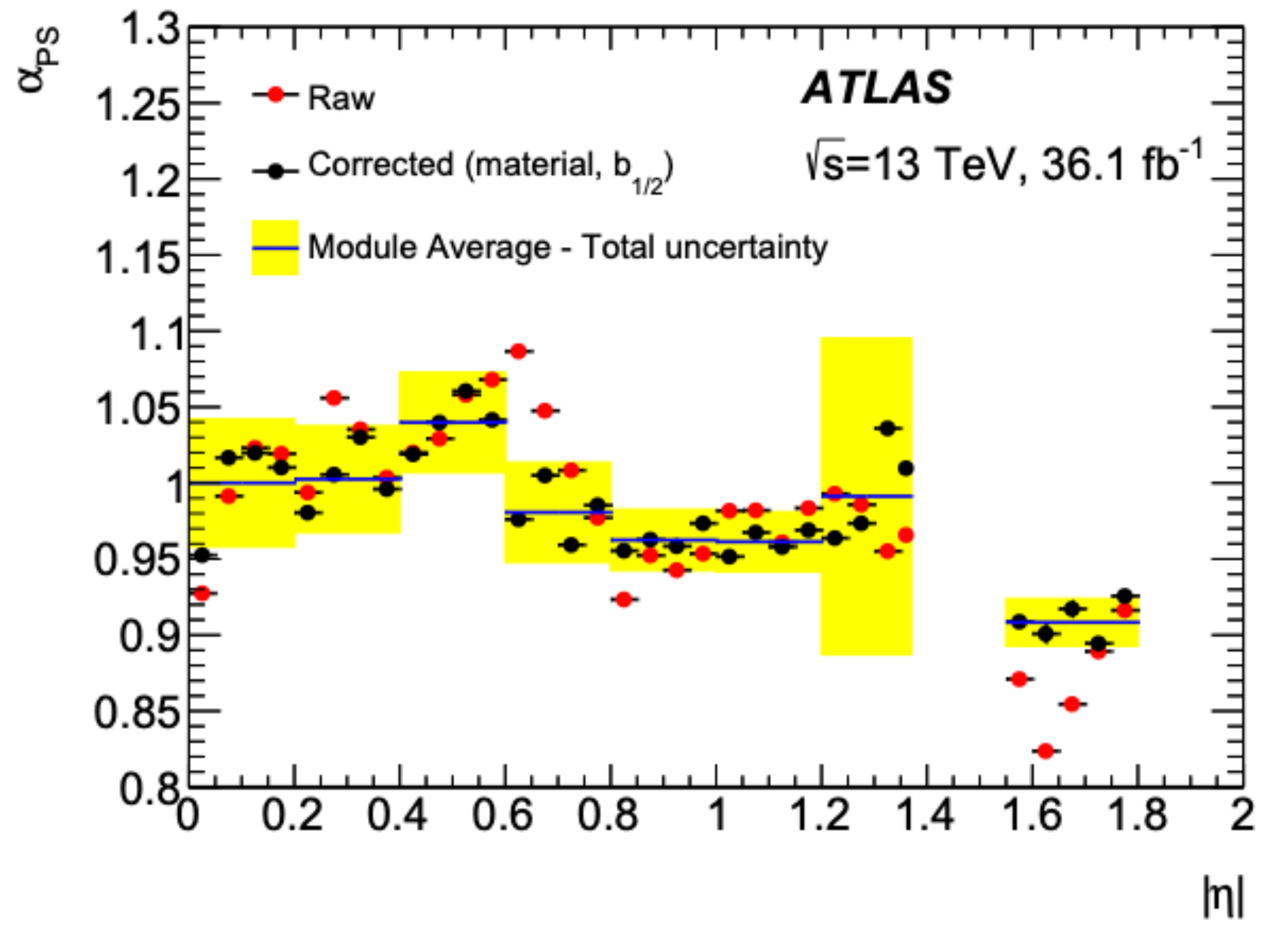
Correction on data: Pre-sampler (PS) energy scale

✦ **Pre-sampler energy scale calibration measured as the ratio of PS energy in data and MC**

- Measured energy in PS from for electrons from Z(ee) decays sensitive to:
    - amount of material in front of the PS
- Procedure: study the correlation between the PS energy deposit (E0) and ratio of the energies deposited in the first two layers (E1/2)

$$\alpha_{PS} = \frac{E_0^{Data}(\eta)}{E_0^{MC}(\eta)} \times \frac{1}{1 + (A(\eta)\frac{E_{1/2}^{Data}(\eta)}{E_{1/2}^{MC} b_{1/2}(\eta)} - 1)}$$

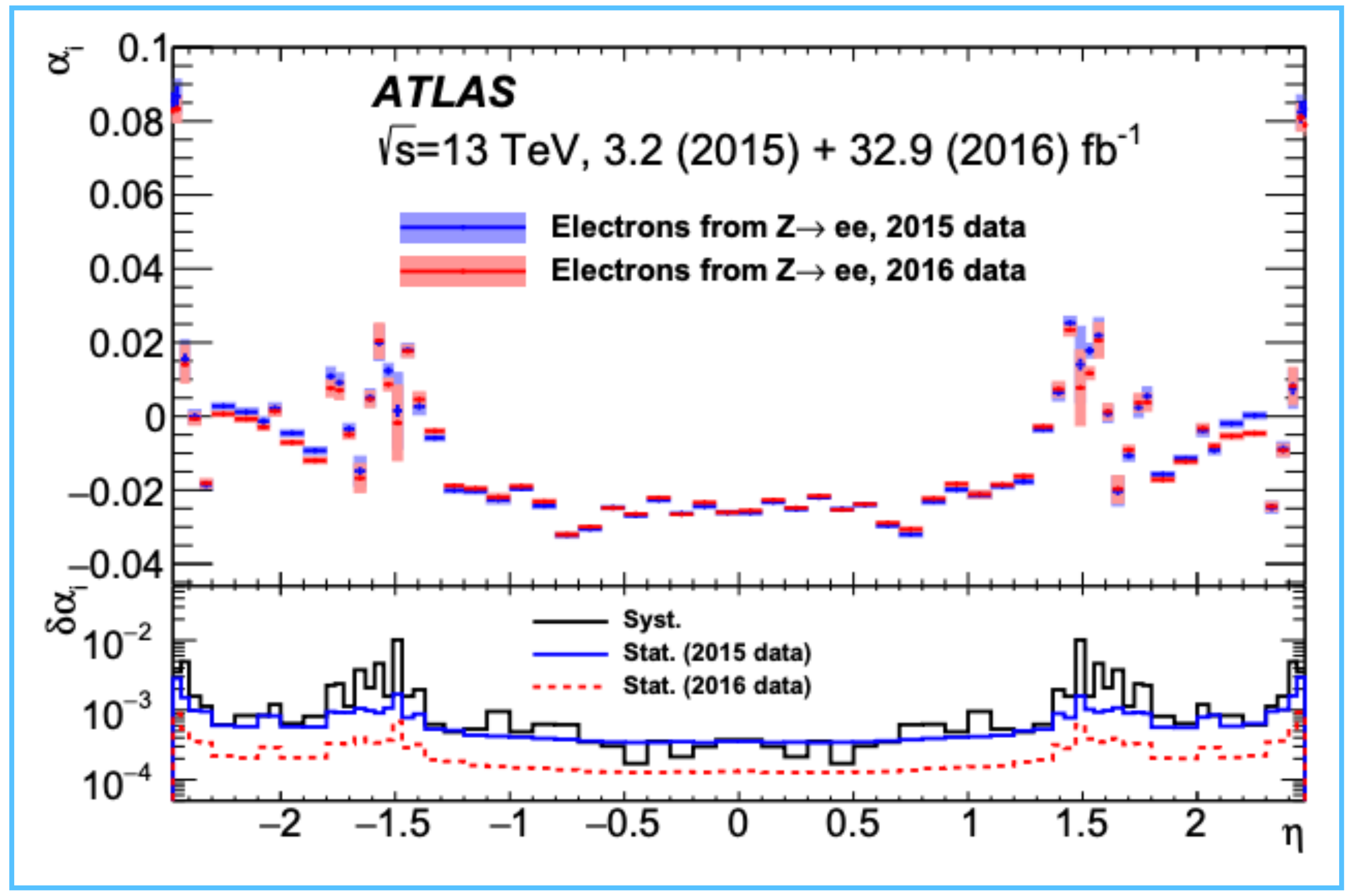
- A: correlation between E0 and E1/2 for changes in material
- b1/2: correction for E1/2 of any mis-modelling due to material between PS and calorimeter
- *Uncertainties on α_{PS} varies between 3% and 1.5% depending on η*

