Electron and Photon Identification

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On behalf of the ATLAS Collaboration

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Why need Electrons or Photons?

Electron and photon identification is needed to select interesting signal events.

Excellent resolution at high $p_T$ crucial for high mass new phenomena searches.

Total Event Rate

SM Physics

Searches
Electron and Photon Reconstruction

**EM Calorimeter:**
- Pb/Liquid Argon accordion ($|\eta|<3.2$)
- 4/3/2 layers $|\eta|<1.8/2.5/3.2$
- $\sigma_E/E = 10%/\sqrt{E} \oplus 0.7%$ @ $|\eta|\sim0.7$
- linearity $<0.5%$ up to 300GeV
- shower direction $\sigma_0 \sim 50\text{mrad}/\sqrt{E}$

**Inner Detector (ID) $|\eta|<2.5$:**
- 4 layer Pixel Detector
- 4 layer Semi-Conductor Tracker (SCT)
- 73-layer Transition Radiation Detector (TRT) $|\eta|<2.0$ electron ID $1<p_T<150\text{GeV}$

**Hadronic Calorimeter:**
- 3 layers of scintillating tile/steel to $|\eta|<1.7$
- 4 layers copper/LAr for $1.5<|\eta|<3.2$

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<table>
<thead>
<tr>
<th></th>
<th>EM Cluster</th>
<th>Matched Track</th>
<th>IBL hit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>$</td>
<td>\eta</td>
<td>&lt;2.47$</td>
</tr>
<tr>
<td>Unconverted $\gamma$</td>
<td>$</td>
<td>\eta</td>
<td>&lt;2.37$</td>
</tr>
<tr>
<td>Converted $\gamma$</td>
<td>$</td>
<td>\eta</td>
<td>&lt;2.37$</td>
</tr>
</tbody>
</table>
Electron & Photon Clustering

EM “sliding window” fixed-size rectangular clusters, that can be associated to tracks

- $\Delta \eta \times \Delta \phi$: $\gamma = 3 \times 5$, $e = 3 \times 7$ or $5 \times 5$ cells in the middle layer
- Size is trade-off between energy leakage and noise pickup

New Supercluster approach (2017):

- Improvement of energy resolution low $E_T$ and high $|\eta|$ due to inclusion of

$E_{\text{Raw}} = 16.98$ GeV, $E_{\text{Gen}} = 17.59$ GeV, $\eta_{\text{Gen}} = -0.50$

$E_{\text{old}} = 13.57$ GeV, $E_{\text{new}} = 16.98$ GeV
Shower Shape Variables

Variables and Position

<table>
<thead>
<tr>
<th>Strips</th>
<th>2nd</th>
<th>Had.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratios</td>
<td>$f_1$, $f_{\text{side}}$, $R_{\eta}^<em>$, $R_{\phi}$, $R_{\text{Had.}}^</em>$</td>
<td></td>
</tr>
<tr>
<td>Widths</td>
<td>$w_{S,3}$, $w_{S,\text{tot}}$, $w_{\eta,2}^*$</td>
<td></td>
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<tr>
<td>Shapes</td>
<td>$\Delta E$, $E_{\text{ratio}}$</td>
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* Used in PhotonLoose.

Energy Ratios

\[ R_{\eta} = \frac{E_{3 \times 7}^{S2}}{E_{7 \times 7}^{S2}} \]

\[ R_{\phi} = \frac{E_{3 \times 3}^{S2}}{E_{3 \times 7}^{S2}} \]

\[ R_{\text{Had.}} = \frac{E_{T}^{\text{Had.}}}{E_{T}} \]

\[ f_1 = \frac{E_{7 \times 1}^{S1} - E_{3 \times 1}^{S1}}{E_{3 \times 1}^{S1}} \]

\[ f_{\text{side}} = \frac{E_{7 \times 1}^{S1} - E_{3 \times 1}^{S1}}{E_{3 \times 1}^{S1}} \]
Shower Shape Variables

### Variables and Position

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<td>$R_{\eta}^*$, $R_\phi$</td>
<td>$R_{\text{Had.}}^*$</td>
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### Shower Shapes

$$E_{\text{ratio}} = \frac{E_{\text{max},1}^{S_1} - E_{\text{max},2}^{S_1}}{E_{\text{max},1}^{S_1} + E_{\text{max},2}^{S_1}}$$

$$\Delta E = E_{\text{max,2}}^{S_1} - E_{\text{min}}^{S_1}$$
Shower Shape Variables

Variables and Position

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* Used in Photon Loose.

