Reconstruction and identification of photons and electrons with the ATLAS detector

O. Fedin
on behalf of ATLAS collaboration

1st International Conference on Technology and Instrumentation in Particle Physics, 12-17 March 2009, Tsukuba
Electrons and photons signal @LHC

- Excellent e/\gamma identification capability is required at the LHC for most physics studies
- Physics channels of prime interest are expected to produce electrons with $p_T$ between few GeV and few TeV:
  - Low energy resonance J/$\Psi$ and $\Upsilon$
  - SM: $Z \rightarrow ee$, $W \rightarrow e\nu_e$ (background to new physics)
  - High $p_T$ electron $t \rightarrow Wb \rightarrow e\nu_e b$
  - Higgs search $H \rightarrow ZZ^* \rightarrow 4e$
  - BSM: TeV resonance ($Z' \rightarrow ee$), SUSY cascades and extra dimensions
- Good electron identification is needed over a broad energy range
- The ratio between the rates of isolated electrons and the rate of QCD jets with $p_T$ 20-50 GeV is $\sim 10^5$ ($\sim 50$ times worse than for Tevatron!)
- Isolated photons with the large transverse momentum in the final state are also signatures for most physics analyses ($H \rightarrow \gamma \gamma$, $G \rightarrow \gamma \gamma$, etc)
- Low energy resonances (J/$\Psi$, $\Upsilon$) are ideal to study performance of trigger and offline reconstruction. Useful for the in-situ calibration of the EM calorimeter
Calorimeter and Tracker

Calorimeter EM:

- Identify efficiently e/γ within a large energy scale
- To measure e/γ energies – linearity < 0.5%
- Pb-LAr Sampling calorimeter (870K)
- Barrel+2 End-Caps (|η|<3.2)
- Depth >22X₀
- ~170k channels
- Barrel 6.8 m long cryostat, outer radius 2.25 m and inner radius 1.115 m

Inner Detector:

- Pixel:
  - barrel - 3 layers, 67M pixels
  - end-cap – 3 layers 6.6M pixels
- SCT (Semi Conductor Tracker):
  - barrel - 8 layers, ~2M channels
  - end-cap – 9 layers, ~2M channels
- TRT (Transition Radiation Tracker)
  - barrel - 73 layers, ~53k channels
  - end-cap - 160 layers, ~123k channels
Transition Radiation Tracker

- Large-scale gaseous detector
- Xe filled drift tubes (or straws) 4 mm diameter interleaved by radiators fibres (barrel) or foils (EC) to produce transition radiation.
- Important contribution to overall momentum resolution
- Plays a central role in electron identification, cross-checking and complementing the calorimeter, especially at energies below 25 GeV
- Contributes to the reconstruction and identification of electron track segment from photon conversions down to 1 GeV and of electrons which have radiated a large fraction of their energy in the silicon layers

Electron identification performance expected for TRT - expected $\pi$ identification efficiency for electron efficiency $\sim$90%
Tracking & conversion reconstruction

Reconstruct tracks with $p_T > 0.5$ and $|\eta| < 2.5$.

Results of three tracking algorithms are merged:

- **Inside-out** (seed with Pixel/SCT, extrapolate to TRT)
- **Outside-in** (seed with TRT, extrapolate to Pixel)
- **TRT standalone**

Good efficiency over most of detector for tracks of moderate momentum

- 10-50% of photons convert before leaving the SCT
- For $R_c < 50$ cm, conversion vertices found with good efficiency ~80%
- For larger radii, look for single TRT tracks to improve efficiency
- Efficiency ~80% for $R_c < 80$ cm

![Single-electron tracking efficiency graph](image)
**EM calorimeter**

- Accordion geometry allow a full $\phi$ coverage without cracks and fast extraction of the signal
- 3 longitudinal compartments and presampler
- Each channel calibrated to the EM scale with the electronic calibration system
- Good energy resolution $\sigma(E)/E \sim 10%/\sqrt{E} \oplus 0.7$
- Excellent angular/position resolution and particle identification capability
  - $\sigma(R_\phi)$ $\sim 9$ mm/$\sqrt{E}$ and $\sigma(R_\theta)$ $\sim 3$ mm/$\sqrt{E}$
- Middle - main sampling for measuring energy
- Strip - fine granularity in order to allow for $\pi^0$ rejection up to $E_T \sim 50$ GeV or more