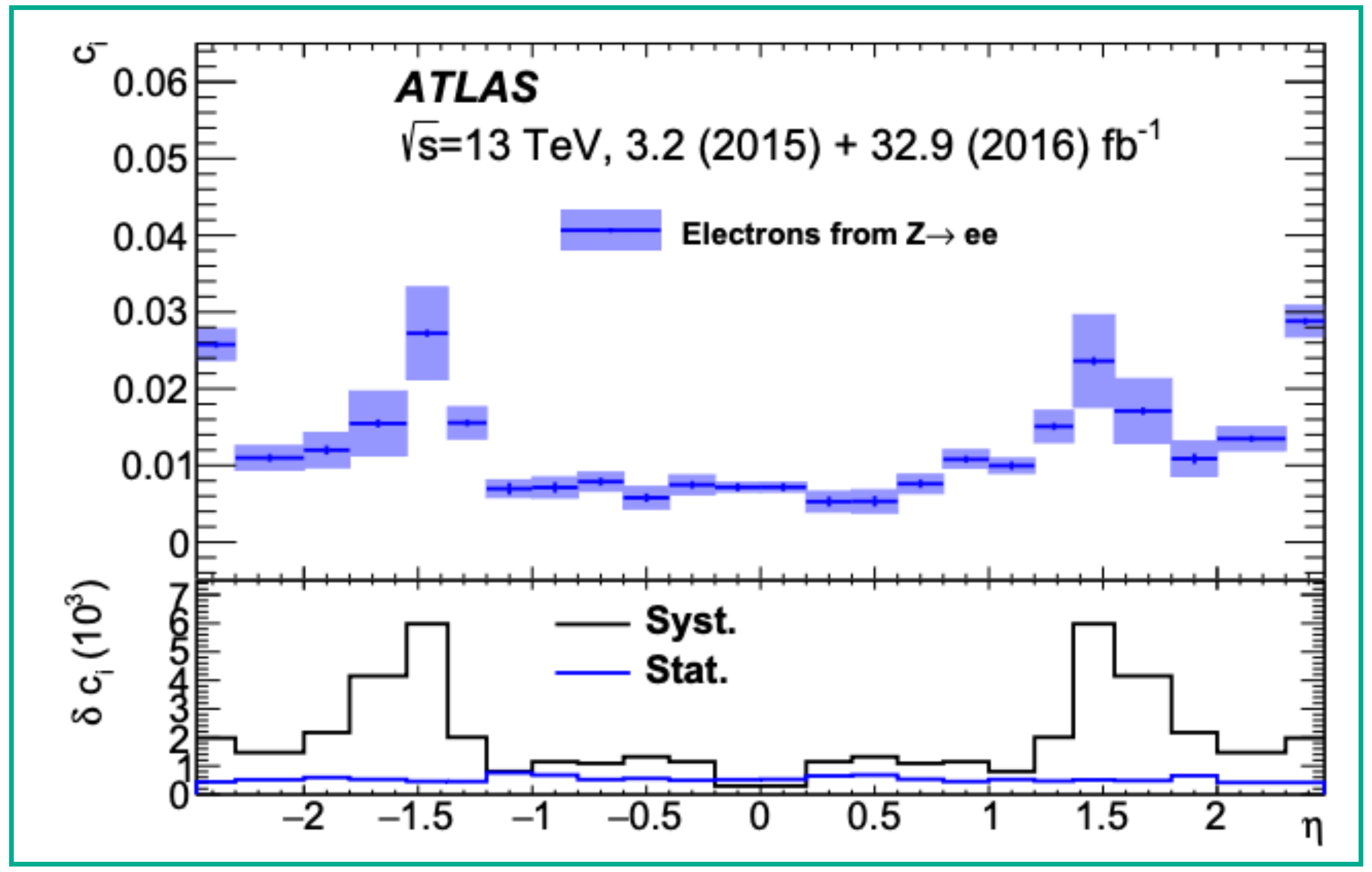


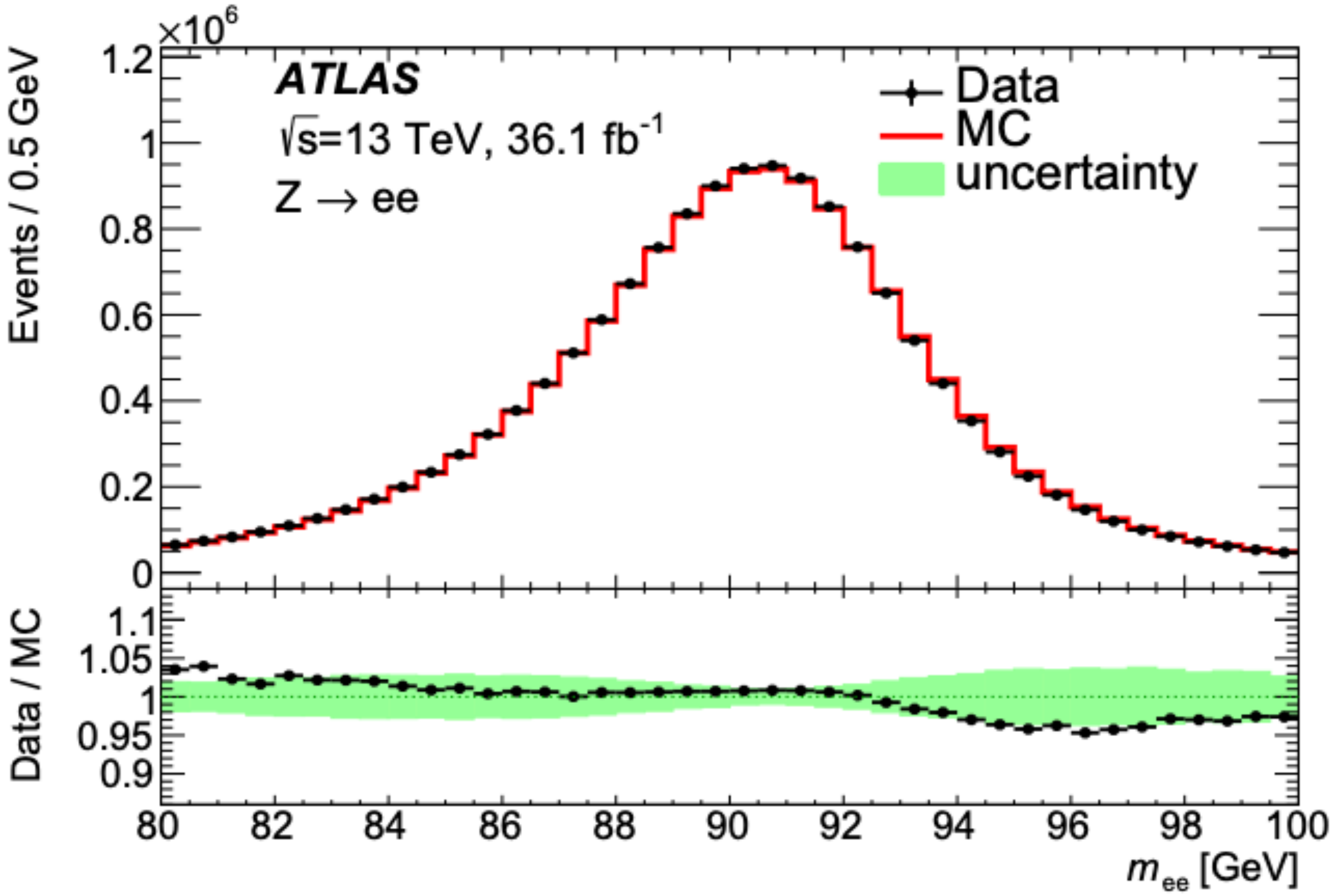
Energy scale and resolution

- **Energy Scale**
  - $E_i^{Data} = E^{MC}(1+\alpha_i)$
    - α_i correction from chi2 minimization (applied on data)
    - *total systematic uncertainty < 0.2%*
- **Energy Resolution**
  - $\left(\frac{\sigma_E}{E}\right)^{Data} = \left(\frac{\sigma_E}{E}\right)^{MC} \oplus c_i$
    - *c_i correction from chi2 minimization* (applied on simulation)
    - *< 1% in barrel region; 1% and 2% in end-cap region and slightly larger in the transition region*
    - *total systematic uncertainty is ~0.1% in barrel region; ~0.3% in the end-cap region and 0.6% in the transition region*