**Widths**

\[
\begin{align*}
\sqrt{\sum E_i^{\eta_{i}^2} - \left( \sum E_i \right)^2} \quad \text{Width in a 3x5} & \Delta \eta \times \Delta \phi \text{ region of cells in the second layer.} \\
\end{align*}
\]

\[
\begin{align*}
ws & = \sqrt{\sum E_i (i - i_{\text{max}})^2} \\
ws3 & = \text{uses 3 strips in } \eta; \\
ws_{\text{tot}} & \text{ is defined similarly, but uses 20 strips.}
\end{align*}
\]
More Selection Variables

ATLAS preliminary

- Electron candidates
- Generic tracks
- Electrons (MC)
- Generic tracks (MC)

TRT endcap

Barrel

ATLAS Preliminary
\( \sqrt{s} = 13 \text{ TeV}, \int L dt = 12 \text{ pb}^{-1} \)

Z→ee
0.0 < η < 1.37
- Data
- MC Simulation

Endcap

ATLAS Preliminary
\( \sqrt{s} = 13 \text{ TeV}, \int L dt = 12 \text{ pb}^{-1} \)

Z→ee
1.52 < η < 2.47
- Data
- MC Simulation
Electron Identification Algorithm

Electrons: Likelihood discriminant ($\mathcal{L}$) using Probability Density Functions of electron cluster and track related quantities: $d\mathcal{L} = \mathcal{L}_s / (\mathcal{L}_s + \mathcal{L}_b)$

- $d\mathcal{L}$ cut depends on $E_T$ and $\eta$
- Input set variables varies with $E_T$ (e.g. $f_3$ is not used above $100$ GeV)
- Three operating points loose/medium/tight (subset of each other)
Electron Efficiencies: Tag & Probe

- Efficiencies measured in data ($\varepsilon_{\text{data}}$) and Monte Carlo simulation ($\varepsilon_{\text{MC}}$) following the same procedure

- Strict selection for one electron ("tag") and a looser electron ("probe"), the di-electron invariant mass in the mass window

- $Z \rightarrow e\!e$ for $p_T > 15\text{GeV}$ and $J/\psi \rightarrow e\!e$ for $p_T < 15\text{GeV}$

- Only selected probes are used for the efficiency measurement after proper background subtraction
Electron ID Efficiencies

MC simulations needs to be corrected by Scale Factors (SF):

$$SF = \frac{\varepsilon_{\text{data}}}{\varepsilon_{\text{MC}}}$$

ATL-COM-PHYS-2017-260
Dependencies on pile-up ($\mu$)*

**Efficiency**

- **ATLAS** Preliminary
- $\sqrt{s} = 13$ TeV, 33.9 fb$^{-1}$
- $E_T > 30$ GeV
- *Loose*, *Medium*, *Tight*
- Data: full, MC: open

**Energy response**

- **ATLAS** Preliminary
- $\sqrt{s}=13$ TeV, $L = 33.9$ fb$^{-1}$
- 2016 data

* Number of collision events per LHC bunch crossing
Cut-based selection
• depend on $E_T$ and $\eta$
• shower-shape variables for unconverted photons;
• add tracking and track-cluster matching for converted photons
• Background rejections: loose $\sim$1000, tight $\sim$5000
Radiative Z decays

- Selection: $\Delta R(e/\mu, \gamma)$>0.4/0.2, $E_{\gamma T}$>10GeV + tight isolation (no ID!), $p_T>$10GeV, e tight ID, combined $\mu$...
- Pure sample of photons: Z+jets $\sim$7.3 (8.4)% in ee$\gamma$(\mu\mu$\gamma$) for 10GeV<$E_{\gamma T}$<20GeV
- Allows efficiency measurements between 10GeV and 100GeV
Electron Extrapolation Method