<table>
<thead>
<tr>
<th>Compartment</th>
<th>$\eta \times \phi$ barrel granularity</th>
</tr>
</thead>
<tbody>
<tr>
<td>preSampler</td>
<td>0.025$x\times$0.1</td>
</tr>
<tr>
<td>Layer 1 (Strip)</td>
<td>0.003$x\times$0.1</td>
</tr>
<tr>
<td>Layer 2 (Middle)</td>
<td>0.025$x\times$0.025</td>
</tr>
<tr>
<td>Layer 3 (Back)</td>
<td>0.05$x\times$0.025</td>
</tr>
</tbody>
</table>
Electron and photon reconstruction proceeds through a series of steps:

- Start from calorimeter cells calibrated to EM scale
- Build a cluster using a fixed-size $\Delta \eta \times \Delta \phi = 5 \times 5$ window of cells. Position defined at local maximum in energy
- Match cluster with tracks and conversions compatible with the cluster energy ($E/p < 10$) to determine particle hypothesis $\Delta \eta \times \Delta \phi = 0.05 \times 0.1$
  - electron, photon, or converted photon
- Early classification allows apply different correction to electron and photon candidates
- Rebuild cluster:
  - Size depends on particle hypothesis and calorimeter region
  - Apply cluster calibrations
- Calculate discriminating variables to reject fakes.
  - Simple cuts
  - Multivariate discriminants: likelihood, H-matrix, etc
Cluster correction & calibration

- Calculate initial cluster position and energy
  - Barrel: $\Delta \eta \times \Delta \phi = 3 \times 7$ for electrons, $\Delta \eta \times \Delta \phi = 3 \times 5$ unconverted photons and $\Delta \eta \times \Delta \phi = 5 \times 5$ for converted photons
  - End-cap: $\Delta \eta \times \Delta \phi = 5 \times 5$ both electrons and photons
  - Position from energy-weighted centroid
- Correct $\eta$ position measurements due to finite granularity of the readout
  - Correct S-shape in $\eta$-position
  - Small energy and particle dependence
  - Currently same correction for electron and photons
- $\eta$ position resolution for $\gamma$ is $\sim 3 \times 10^{-4}$ in strips (Layer 1) and $\sim 6 \times 10^{-4}$ in middle (Layer 2)
- $\phi$ position resolution $0.5 \sim 1.5 \times 10^{-3}$
Cluster calibration: energy reconstruction

- Combine the energies deposited in each layer
- Compute correction for each effect (from Monte Carlo) correlating each energy deposition to a measurable quantity (separately for electrons and photons)
- Energy deposition into the inactive material studied using special MC simulation (Calibration Hits)

\[
E^{\text{reco}} = F(E^{\text{acc}}_{\eta}, \eta) \cdot E^{\text{cl/LAr}}_{\text{ps}} + S_{\text{acc}}(X, \eta) \cdot \left( \sum_{i=1}^{13} E^{\text{cl/LAr}}_i \right) \left( 1 + C_{\text{out}}(X, \eta) \right) \left( 1 + f_{\text{leak}}(X, \eta) \right)
\]
Cluster calibration: energy reconstruction performance

\[ \sigma(E) = \frac{a}{E} + \frac{b}{\sqrt{E}} + c \]

\( \eta = 0.3 \)

- The amount of material in front of EM calo for the as-built detector is significantly larger than was initially estimated
- Linearity (Ereco/Etrue) better than 0.5% for both electrons and photons
- Sampling term for electrons goes from \( \sim 8\% \) in center to 22% in end-cap. Constant term <0.6%.
Electron/photon identification variables

The following variables are used to discriminate $e/\gamma$ from background:

- Fractional hadronic leakage $E_{T_{\text{had1}}}/E_{T_{\text{clus}}}$
- Shape in the middle sampling $E(3\times7)/E(7\times7)$
- Shape in the 1-st sampling: size and search for second maximum ($\pi^0$ rejection)
- Isolation in calorimeter

For electrons only:

- Track quality (# of hits, impact parameter)
- Track match ($\Delta\eta\times\Delta\phi$, $E/p$)
- Fraction of high threshold TRT hits

- Photons from $H \rightarrow \gamma\gamma$
- Jet background from hard-scattering QCD process
Cut-based electron identification

- Apply cut on each variable ($\eta$ and luminosity dependent)
- More than one definition of identification cuts are available

<table>
<thead>
<tr>
<th>Cut</th>
<th>Efficiency (%)</th>
<th>Jet Rejection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose (Had+Middle)</td>
<td>88</td>
<td>560</td>
</tr>
<tr>
<td>Medium (Loose+strips+ trk match+ num. Si hits )</td>
<td>77</td>
<td>2200</td>
</tr>
<tr>
<td>Tight (Medium+TRT+num. vert. hits)</td>
<td>64</td>
<td>$10^5$</td>
</tr>
</tbody>
</table>

\[ H \rightarrow eeee \]
\[ p_T > 5 \text{ GeV} \]
Cut-based jet rejection

Fraction of surviving candidates (%) which fall into the different categories for medium and tight set of cuts. The isolated electron are prompt electrons from W,Z and top quark and the non-isolated electrons from b,c decay. The residual background is split into its two domain components, electrons from photon conversion and Dalitz decay (first term in brackets) and charged hadrons (second term in brackets).