Fair agreement between the m(ee) in data and MC within the uncertainties



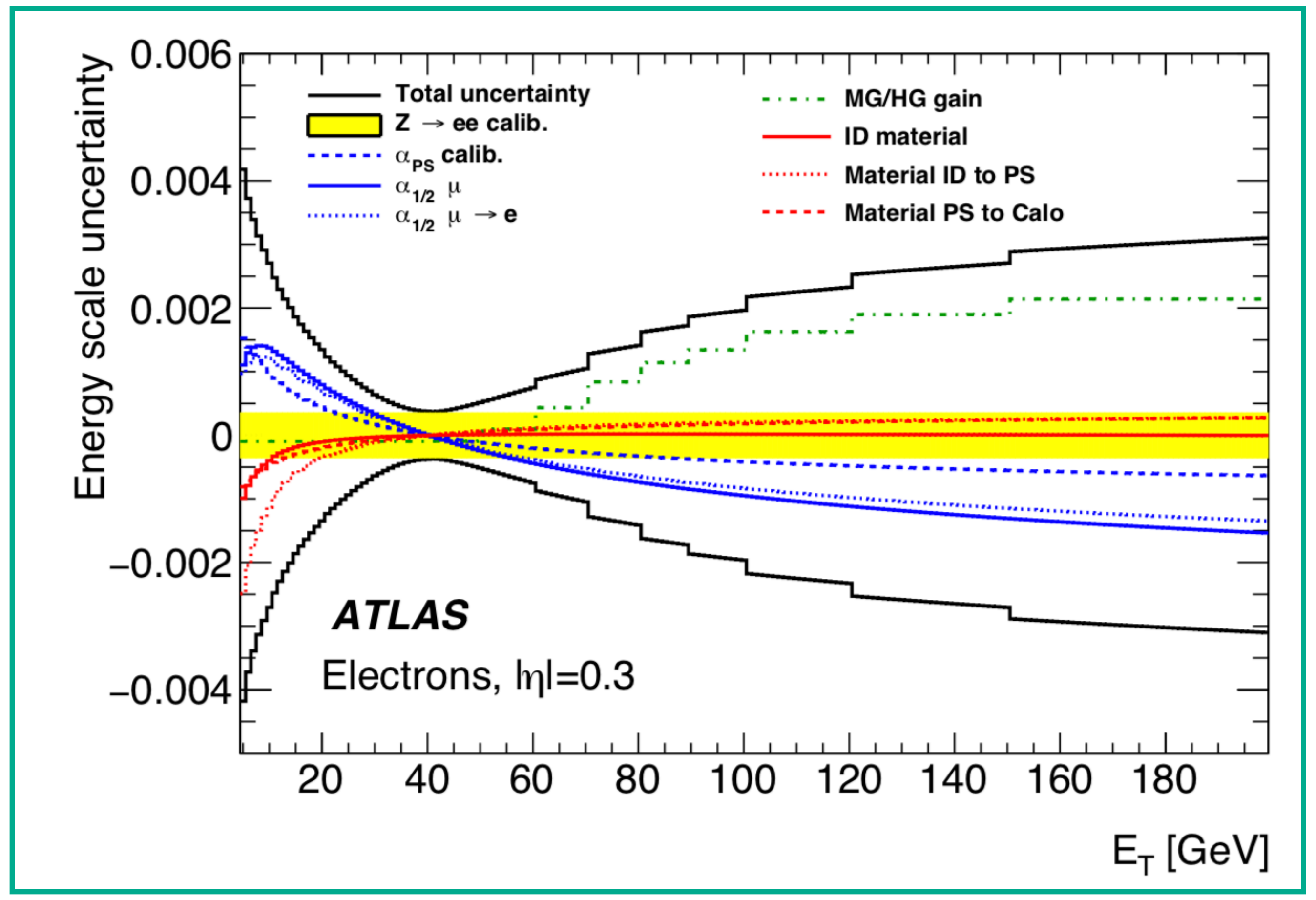


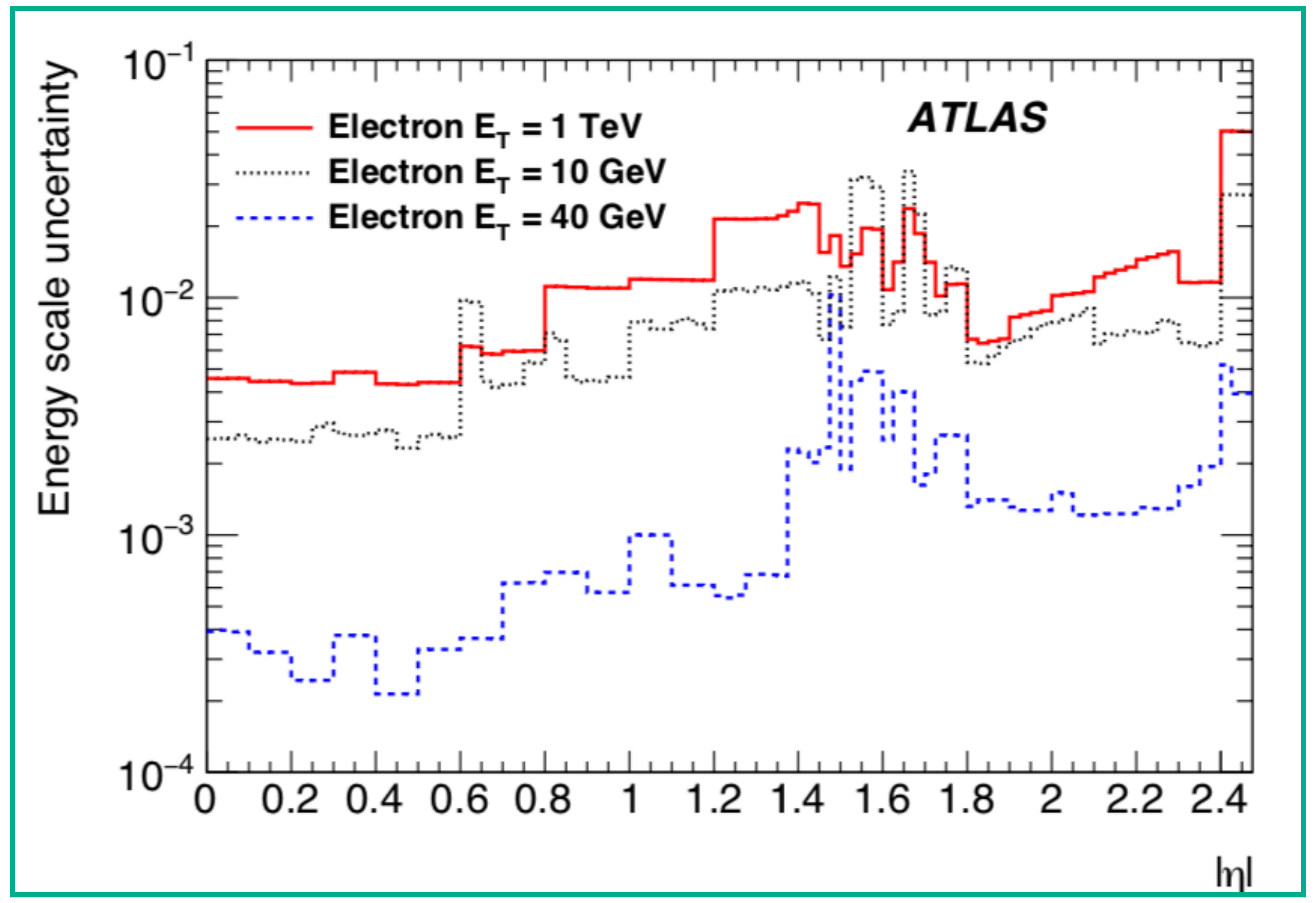


Systematic uncertainties

✦ **Systematic Uncertainties on the scale energy**

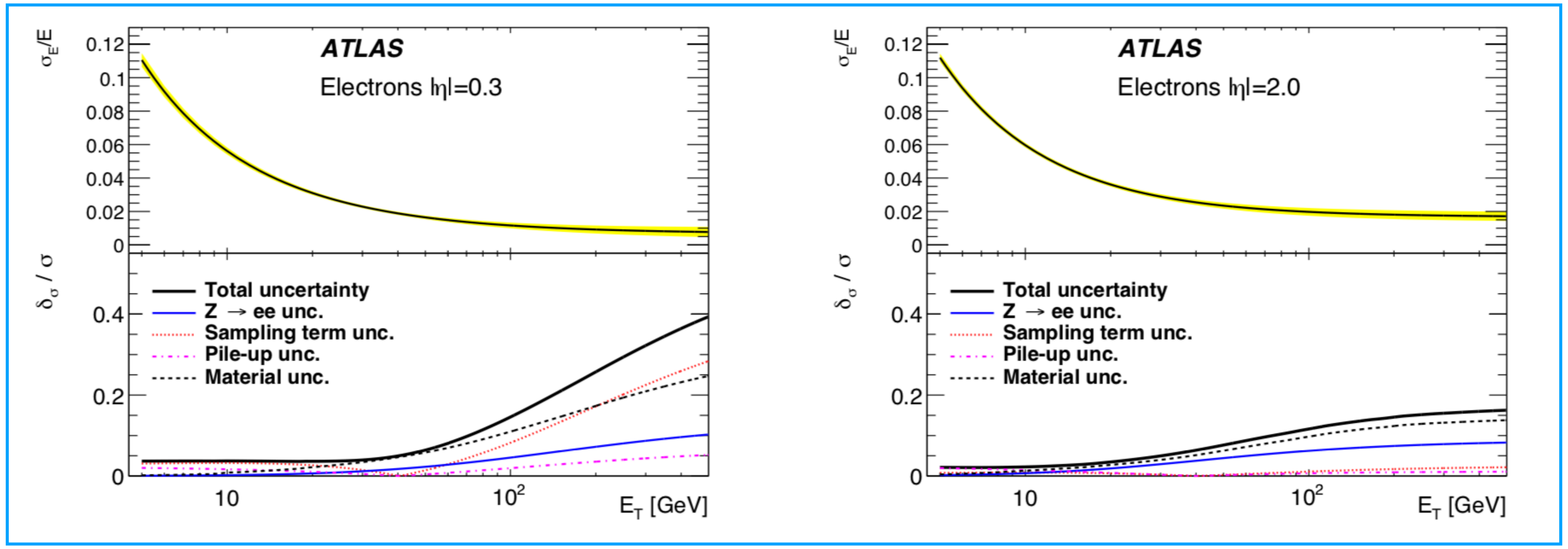
- Set of 64 uncertainty variations (in transverse energy and pseudo-rapidity)
  - Zee calibration + non-linearity
  - Layer inter-calibration (E1/E2 and PS)
  - E4 scintillators in transition region
  - Amount of material in different eta region of the detector
  - Lateral shower shape development
  - Conversion reconstruction





