Electron and photon reconstruction and identification with the ATLAS detector

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Calorimeter and Tracker

Calorimeter EM

- Pb-Lar Sampling calorimeter (87°K)
- **Barrel** + 2 **EndCaps** ($|\eta| < 2.5$)
- Depth 25-35 X_0 (barrel 6.8 m long cryostat, outer radius of 2.25 m and an inner radius of 1.15 m)
- ~170k channels

Inner Detector constituted of 3 sub detector:

- **Pixel**: (3 layers)
- **SCT**: SemiConductor Tracker (8 layers)
- **TRT**: Transition Radiation Tracker (straw tube, ~36 hits for track)

EM Calorimeter

- Accordion geometry allow for a full Φ coverage
- 3 longitudinal compartments, plus the Presampler
- ~170k channel
- Each channel calibrated to the EM scale with the electronic calibration system

Compartment	$\eta \times \phi$ barrel granularity
PreSampler	0.025 x 0.1
Layer 1 (Strip)	0.003 x 0.1 (up to 0.025 x 0.1 in EndCap)
Layer 2 (Middle)	0.025 x 0.025
Layer 3 (Back)	0.05 x 0.025

Electrons and photons reconstruction in calorimeter pass through a series of steps:

- Start from calorimeter cells calibrated to EM scale
- Build a cluster using a fixed-size $\Delta\eta \times \Delta\phi = 5 \times 5$ rectangular window of cells; position at local maxima in energy.
- Match clusters against tracks and conversions to determine particle hypothesis:
 - Electron, photon, or converted photon.
- Rebuild clusters; sizes depend on particle hypothesis and calorimeter region. Apply cluster calibrations.
- If there's a matching track, take the candidate direction from the track. Otherwise, infer direction from the calorimeter.
- Calculate discriminating variables to reject backgrounds. Combine variables:
 - Simple cuts.
 - Multivariate discriminant: likelihood ratio, H-matrix, etc.

e/ γ identification

Electron/photon reconstruction matches an EM cluster with ID tracks

Electrons: EM cluster with associated primary track

Unconverted photon: EM cluster without any associated track

Converted photon -- asymmetric: EM cluster with an associated vertex

Converted photon -- one track: EM cluster with an associated single track

Pixel

SCT

TRT

Sol PS

LArEM

Electrons and
photons with
 $E = 50 \text{ GeV}$

Tracking & conversion reconstruction

Results of three tracking algorithms are merged:

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

Good efficiency over most of detector for tracks of moderate momenta.

- 10–50% of photons convert before reaching the calorimeter
- For $R_c < 50$ cm, conversion vertices found with good efficiency $\sim 80\%$.
- For larger radii, look for single TRT tracks to improve efficiency
- **Efficiency $\sim 80\%$ for $R_c < 80$ cm**

Single-electron tracking efficiency

Cluster calibration

Calculate initial cluster position and energy

Correct position measurements

Correct energy for lateral and longitudinal shower shapes

Correct for η, Φ energy modulations

Cluster energy set to sum of cells depending on particle hypothesis and calorimeter region:

- Barrel: 3x7 electrons and unconverted photons, 5x5 converted photons
- Endcap : 5x5 both electrons and photons

Position from energy-weighted centroid.

η modulation due to the incomplete shower containment into the fixed size cluster. Correction to the cluster barycenter up to 20% of middle cell width.

- η position resolution for γ is $\sim 3 \times 10^{-4}$ in strips and $\sim 6 \times 10^{-4}$ in middle, ϕ position resolution $0.5\text{-}1.5 \times 10^{-3}$.

Cluster calibration: energy reconstruction

- Compute corrections for each effect (from Monte Carlo) correlating each energy depositions to a measurable quantity
- Energy deposition into the inactive material studied using special MC simulation (Calibration Hits)

$$E^{reco} = F(E_{acc}^{reco}, \eta) \cdot E_{ps}^{cl LAr} + S_{acc}(X, \eta) \cdot \left(\sum_{i=13} E_i^{cl LAr} \right) (1 + C_{out}(X, \eta)) \cdot (1 + f_{leak}(X, \eta))$$

Energy deposited in front of calo

Energy deposited into the cluster

Energy deposited out of cluster

Energy deposited behind calo

Cluster calibration: energy modulation

η and Φ modulation on the reconstructed energy need to be taken into account.

$\Delta E \sim 1\%$

The Φ modulation reflects the internal structure of the accordion cell (alternation of electrodes and absorbers) while the η modulation is due to the finite size of the cell.