- Derive CDF-based Smirnov-Transform from MC to modify e-shower shapes to reproduce $\gamma$
- Apply the correction to electrons shower shapes obtained from $Z \rightarrow ee$ Tag & Probe analysis
Matrix Method

- Collect photon-enriched sample with loose photon triggers
- Track isolation efficiencies:

<table>
<thead>
<tr>
<th>Identification</th>
<th>No Cut</th>
<th>tight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>all</td>
<td>pass</td>
</tr>
<tr>
<td>Signal MC</td>
<td>S, all</td>
<td>S, pass</td>
</tr>
<tr>
<td>Background</td>
<td>B, all</td>
<td>B, pass</td>
</tr>
</tbody>
</table>

\[
\varepsilon_{ID} = \frac{\varepsilon_{pass} - \varepsilon_{B}^{pass}}{\varepsilon_{S}^{pass} - \varepsilon_{B}^{pass}} \times \frac{N_{all} - \varepsilon_{B}}{\varepsilon_{all} - \varepsilon_{B}}
\]

ATLAS Preliminary

\[\sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1}, \quad 0.0 \leq |\eta| < 0.6\]

Unconverted γ after tight ID

\[\varepsilon_{pass}^{S}, \varepsilon_{pass}^{B}\]

ATLAS Preliminary

\[\sqrt{s} = 13 \text{ TeV}, 3.2 \text{ fb}^{-1}, \quad 0.0 \leq |\eta| < 0.6\]

Unconverted γ before tight ID

\[\varepsilon_{all}^{S}, \varepsilon_{all}^{B}\]
SF from three methods are combined independently in each \( p_T/\eta \) bin using BLUE technique.
$E_T^{\text{iso}}$ is corrected for the energy leakage and pile-up event-by-event. Excluded: $\Delta\eta \times \Delta\phi = 0.125 \times 0.175$

$p_T^{\text{iso}(\text{var})}$ sums tracks (>1 GeV) within $\Delta R = 10 \text{ GeV}/p_T^e$
Summary

- ATLAS e/γ reconstruction and ID presented
- Data driven measurements for e/γ efficiencies compared to MC predictions
  - Good MC modeling, residual differences corrected by SF
  - Ten fold increase in collected data (2016 vs 2015) allowed to extending the measurement to higher and lower energies
- More e/γ performance results are available at [https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ElectronGammaPublicCollisionResults](https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ElectronGammaPublicCollisionResults)
Backup
### Electron Identification Variables