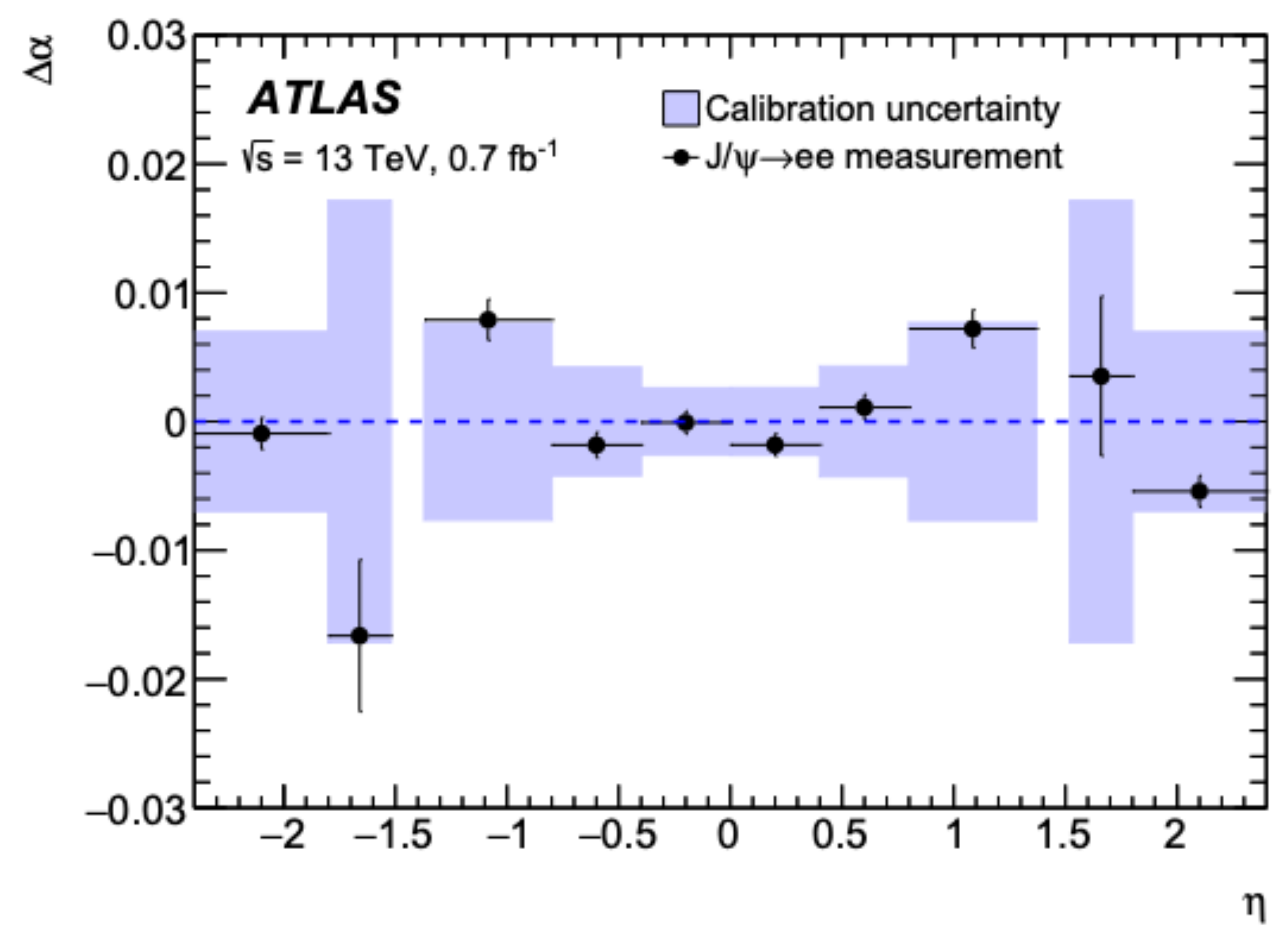
✦ **Systematic Uncertainties on the energy resolution**

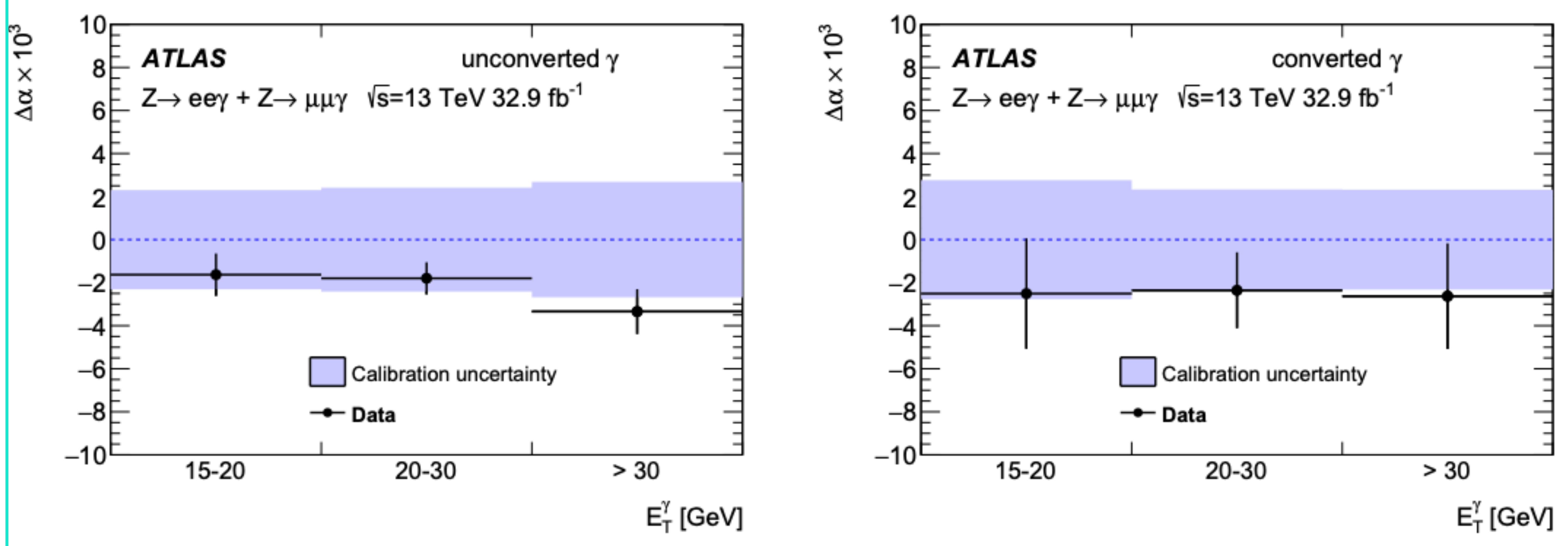
- Shower and sampling fluctuations in the calorimeter
- Energy loss before the calorimeter
- Effect of electronics and pile-up noise
- Residual non-uniformities affecting the energy measurement
- ***Electrons/Photons (30-60GeV), energy resolution precision from 5% to 10%***
- ***Relative uncertainty in the energy resolution reaches 20% to 50%***



Cross-checks with $J/\psi(ee)$ and $Z(ee)\gamma$ decays

- **$J/\psi(ee)$ events to probe the energy scale of low energy electrons**
  - full calibration procedure + energy scale from Z(ee) is applied
  - $\Delta\alpha$ (residual energy scale difference) extracted in data and MC:
    - peak position of invariant mass
  - ***$\Delta\alpha$ is consistent with zero: good agreement between the measurement and calibration procedure***
    - validates the calibration procedure to extract nominal scales + estimate systematic uncertainties over a wide range of electron energies





- **Radiative Z decay used to cross-check the energy resolution of photons**
  - Converted and uncovered photons as well as ee and mumu channel studied separately
    - ee + mumu channel result is combined
  - Corrections from Z(ee) applied on electrons/photons and residual energy scale factors are derived from data/MC comparison
  - ***$\Delta\alpha$ is consistent with zero within the uncertainties in the measurement***
    - measurement statistical limited

Summary

- ***The calibration of energy measurement for electrons and photons for early Run2 data (2015-2016) @ 36fb-1 has been presented***
  - optimization of energy measurement in MC by using variables related to shower development and photon conversions
  - gap scintillators (E4) information provide improvement in the energy resolution
  - E1/E2 measurement with accuracy from 0.7% to 2.5% while PS measurement ranging from 1.5% and 3%
  - energy scale measurement accuracy is found to be between 0.03% to 0.2% depending on |eta| while the constant c extracted from resolution is <= 1% in barrel and 1-2% in end-cap region
  - calibration procedure accuracy is verified with cross-checks with $J/\psi(ee)$ and $Z(ee)\gamma$ events for low-energy electrons and good agreement is found
- ***A few words on full Run2 measurement…***
  - ✓ *Reduction of the energy scale and resolution systematics*
    - benefit to H(yy) mass measurement, H(yy) couplings and W mass measurement
  - ✓ *Improvement of the electron forward calibration*
    - benefit Electroweak precision measurements

Thank you for the attention!