<table>
<thead>
<tr>
<th></th>
<th>di-jet (E_T &gt; 17) GeV</th>
<th>min.-bias (E_T &gt; 8) GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Isolated     Non-isolated  Jets</td>
<td>Non-isolated     Jets</td>
</tr>
<tr>
<td>Medium</td>
<td>1.1%         7.4%            91.5% (5.5%+86.0%)</td>
<td>9.0%            91.0% (5.0%+86.0%)</td>
</tr>
<tr>
<td>Tight</td>
<td>10.5%        63.3%           26.2% (8.3%+17.9%)</td>
<td>77.8%          22.2% (7.1%+15.1%)</td>
</tr>
</tbody>
</table>

**Di-jet \(E_T > 17\) GeV**

**min.-bias \(E_T > 8\) GeV**
Cut-based photon identification

Fake rate = 1/jet rejection

- Photons from $H \to \gamma\gamma$
- Jet background from hard-scattering QCD process

Photon identification uses same calorimeter variables (plus track isolation):
- Only one defined set of identification cuts
- Overall efficiency ~80%, with rejection ~8000 (with isolation)
- Rejection depends strongly on parton type:
  - Gluons \( \sim 3 \cdot 10^4 \)
  - Quarks \( \sim 3 \cdot 10^3 \)

\( E_T > 17 \text{ GeV} \)
In-situ intercalibration with $Z \rightarrow ee$

- Experience from test beam shows that response of EM calo is uniform within 0.5% over regions of size $\Delta \eta \times \Delta \phi \sim 0.2 \times 0.4$
- Intercalibration between 384 local regions necessary to take into account all non-uniformities of the EM calo (temperature, mechanical deformation, HV, material in front,..)
- Overall goal is global constant term <0.7%
- Calibration method – use $Z \rightarrow ee$ data. This also constrains the absolute energy scale (~0.1%).
- Modify the measured electron energy for each region $E_{\text{reco}}^i = E_{\text{true}}^i (1 + \alpha_i)$
- Construct reference $Z$ line shape from BW distribution convoluted with electron resolution and parton luminosity term
- Adjust $\alpha_i$ so that reconstructed $Z$ shape matches the reference shape.
- Apply $\alpha_i$ in offline cell energy corrections
- But this depends on excellent knowledge of material in front of EM calorimeter (mapped with photon conversions)

Reference distribution

$ATLAS$

$Z$ line shape

Before corr. $90.38 \pm 0.03$

After corr. $91.42 \pm 0.03$

Integrated luminosity (pb$^{-1}$)

$ATLAS$

Const term

$\sigma_{\text{ee}}$ $\times 10^3$

Number of Z $\rightarrow$ ee events

Oleg Fedin
In-situ electron efficiency determination

- The experimental uncertainty on the electron identification is expected to be the source of one of the main systematic errors in many measurements
- Need to measure electron efficiency from data. Important to scale MC prediction
- Use tag&probe method in $Z \rightarrow ee$ data:
  - Select electron candidates pairs near the $Z$ mass with one electron (tag) passing a set of cuts
  - Measure efficiency for the other (probe) to also pass a tighter set of cuts
- Example for finding medium cut efficiency
Conclusion

• Electron and photon identification and reconstruction are essential ingredients for measurements of SM and for searches for new physics at the LHC.

• Photon and electron identification and reconstruction strategy and algorithms are reasonably mature (photon conversions, bremsstrahlung).

• Different algorithms for electron/photon identification have been developed.

• Procedures and methods for calibration have been established and accurately tested in test-beam. Absolute scale of EM calo known to ~2%, linearity better than ~0.5% for energy 20-250 GeV.

• A lot of work will be done with the early data:
  • Alignment of EM calorimeter to inner tracker
  • Derive energy scale and inter calibration from di-electron resonances and E/p
  • Tune reconstruction algorithms
  • Measure reconstruction efficiencies using tag and probe.
  • Map material in front of the calorimeter using conversion, E/p and minimum bias events