PROCEEDINGS OF SCIENCE

Electron and photon energy measurement calibration with the ATLAS detector

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An accurate calibration of the energy measurement of electrons and photons is paramount for many ATLAS physics analyses. The calibration of the energy measurement is performed *in-situ* using a large sample of $Z \to ee$ events. The results obtained with the pp collisions data recorded in 2015 and 2016 at $\sqrt{s} = 13$ TeV, corresponding to an integrated luminosity of 3.2 fb^{-1} and 2.7 fb^{-1} respectively, as well as the corresponding uncertainties on the electron and photon energy scales, are presented.

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1. Introduction

This document presents the photon and electron energy calibration used by the ATLAS experiment [1] for the analyses in Run-2 in the central region of the detector ($|\eta| < 2.47$) [2] and the related measurement obtained with 3.2 fb^{-1} and 2.7 fb^{-1} of *pp* collisions data recorded at $\sqrt{s} = 13$ TeV in 2015 and 2016. The document refers also to the Run-1 calibration procedure [3], performed using about 25 fb^{-1} of *pp* collision data taken at $\sqrt{s} = 7$ and 8 TeV in 2011 and 2012.

The energy calibration scheme can be summarized in three main steps: simulation-based calibration (applied to data and simulation); data-driven corrections for the non-uniformity of detector response (applied only to data); data to Monte Carlo energy scale factors (applied on data) and resolution corrections (applied on simulation).

The reconstruction of electron[1] and photons in the central region starts from energy deposits in fixed-size rectangular clusters of cells of the electromagnetic calorimeter (ECAL) [3]. Clusters matched to tracks originating from a vertex found in the beam interaction region are classified as electrons. If the matched track is consistent with originating from a photon conversion and if in addition a conversion vertex is reconstructed, the candidates are considered as converted photons. Clusters without matching tracks are classified as unconverted photons.

Uniformity corrections are applied on data to equalize the response of the longitudinal layers of ECAL between data and simulations. These corrections have been derived using Run-1 data [3], validated using Run-1 data reprocessed with the 2015 reconstruction algorithm, and used in Run-2. Other corrections, such as to account for geometric effects, are the same as in Run-1 [3]. Reconstructed electron and photon clusters are calibrated using a multivariate algorithm to correct for the energy deposited outside of the cluster in the lateral and longitudinal direction, as well as for the variation of the energy response as a function of the impact point on the calorimeter. The updated version of this algorithm is described in the next section. Finally in order to account for any residual disagreement between data and simulation, the energy scale of electrons is extracted using $Z \to ee$ events through an *in-situ* procedure described in Section 3.

2. Monte Carlo based calibration

The Monte Carlo based calibration relies on a multivariate boosted decision tree with gradient boosting. Its optimisation is performed separately for electrons, converted and unconverted photons using single particle simulations without contribution from additional inelastic *pp* collisions and underlying events.

With respect to the Run-1 configuration [3] the list of input variables has been updated replacing the longitudinal shower depth with the ratio of the energy measured in the first layer of the electromagnetic calorimeter with the energy in the second layer of the calorimeter E_1/E_2.

The pseudorapidity region covered by the calibration has been extended to cover the region $|\eta| \in [0, 2.5]$, including the transition region between the barrel and the endcap electromagnetic calorimeter. In this region, $1.4 < |\eta| < 1.6$, electrons and photons deposit energy in the electromagnetic barrel and endcap calorimeters but also in the so called "E4" scintillators that are part of the Intermediate Tile Calorimeter (ITC), which is located in the gap region, in between the long and

[1] In the document electrons indicates both the electron and the positron

the extended barrels of the tile calorimeter. The energy measured by the E4 scintillators has been introduced as an additional variable to the training in order to mitigate the energy resolution degradation due to the large amount of material crossed by the particles in this region. The improvement in the energy resolution in the region $1.4 < |\eta| < 1.6$ for electrons, converted and unconverted photons with true energy between 50 and 100 GeV is about 25%, 17% and 10% respectively.

3. In-situ correction

After the application of the corrections for the non-uniformity of the detector response and of the simulation-based calibration, a residual disagreement in the energy scale and resolution is still present between data and simulation.

The energy mis-calibration is defined as the difference in response between data and simulation, and is parametrised as: $E_i^{\rm data} = E_i^{\rm MC}(1+\alpha_i)$, where $E_i^{\rm data}$ and $E_i^{\rm MC}$ are the electron energy in data and simulation, and α_i represents the deviation from the unbiased calibration in a given pseudorapidity region labelled i.

The difference in energy resolution between data and simulation can be modelled by an additional constant term (c_i'): $\left(\frac{\sigma(E)}{E}\right)_i^{\rm data} = \left(\frac{\sigma(E)}{E}\right)_i^{\rm MC} \oplus c_i'$.

Energy scale corrections (α_i) and additional constant terms for energy resolution (c_i') have been evaluated using a pure control sample of $Z \to ee$ events selected in the 2015 data.