BACK-UP SLIDES

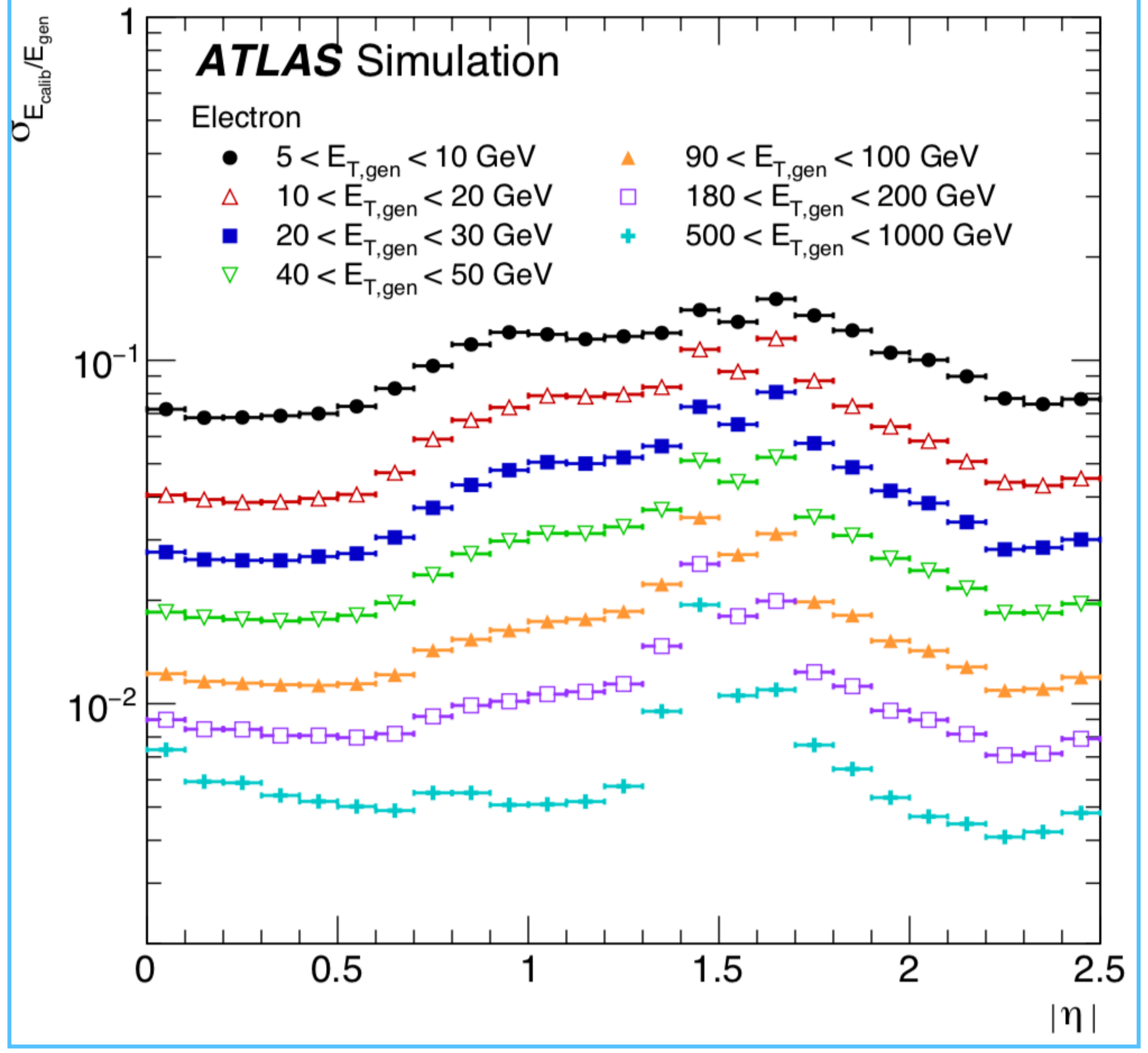
Summary of event selection

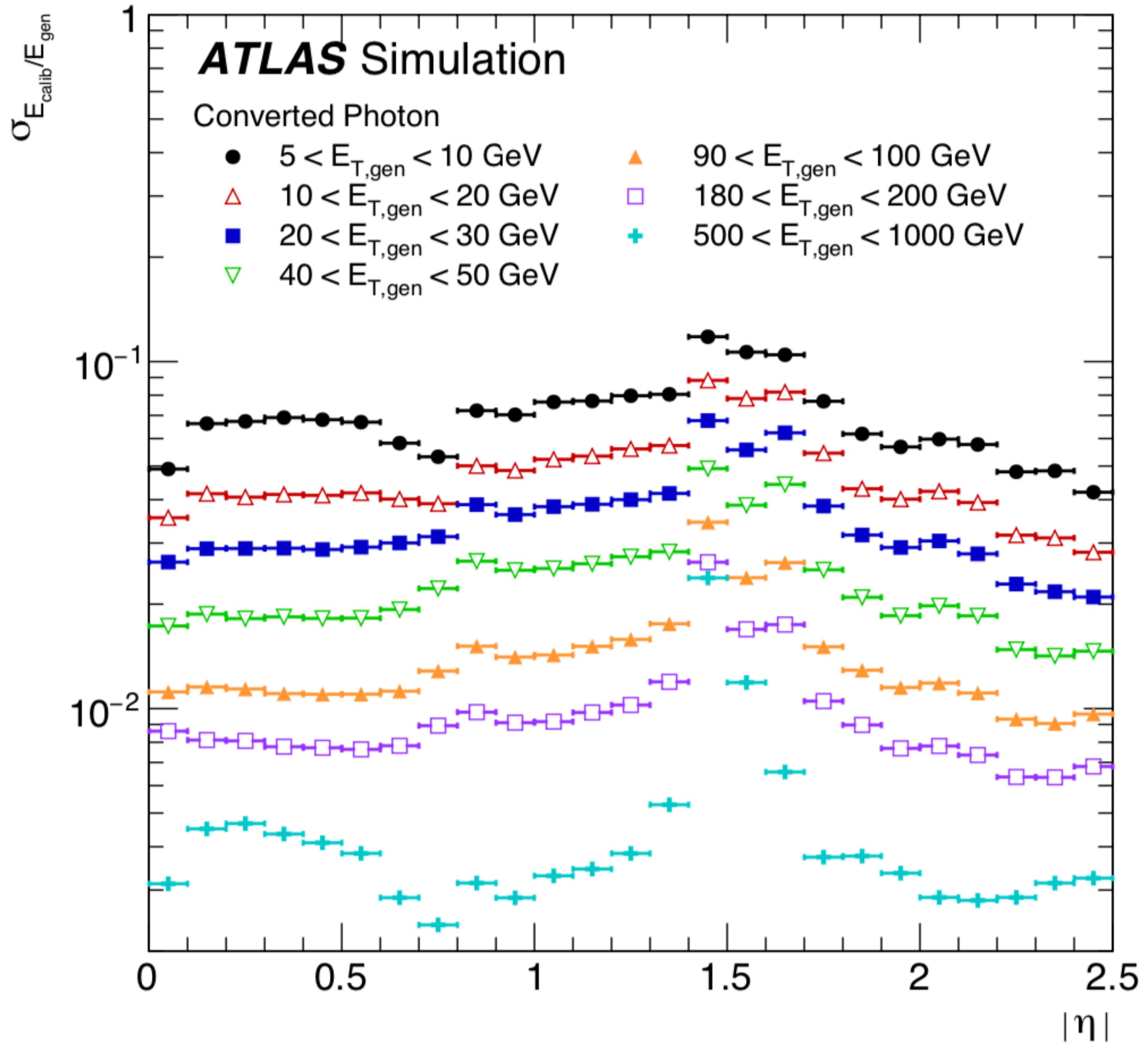
Table 1. Summary of the kinematic selections applied to the main samples used in the calibration studies and number of events fulfilling all the requirements described in the text in the 2015–2016 dataset, except for the $Z \to \ell\ell\gamma$ and inclusive photon samples, which use only data collected in 2016. The symbol ℓ denotes an electron or a muon.

