Electron and photon reconstruction and identification with the ATLAS detector and performance with $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$ with $\sqrt{s} = 900\,\text{GeV}$ data

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Abstract. In this article the electron and photon reconstruction and identification with the ATLAS detector will be illustrated, both on MC simulation and on the data collected in the year 2009 at $\sqrt{s} = 900\,\text{GeV}$. The performance with $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$ on the same data will also be discussed.

1. Introduction
The ATLAS electromagnetic (EM) calorimeter, see Fig. 1, is a LAr-Pb sampling calorimeter with a fine segmentation in both the lateral ($\eta \times \phi$ space) and longitudinal directions of the showers [1]. At high energy, most of the EM shower energy is collected in the second layer which has a lateral granularity of $0.025 \times 0.025$ in $\eta \times \phi$ space. The first layer consists of finer-grained strips in the $\eta$-direction (with a coarser granularity in $\phi$), which offer excellent $\gamma - \pi^0$ discrimination. These two layers are complemented by a presampler layer placed in front with coarse granularity to correct for energy lost in the material before the calorimeter, and by a back layer behind, which enables a correction to be made for the tail of very highly energetic EM showers. The ATLAS inner detector, see Fig. 1, provides precise track reconstruction over $|\eta| < 2.5$. It consists of three layers of pixel detectors close to the beam-pipe, four layers of silicon microstrip detectors (SCT), and a transition radiation tracker (TRT) at the outer radii, providing about 35 hits per track (in the range $|\eta| < 2.0$).

2. Data Sample
The analysis [2, 3, 4] is based on a data sample collected at $\sqrt{s} = 900\,\text{GeV}$. The events are triggered during LHC collisions using the Minimum-Bias-Trigger-Scintillators (MBTS), which cover the pseudo-rapidity range $2.09 < |\eta| < 3.84$ and are located in front of the end-cap EM calorimeters. Collision candidates are selected using additional timing requirements to provide further rejection against beam backgrounds: either coincident signals from the EM calorimeter end-caps or from the MBTS. The sample requires good data quality for the electromagnetic calorimeter and hadronic calorimeters. The solenoidal field is required to be at its nominal value. The data sample consists of 493,683 collision candidates which corresponds to an integrated luminosity of approximately $11.5\,\mu\text{b}^{-1}$. 
Electron and photon reconstruction

Electron and photon reconstruction [4] begins with the creation of a preliminary set of clusters in the EM calorimeter whose size corresponds to $3 \times 5$ cells in $\eta \times \phi$ in the middle layer. Electron and photon reconstruction is seeded from such clusters with $E_T > 2.5$ GeV, using a sliding window algorithm over the full acceptance of the EM calorimeter. The final cluster size is dependent on the particle hypothesis and the region of the detector ($3 \times 5$ for unconverted photons in the barrel, $3 \times 7$ for converted photons and electrons in the barrel, $5 \times 5$ in all other cases). In addition to identifying efficiently EM showers, the ATLAS EM calorimeter measures their energies with high accuracy and with a linearity better than 0.5% over a large energy range, from 10 GeV to a few TeV. The cluster energy is determined precisely by computing and summing four different contributions: the energy deposited in the material in front of the EM calorimeter, that deposited in the calorimeter inside the cluster, that deposited outside the cluster (lateral leakage) and the energy deposited beyond the EM calorimeter (longitudinal leakage). The four terms are parametrised as a function of the cluster measured energies in the presampler (where it is present) and in the three accordion longitudinal layers.

Electron and photon identification

The baseline electron and photon identification algorithms in ATLAS rely on rectangular cuts using variables which deliver good separation between isolated electrons/photons and fake signatures from QCD jets. Three reference sets of cuts have been defined for electrons: loose, medium and tight, and two sets for photons: loose and tight. The cut values are optimised in bins of $E_T$ and $\eta$ for electrons and only in bins of $\eta$ for photons, but separately for unconverted photons and converted photons. The loose selection includes shower-shape variables based on information from the middle calorimeter layer, together with hadronic leakage, the fraction of the cluster energy deposited in the hadronic calorimeter. The electron candidates will consist of clusters associated to a loosely matching track whereas the photon candidate clusters will in general lack such a track. The medium selection for electrons includes requirements on their energy deposits in the strip layer and on the track quality and track-cluster match. The tight electron selection uses the ratio between measured cluster energy and track momentum, $E/p$, and the fraction of high-threshold hits in the TRT, require the presence of a hit on the track in the pixel vertexing layer and rejecting candidates with a matching conversion vertex. The tight photon requirements comprise tighter cuts on the variables used for the loose cut selection and additional cuts on the middle layer and especially the strip layer with its fine granularity which provides good $\gamma - \pi^0$ separation.
Table 1. Expected jet rejections with overall isolated and non-isolated electron efficiencies for the three sets of identification cuts and an \(E_T\)-threshold of 20 GeV. The total jet rejection includes hadron fakes and background electrons from photon conversions and Dalitz decays.