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hadronic leakage</td>
<td>Ratio of $E_T$ in the first layer of the hadronic calorimeter to $E_T$ of the EM cluster (used over the range $</td>
<td>\eta</td>
</tr>
<tr>
<td></td>
<td>Ratio of $E_T$ in the hadronic calorimeter to $E_T$ of the EM cluster (used over the range $0.8 &lt;</td>
<td>\eta</td>
</tr>
<tr>
<td>Back layer of EM calorimeter</td>
<td>Ratio of the energy in the back layer to the total energy in the EM accordion calorimeter</td>
<td>$f_3$</td>
</tr>
<tr>
<td>Middle layer of EM calorimeter</td>
<td>Laterat shower width, $\sqrt{(\sum E_i/\eta^2) - ((\sum E_i/\eta)/((\sum E_i))/2)$, where $E_i$ is the energy and $\eta$ is the pseudorapidity of cell $i$ and the sum is calculated within a window of $3 \times 5$ cells</td>
<td>$W_{\eta2}$</td>
</tr>
<tr>
<td></td>
<td>Ratio of the energy in $3\times3$ cells over the energy in $3\times7$ cells centered at the electron cluster position</td>
<td>$R_\phi$</td>
</tr>
<tr>
<td></td>
<td>Ratio of the energy in $3\times7$ cells over the energy in $7\times7$ cells centered at the electron cluster position</td>
<td>$R_\eta$</td>
</tr>
<tr>
<td>Strip layer of EM calorimeter</td>
<td>Ratio of the energy difference between the largest and second largest energy deposits in the cluster over the sum of these energies</td>
<td>$E_{\text{ratio}}$</td>
</tr>
<tr>
<td></td>
<td>Ratio of the energy in the strip layer to the total energy in the EM accordion calorimeter</td>
<td>$f_1$</td>
</tr>
<tr>
<td>Track quality</td>
<td>Number of hits in the innermost pixel layer (the newly added B layer), discriminates against photon conversions</td>
<td>$n_{\text{BLayer}}$</td>
</tr>
<tr>
<td></td>
<td>Number of hits in the pixel detector</td>
<td>$n_{\text{Pixel}}$</td>
</tr>
<tr>
<td></td>
<td>Number of total hits in the pixel and SCT detectors</td>
<td>$n_{\text{Si}}$</td>
</tr>
<tr>
<td></td>
<td>Transverse impact parameter with respect to the beamspot</td>
<td>$d_0$</td>
</tr>
<tr>
<td></td>
<td>Significance of transverse impact parameter defined as the ratio of $d_0$ and its uncertainty</td>
<td>$\sigma_{d_0}$</td>
</tr>
<tr>
<td></td>
<td>Momentum lost by the track between the perigee and the last measurement point divided by the original momentum</td>
<td>$\Delta p/p$</td>
</tr>
<tr>
<td>TRT</td>
<td>Likelihood probability based on transition radiation in the TRT</td>
<td>TRTPID</td>
</tr>
<tr>
<td>Track-cluster matching</td>
<td>$\Delta \eta$ between the cluster position in the strip layer and the extrapolated track</td>
<td>$\Delta \eta_1$</td>
</tr>
<tr>
<td></td>
<td>$\Delta \phi$ between the cluster position in the middle layer and the extrapolated track, where the track momentum is rescaled to the cluster energy before extrapolating the track to the middle layer of the calorimeter</td>
<td>$\Delta \phi_{\text{res}}$</td>
</tr>
</tbody>
</table>
Photon Identification Variables

### Diagram

- **ATLAS Preliminary**
- $\sqrt{s} = 13$ TeV, $L = 19$ pb$^{-1}$
- $|\eta| < 2.37$ (1.37 < $|\eta|$ ≤ 1.52 excluded)
- $E^*_{T} > 125$ GeV

### Table

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Name</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance</td>
<td>$</td>
<td>\eta</td>
<td>&lt; 2.37$, with 1.37 &lt; $</td>
<td>\eta</td>
</tr>
<tr>
<td>Hadronic leakage</td>
<td>Ratio of $E_T$ in the first sampling layer of the hadronic calorimeter to $E_T$ of the EM cluster (used over the range $</td>
<td>\eta</td>
<td>&lt; 0.8$ or $</td>
<td>\eta</td>
</tr>
<tr>
<td></td>
<td>Ratio of $E_T$ in the hadronic calorimeter to $E_T$ of the EM cluster (used over the range 0.8 &lt; $</td>
<td>\eta</td>
<td>$ &lt; 1.37)</td>
<td>$R_{had}$</td>
</tr>
<tr>
<td>EM Middle layer</td>
<td>Ratio of $3 \times 7 \times 3 \times 7$ cell energies</td>
<td>$R_{hi}$</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Lateral width of the shower</td>
<td>$w_{x,y}$</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Ratio of $3 \times 3 \times 3 \times 3 \times 3 \times 3$ cell energies</td>
<td>$R_{ho}$</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>EM Strip layer</td>
<td>Shower width calculated from three strips around the strip with maximum energy deposit</td>
<td>$w_{x,y}$</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Total lateral shower width</td>
<td>$w_{x,y}$</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Energy outside the core of the three central strips but within seven strips divided by energy within the three central strips</td>
<td>$E_{side}$</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Difference between the energy associated with the second maximum in the strip layer and the energy reconstructed in the strip with the minimum value found between the first and second maxima</td>
<td>$\Delta E$</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td></td>
<td>Ratio of the energy difference associated with the largest and second largest energy deposits to the sum of these energies</td>
<td>$E_{ratio}$</td>
<td>•</td>
<td>•</td>
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