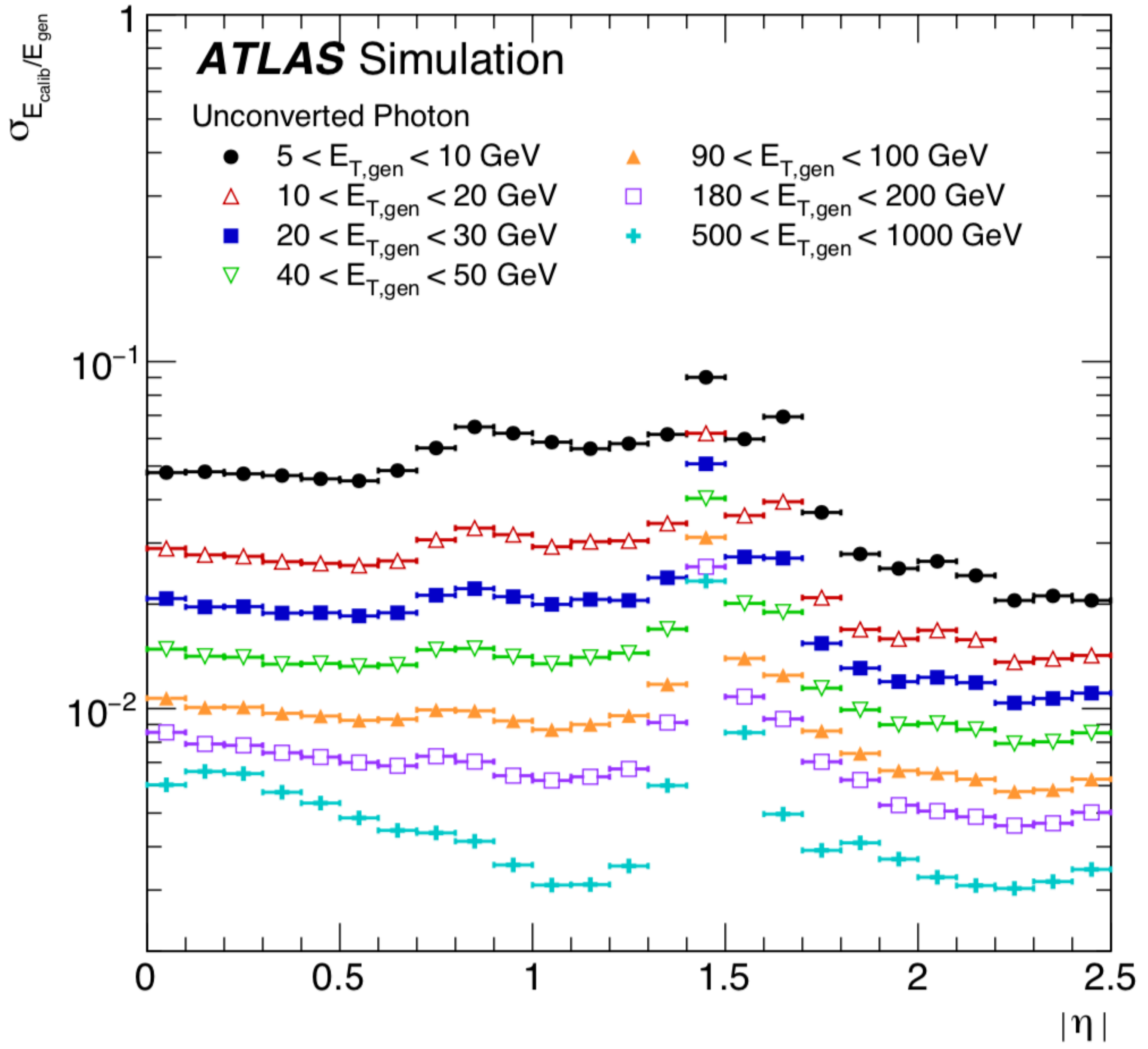
Process	Selections	N(events)
$Z \to ee$	$E_{\mathrm{T}}^{e} > 27$ GeV, $\lvert\eta^{e}\rvert < 2.47$	17.3 M
	$m_{ee} > 50$ GeV	
$Z \to \mu\mu$	$p_{\mathrm{T}}^{\mu} > 27$ GeV, $\lvert\eta^{\mu}\rvert < 2.5$	29.4 M
	$80 < m_{\mu\mu} < 105$ GeV	
$J/\psi \to ee$	$E_{\mathrm{T}}^{e} > 5$ GeV, $\lvert\eta^{e}\rvert < 2.4$, $2.1 < m_{ee} < 4.1$ GeV	60 k
$Z \to \ell\ell\gamma$	$E_{\mathrm{T}}^{e} > 18$ GeV, $\lvert\eta^{e}\rvert < 1.37$ or $1.52 < \lvert\eta^{e}\rvert < 2.47$,	27 k ($ee\gamma$)
	$p_{\mathrm{T}}^{\mu} > 15$ GeV, $\lvert\eta^{\mu}\rvert < 2.7$,	50 k ($\mu\mu\gamma$)
	$E_{\mathrm{T}}^{\gamma} > 15$ GeV, $\lvert\eta^{\gamma}\rvert < 1.37$ or $1.52 < \lvert\eta^{\gamma}\rvert < 2.37$	
	$\Delta R(\ell,\gamma) > 0.4$	
	$40 < m_{\ell\ell} < 80$ GeV	
Inclusive photons	$E_{\mathrm{T}}^{\gamma} > 147$ GeV, $\lvert\eta^{\gamma}\rvert < 1.37$ or $1.52 < \lvert\eta^{\gamma}\rvert < 2.37$	3.6 M

MC-based simulation (energy resolution)

- Energy resolution for **electrons** and **converted** and **unconverted photons** from the simulation