Several systematic uncertainties affect this measurement. The most relevant one is the uncertainty on the description of the material in front of the ECAL. The measured values are reported in Figure 1, along with the total systematic uncertainty of the full calibration procedure. These corrections are applied to both electrons and photons.

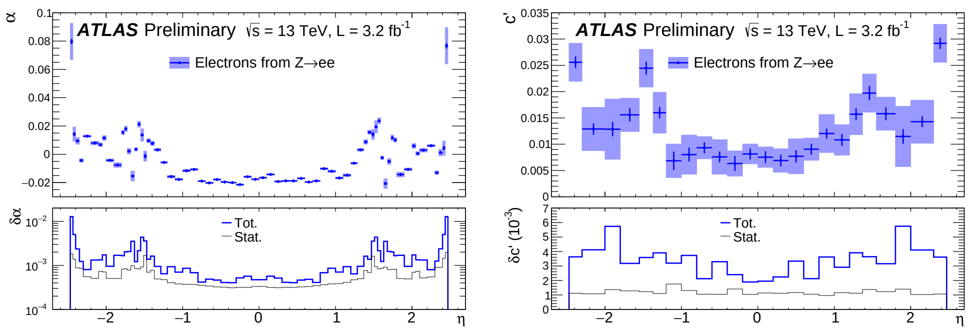

Figure 1: Energy scale factor α (left) and additional constant term c' (right) for energy resolution from $Z \to ee$ events as a function of η. In the bottom insets the statistical and systematic uncertainties are reported [2].

4. Uncertainties on energy scale and resolution

Many sources contribute to the uncertainty on the energy scale and resolution for electrons and photons. A detailed analysis of all those sources was performed in Run-1 [3]. The same model has been implemented for the Run-2 calibration with the updates described in the following. One additional term of uncertainty is added in the gap region due to the use of additional inputs from the E4 scintillators. This term results from the quadrature sum of the uncertainties due to: data-simulation difference in the mean of the energy in the scintillators in $Z \to ee$ events ($1\% \div 4.3\%$ depending on η), the electromagnetic scale calibration factor that converts the ITC signals to the energy deposited by electrons (2.4%) and the time-dependent calibration of the E4 scintillators responses (1% due to the initial inter-calibration using minimum-bias collision events and 4% due to the laser calibration performed during the data-taking period). An additional systematic uncertainty ($\sim 1.5\%$) has been included to account for residual disagreement in the extrapolation of the inter-calibration of the first two layers of the ECAL from Run-1 to Run-2. Finally, additional terms are introduced to account for differences in the pileup conditions (0.02%) and in the liquid argon temperature conditions (0.05%) between the 2015 and 2016 datasets.

5. Calibration checks and conclusion

In order to check the goodness of the whole calibration procedure, the invariant mass distribution of Z boson candidates, reconstructed through their decay to central electrons, is compared with the prediction from the simulation. For both data and simulated events, the full calibration is applied to the candidate electrons, but no subtraction of the background is performed on the data distribution. As shown in Figure 2 this comparison confirms a good agreement between the data and the simulation for both the 2015 and 2016 data samples. The residual discrepancy is fully covered by the systematic uncertainty for di-electron invariant masses close to the Z boson mass.

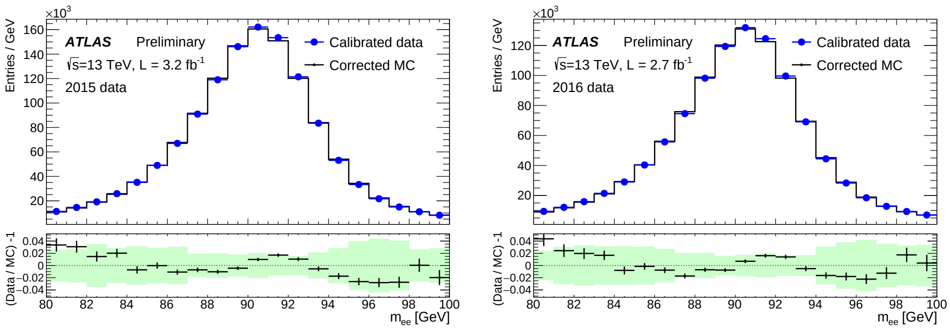

Figure 2: Electron-positron invariant mass distribution for $Z \to ee$ candidates in data is compared to the simulation after the full calibration is applied, for the 2015 (left) and the 2016 (right) data samples. In the bottom insets the ratio between the fully-calibrated data and the simulation (points with error bars) is compared to the total systematic uncertainty (green band) [2].

In summary, the electron and photon energy scale uncertainties obtained from $Z \to ee$ for Run-2 at this stage are between one per mil in the barrel ECAL and a few per mil in the end-caps. The uncertainty on the effective constant term added to the simulation is between two and five per mil.

References

[1] ATLAS Collaboration, JINST **3** (2008) S08003.

[2] ATLAS Collaboration, ATL-PHYS-PUB-2016-015 (2016), https://cds.cern.ch/record/2203514.

[3] ATLAS Collaboration, Eur. Phys. J. **C74** (2014) 3071, `arXiv:1407.5063 [hep-ex]`.