| Efficiency (%) | Jet rejection (total) |
|---------------|-----------------------|
| \(Z \rightarrow ee\) | \(b, c \rightarrow e\) |
| Loose         | 94.30 ± 0.03, 36.8 ± 0.5 | 1066 ± 4 |
| Medium        | 89.97 ± 0.03, 31.5 ± 0.5 | 6821 ± 69 |
| Tight         | 71.52 ± 0.03, 25.2 ± 0.5 | (1.38 ± 0.06) \(\times 10^5\) |

Table 1 shows that the specific cuts optimised for the tight selection successfully remove the large backgrounds from hadrons and converted photons, which are largely dominant after the medium selection.

4.1. Electron candidates
The transverse energy spectra for all selected electron candidates are shown in Figure 2-(a). The numbers of events for different selection levels are given in Table 2. According to the MC 15\% of the electrons passing the tight cuts are expected to be prompt electrons, therefore three out of the twenty electron candidates passing the tight cuts in the data would be expected to originate from heavy flavor decays.

4.2. Photon candidates
Table 2 presents the numbers of reconstructed photon candidates as a function of the selection cuts applied. Transverse energy and pseudorapidity spectra for all selected photon candidates are found to be in agreement between data and Monte Carlo, see Figs. 2-(b). From the MC approximately 71\% of the candidates correspond to photons from \(\pi^0\) decay, whereas \(\sim 14\%\) are from \(\eta, \eta'\) or \(\omega\) decay into two photons, and \(\sim 14\%\) are from other hadrons with complex decay chains. Only \(\sim 0.7\%\) of all photon candidates are expected to be “prompt” at these energies, i.e. from initial or final state radiation of quarks.

Various calorimeter variables, used for candidates identification, are illustrated for the photon candidates, the equivalent distributions for electron candidates display very similar features. The lateral development of the shower, as detailed by the variables \(w_2\) and \(R_\eta\), is illustrated for the photon candidates in Figs. 3. These variables display small shifts between the shapes observed in data and those expected from simulation. The shower width \(w_2\) is slightly larger in the data: preliminary studies show that including the cross-talk between neighbouring middle layer cells (\(\sim 0.5\%\)) in the simulation would explain part of the observed difference.

The variables sensitive to the shower lateral width in the strip layer, also shown in Figs. 3, \(F_{side}\) and \(w_{s3}\), display distributions shifted slightly towards higher values in the data than in the

Table 2. Breakdown of electron and photon candidates according to identification cuts applied. The numbers in brackets give the percentage of Monte Carlo electron candidates which are electrons from photon conversions or prompt electrons (the remainder are charged hadrons).

| Candidates | Electron 879 | Photon 1094 |
|------------|--------------|-------------|
| Loose      | Data (\%)    | MC (\%)     | Data (\%)   | MC (\%)     |
|            | 46.5±1.7     | 50.9±0.2 (40.0±0.3) | 25.4±1.0 | 30.5±0.1 |
| Medium     | 10.6±1.0     | 13.1±0.2 (26.4±0.6) | -          | -          |
| Tight      | 2.3±0.5      | 2.4±0.1 (37.9±1.5) | 4.1±0.5    | 6.6±0.1    |
Figure 2. Cluster $E_T$ for all selected electron (a) and photon (b) candidates.

Figure 3. Distributions of calorimeter variables compared between data and simulation for all photon candidates. Shown are the variables $w_2$ (lateral width of the shower) and $R_\eta$ (ratio in $\eta$ of cell energies in $3 \times 7$ versus $7 \times 7$ cells), $F_{\text{side}}$ (fraction of energy outside core of three central strips but within seven strips) and $w_{3\times3}$ (shower width for three strips around maximum strip).