Cluster calibration: energy reconstruction performance

- Linearity ($E_{\text{reco}}/E_{\text{true}}$) better than 0.5% for both electrons and photons.
- Sampling term for electrons goes from ~10% in center to ~22% in Endcap.

Electron / photon discriminating variables

Some variables are used to discriminate true e/ γ from background:

- Fractional hadronic leakage
- Shape in middle sampling : E(3x7)/E(7x7)
- Shape in first sampling: size and search for second maximum (π^0 rejection)
- Isolation in calorimeter
- Track quality (number of hits, impact parameter)
- Track match ($\Delta\eta\Delta\phi$, E/p)
- Fraction of high threshold TRT hits

- Photons from $H \rightarrow \gamma\gamma$
- Jets background from hard-scattering QCD processes

Cut based electron identification

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

Cut	Efficiency (%)	Jet Rejection
Loose (had + middle)	88	560
Medium (Loose + strips + trk qual + trk match)	77.2	2200
Tight (Medium + TRT)	64	10^5

Cut based photon identification

- Photon identification uses same calorimeter variables (plus track isolation)
- Only one defined set of identification cuts
- Overall efficiency ~84%, with rejection ~8000 (with isolation).

- Photons from $H \rightarrow \gamma\gamma$
- Jets background from hard-scattering QCD processes

Multivariate discriminants

- Photons from $H \rightarrow \gamma\gamma$
- Jets background from hard-scattering QCD processes

Rather than cutting on discriminant variables, combine them into a continuous multivariate discriminant using standard method (Likelihood ratio, H -matrix, neural network...)

In-situ intercalibration with $Z \rightarrow ee$

- Intercalibration between the 384 local region ($\sim 0.2 \times 0.4$) necessary to take into account all disuniformity of the detectors (LAr temperature and purity, mechanical deformation, HV, material in front,...)
- Experience from TB shows that within local regions, calorimeter response is uniform within 0.5%
- Overall goal is $< 0.7\%$ $\rightarrow$ intercalibrate local regions within $< 0.5\%$.
- Use $Z \rightarrow ee$ data. This also constrains the absolute energy scale.
- Introduce a scale factor for each region: $E_{\text{reco}}^i = E_{\text{true}}^i (1 + \alpha_i)$.
- Construct reference Z line shape from Breit-Wigner distribution convoluted with electron resolution and parton luminosity.
- Adjust α_i so that reconstructed Z shape matches the reference shape.
- Apply α_i in offline cell energy corrections.

Can get within 0.5% with 200pb^{-1} (87k reconstructed $Z \rightarrow ee$).

In-situ electron efficiency determination

- Need to measure electron efficiency from data, important to scale MC predictions.
- Use **tag&probe** method in $Z \rightarrow ee$ data:
 - Select electron candidate 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

Photon and electron identification and reconstruction strategy and algorithms are very advanced.

A lot of work will be done with the early data:

- Align calorimeter to inner tracker.
- Derive energy scale and intercalibration from dielectron resonances.
- Compare calorimeter to tracker energy scales via E/p .
- Tune reconstruction algorithms.
- Measure reconstruction efficiencies using tag and probe.
- Map material in front of the calorimeter using conversions, E/p and minimum bias events

Backup Slides

Cluster calibration: energy reconstruction (2)

The electromagnetic calorimeter of ATLAS

Calorimeter EM

- Pb-Lar Sampling calorimeter (87°K)
- Barrel + 2 EndCaps
- Depth 25-35 X_0
- ~170k channel

Material estimation with early data

At least three different approach are possible to quantify the amount of material in the ID with early data

Performance on benchmark processes

- Constant term of 0.7% included.

$H \rightarrow \gamma\gamma$ (120GeV)

- Photon directions from pointing of the first two EM cal layers and primary vertex position.

- Central value correct to 0.2GeV, corresponding to 0.3% precision and $\sim 1.2\%$ resolution

$H \rightarrow eeee$ (130GeV)

- Z mass constraints not used.
- Central value correct to 1 GeV, corresponding to 0.7% precision and $\sim 1.5\%$ resolution.

Multivariate discriminants

Rather than cutting on discriminant variables, combine them into a continuous multivariate discriminant using standard method (Likelihood ratio, H -matrix, neural network...)

H -matrix does not use all available information

- Photons from $H \rightarrow \gamma\gamma$
- Jets background from hard-scattering QCD processes