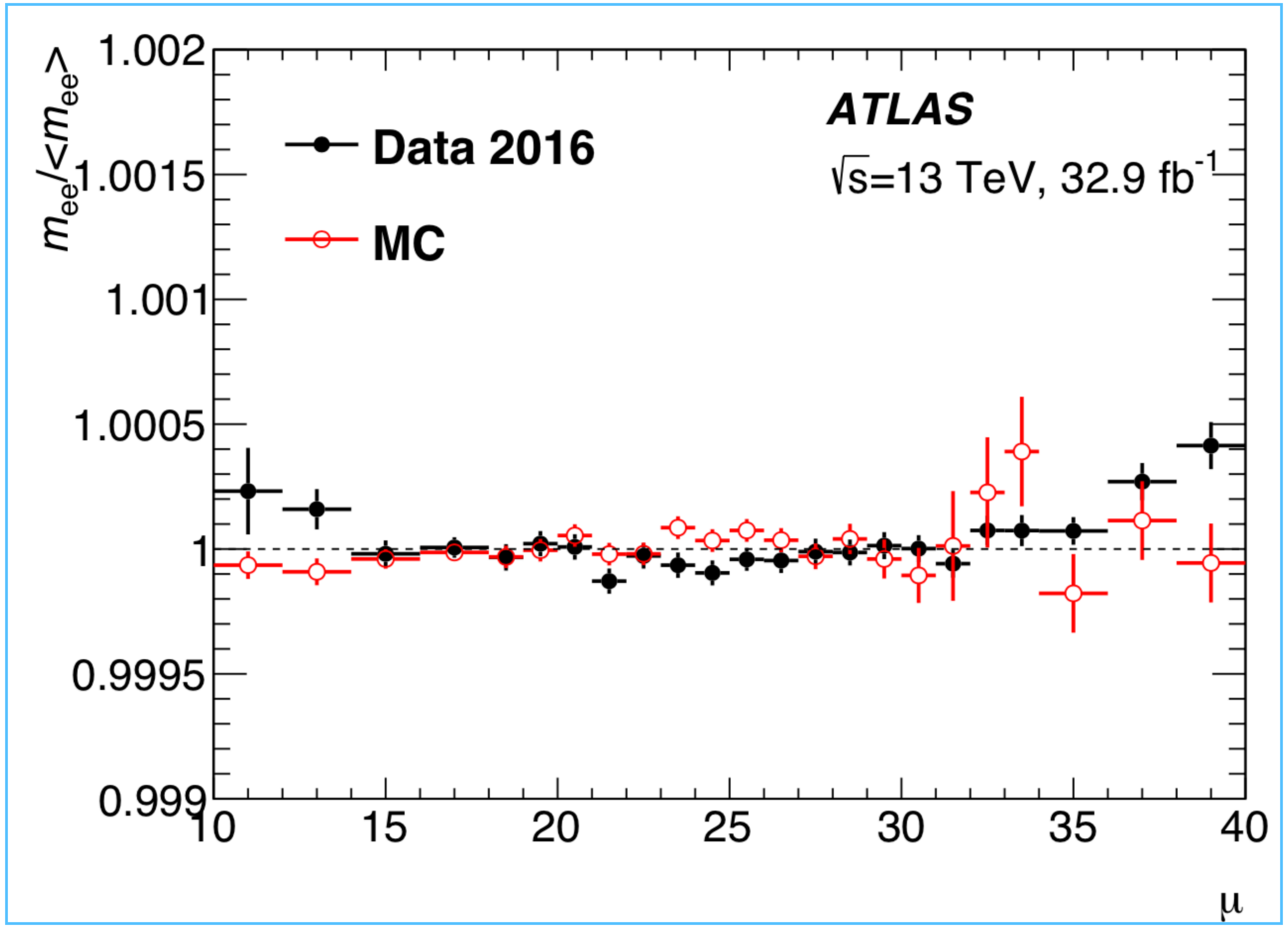


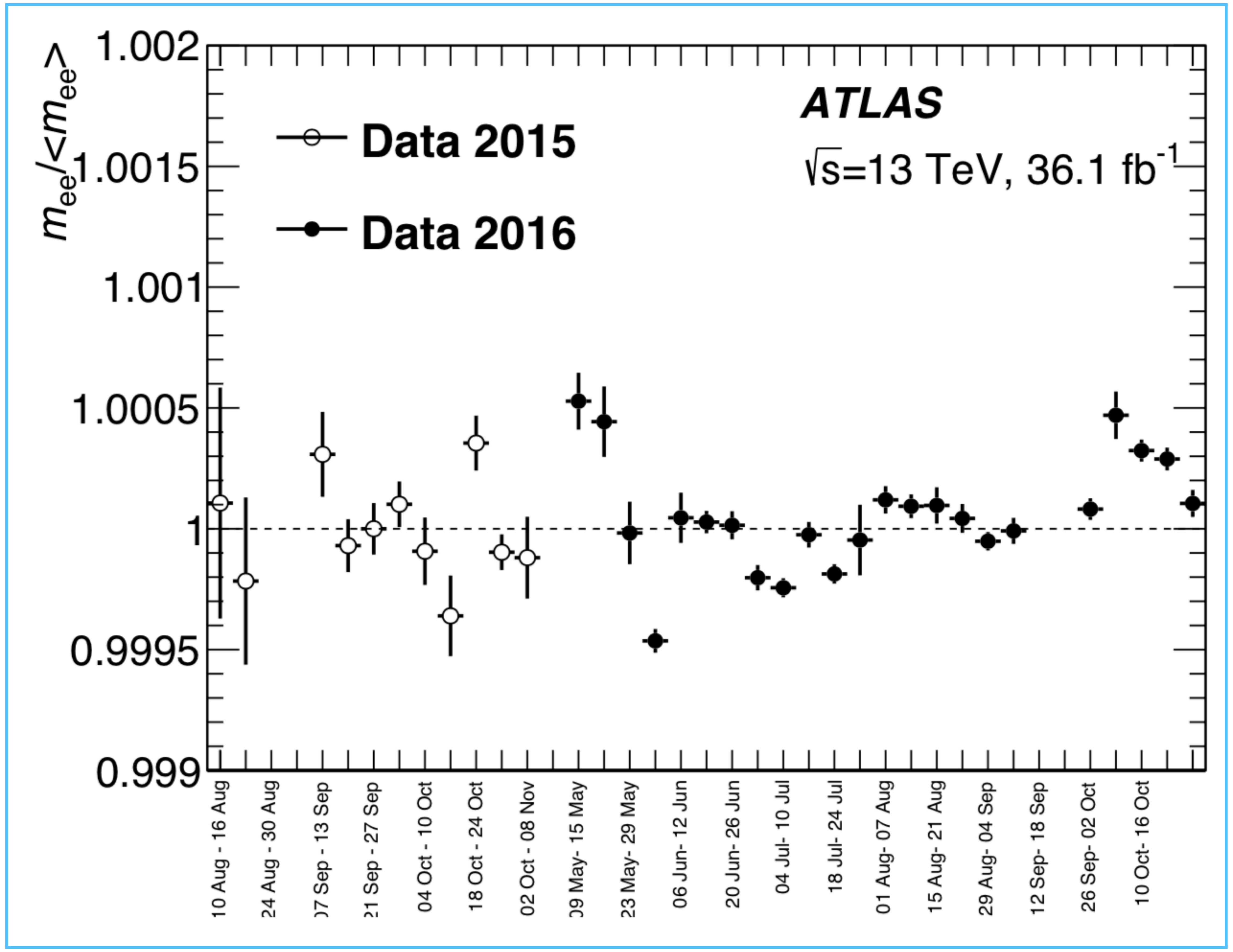




Energy scale stability

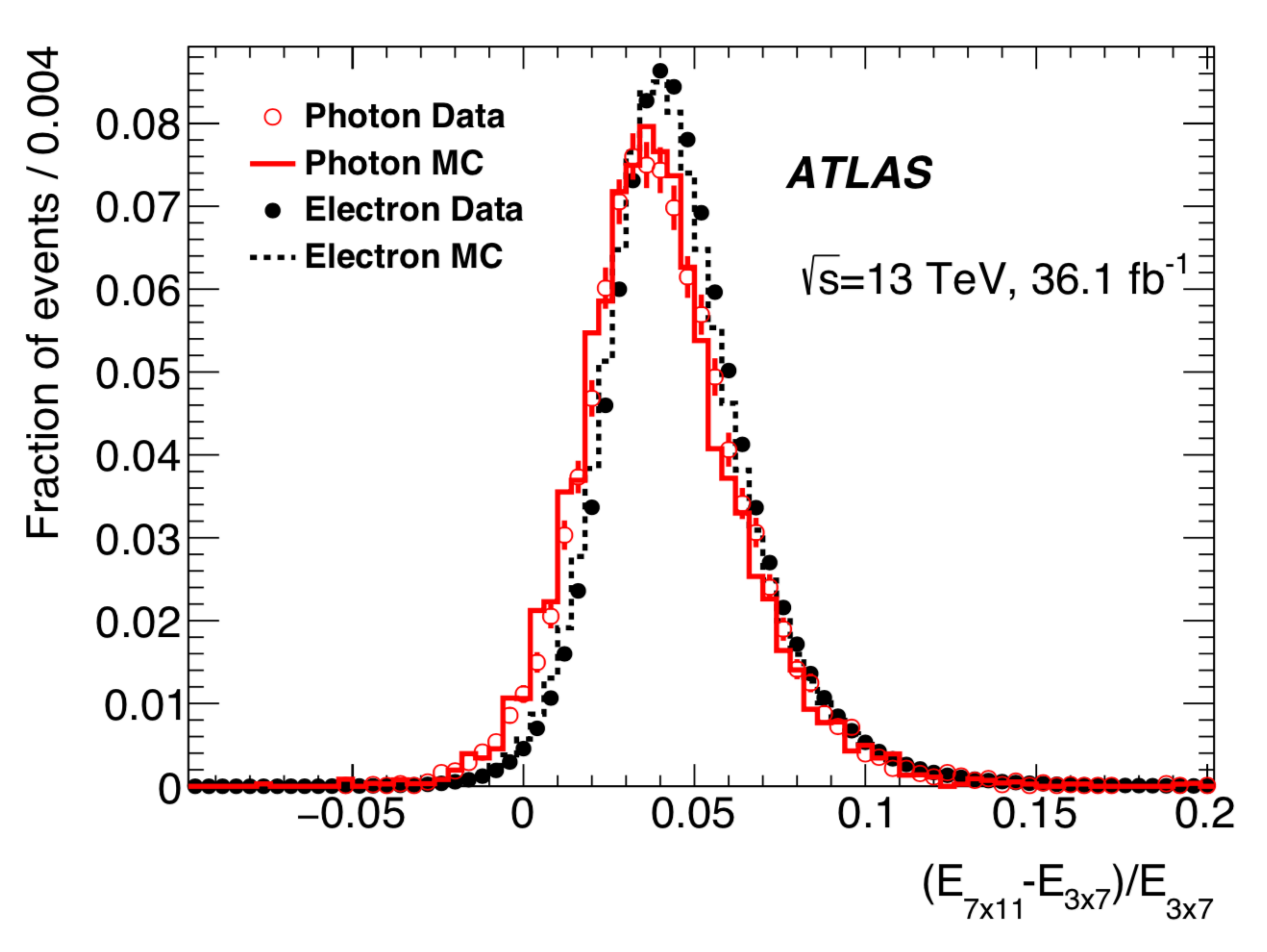
- Reconstructed Z peak vs <mu>: variation < 0.1% in data (no effect on simulation as well)
- Stability of the energy scale vs time: better than 0.1%