Simulation. Neither an inaccurate cross-talk description (the effect observed is too large) nor an incorrect description of the material in front of the EM calorimeter are likely to explain entirely this effect.
5. Converted Photons and material mapping
An accurate and high-granularity map of the ID material is necessary for a precise reconstruction of high-energy photons and electrons. The ID material affects both the track trajectories (especially through bremsstrahlung effects) and the electromagnetic shower development (because of the magnetic field and the energy lost in the ID material). The radiation length of a localized amount of material is related to the fraction of photons that convert in it. The reconstruction of photon conversions [3] uses tracks found by the different track-reconstruction algorithms in ATLAS. The standard inside-out tracking is seeded with hits in the Pixel detector and in the SCT. Tracks found in the silicon detectors are extended outwards into the TRT. The photon conversion reconstruction algorithm begins by selecting single tracks with transverse momentum $p_T > 500$ MeV and a significant fraction of high-threshold hits in the TRT, as expected from transition radiation. Photon conversion candidates are then created by pairing oppositely-charged tracks.

The results for the distributions of the photon conversion vertices in the radial direction in Fig. 4 show, albeit with limited statistics, a good match between the measured material distribution and the Monte Carlo model.

6. $\pi_0 \rightarrow \gamma\gamma$ studies
For low-energy photons [2] the sliding window algorithm developed for high-$E_T$ objects with a seed threshold set to $E_T = 2.5$ GeV is inefficient. For the analysis of $\pi_0$ candidates, cells from the four layers are combined to form a cluster of size $\Delta\eta \times \Delta\Phi = 0.075 \times 0.125$, which corresponds to an area of $3 \times 5$ cells in the middle layer of the EM calorimeter. They are built from a seed provided by EM topological cell clusters with a seed cell threshold $|E_{\text{cell}}| = 4\sigma$ (where $\sigma$ is the measured electronic noise in the cell) and with a cluster transverse energy $E_T > 300$ MeV. To account for upstream energy-loss and lateral and longitudinal leakages, the reconstructed clusters are calibrated using dedicated set of coefficients that has been extracted using low-energy photons coming only from $\pi_0$s in the minimum-bias simulation sample. In order to extract the $\gamma_0$ signal from the combinatorial background, the following criteria are applied:

- A cluster-removal procedure is applied to avoid energy-sharing corrections: if two $3 \times 5$ clusters overlap, they are both rejected. Clusters in the barrel-EC transition region are rejected.
- The fraction of energy in the first layer $E_1/(E_1 + E_2 + E_3)$ is required to be larger than 0.1.
Figure 5. Diphoton invariant mass after application of the selection criteria for $\pi^0$ (left) and for $\eta$ (right) for data and Monte Carlo.

- An additional kinematic cut requiring the $3 \times 5$ clusters to have a minimum transverse energy of $E_T = 400$ MeV is applied.

The invariant mass distribution of the photon pairs is shown in Fig. 5-left for both data and Monte Carlo. A clear excess of events can be observed near the $\pi_0$ mass.

The measured $\pi_0$ mass is $134.0 \pm 0.8$ (stat) MeV for the data and $132.9 \pm 0.2$ (stat) MeV for the Monte Carlo. The 1.5% discrepancy of the Monte Carlo mass with respect to the PDG nominal $\pi_0$ mass is consistent with the expected accuracy of the specific cluster calibration procedure for low-energy photons and the 1% uncertainty on the fitted $\pi_0$ mass arising from the background modeling and the $\sim 2$-3% energy scale uncertainty.

7. $\eta \to \gamma \gamma$ candidates

The number of $\eta \to \gamma \gamma$ candidates is expected to be one order of magnitude smaller than $\pi_0 \to \gamma \gamma$ in the minimum-bias event sample. Therefore, the combinatorial background contribution in the $\eta$-mass region needs to be significantly reduced. This can be achieved by adding the following cuts to the $\pi_0$ analysis:

- Tighter kinematic cuts: $E_{\text{cluster}} > 800$ MeV, $p_{\text{pair}} > 2200$ MeV
- Track veto: only clusters which do not have any matching track are selected

The diphoton invariant mass spectrum obtained using these cuts is shown in Fig. 5-right: the number of $\eta$ candidates is in agreement for the data and the Monte Carlo simulation. The $\eta$ mass extracted from the fit on data, $m_{\eta}^{\text{Data}} = 527 \pm 11$ (stat) MeV, agrees with the expected mass obtained using the same fitting function on the Monte Carlo simulation, $m_{\eta}^{\text{MC}} = 544 \pm 3$ (stat) MeV, within the statistical and energy scale uncertainties of $\sim 2$-3%. The 1% difference observed between the Monte Carlo simulation and the nominal PDG value is consistent with the expected accuracy of the specific cluster calibration.

References
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