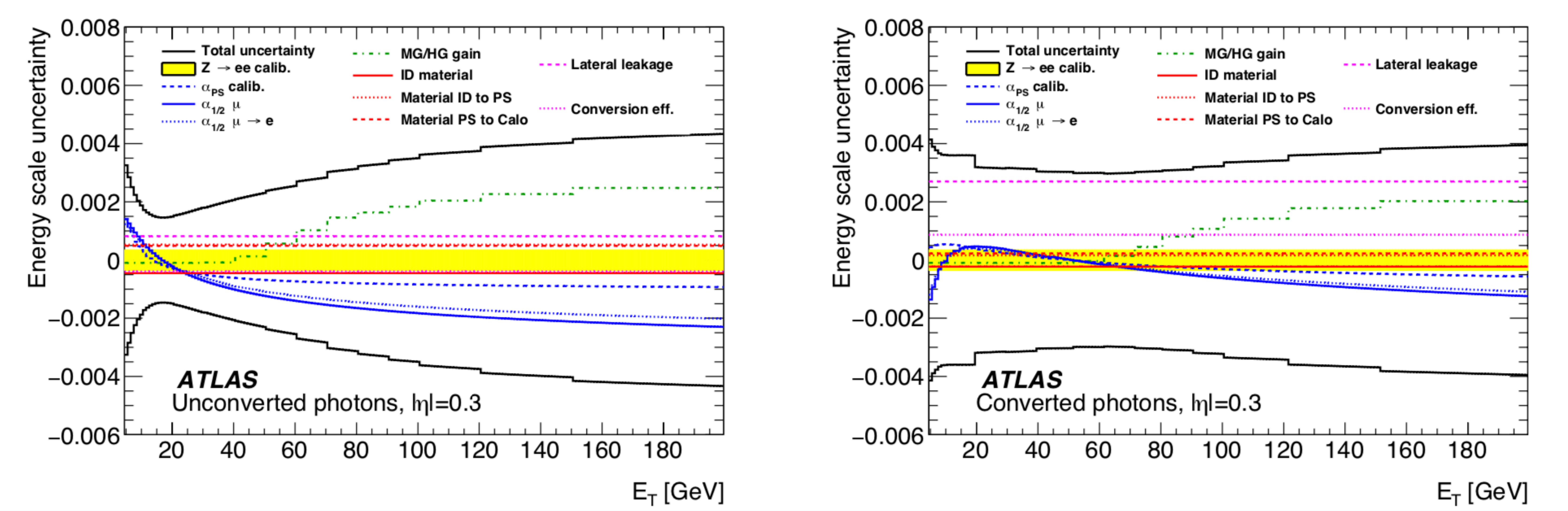


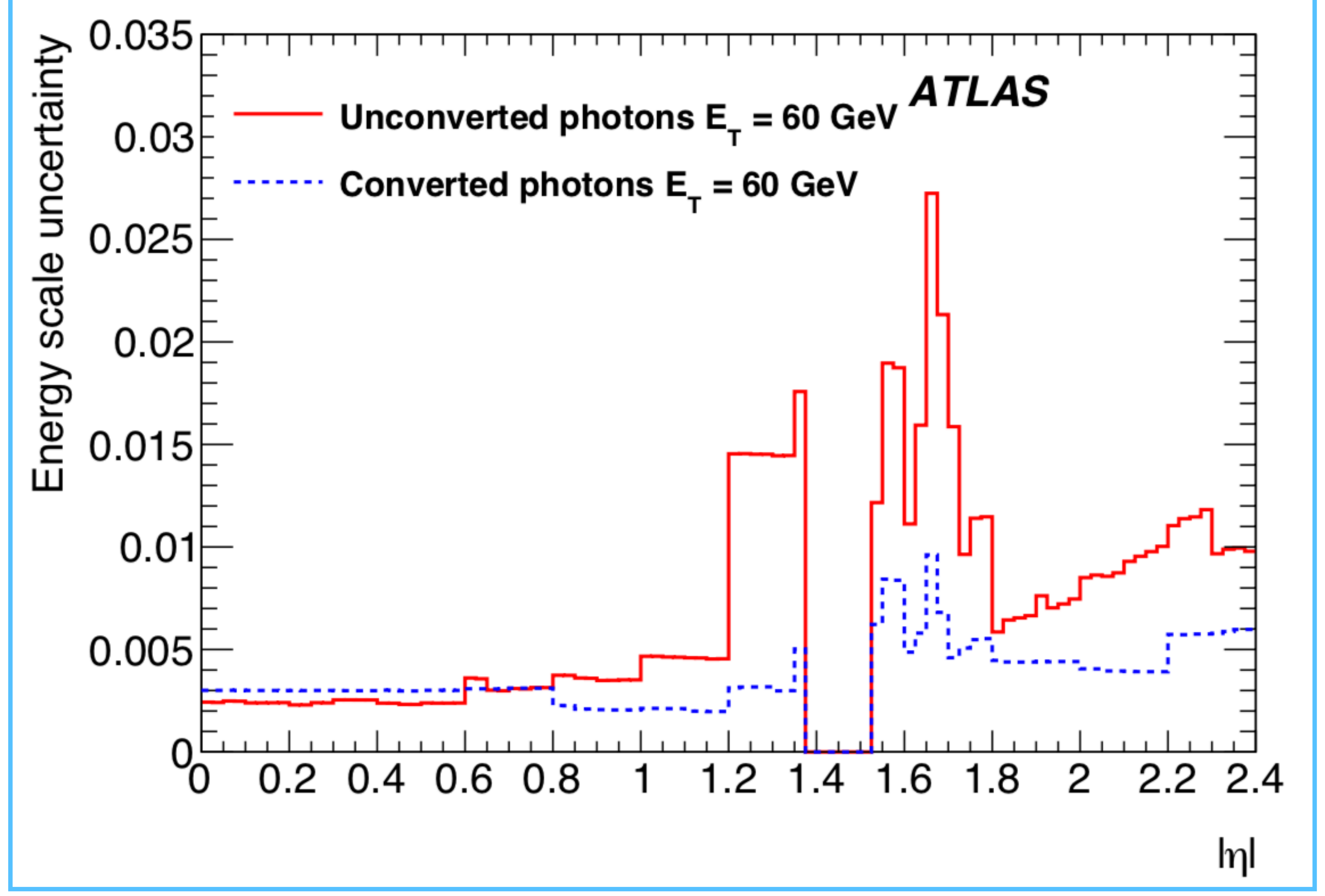
Lateral leakage

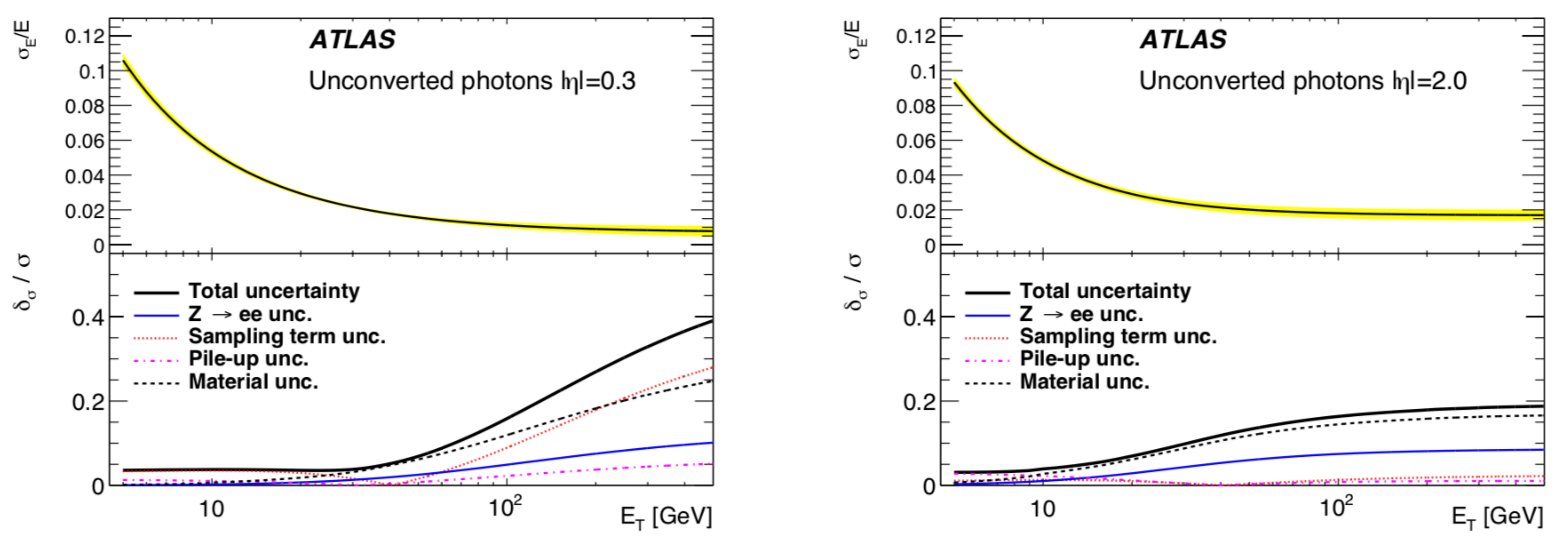
- Estimated as the difference of calorimeter energy in 7x11 are of second-layer cells and the energy collected in cluster size are of 3×7 (5×5) in barrel (end-cap) regions
- Leakage for photons form Z radiative decays and compared to leakage from electrons measured in Z(ee) decays



Systematic on energy scale and resolution for photons







- Systematic uncertainties on the energy scale for converted and unconverted photons vs Et and |eta|
- Systematic uncertainties on the energy resolution for unconverted photons at |eta| = 0.2 and 0.3

ATLAS and CMS M(ee) calibration performance comparison

- Good energy scale and energy resolution achieved in both measurements:
  - good data/MC agreement is observed in both measurements

CERN-CMS-DP-2018-017